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COMITÉ EJECUTIVO DEL FONDO MULTILATERAL
PARA LA APLICACIÓN DEL
PROTOCOLO DE MONTREAL
Octogésima primera Reunión
Montreal, 18 – 22 de junio de 2018

INFORMES DE SITUACIÓN E INFORMES SOBRE PROYECTOS CON REQUISITOS ESPECÍFICOS DE PRESENTACIÓN DE INFORMES

1. El presente documento sirve a guisa de seguimiento de las cuestiones planteadas en los informes financieros y los informes sobre la marcha de las actividades más recientes presentados a la 79ª reunión[1], y al respecto de los proyectos y actividades para los que en reuniones[2] anteriores se pidieron informes específicos.

2. Estos informes se clasifican en las partes que se indican *infra*:

Parte I: Proyectos con demoras en la ejecución por los que se pidieron informes especiales de situación

Parte II: Informes relacionados con planes de gestión de eliminación de HCFC (PGEH)

Parte III: Proyectos de demostración de alternativas de bajo potencial de calentamiento atmosférico (PCA) a los HCFC y estudios de viabilidad de los sistemas de refrigeración centralizada de edificios urbanos (decisión 72/40)

Parte IV: Eliminación del consumo y de la producción de CTC en la India

Parte V: Proyectos de eliminación de desechos de SAO

Parte VI: Proyectos en marcha sobre enfriadores

3. Cada una de estas partes recoge una breve descripción sobre la marcha de las actividades, así como las observaciones y recomendaciones de la Secretaría.

[1] UNEP/OzL.Pro/ExCom/79/8-13.

PARTE I: PROYECTOS CON DEMORAS EN LA EJECUCIÓN POR LOS QUE SE PIDIERON INFORMES ESPECIALES DE SITUACIÓN.

Marcha de las actividades de ejecución de los proyectos en 2017

4. La Secretaría mantuvo deliberaciones con los organismos bilaterales y de ejecución competentes sobre proyectos por los que se pidieron informes especiales de situación en la 80ª reunión. Tras las deliberaciones, se trataron varios temas satisfactoriamente.

5. Los proyectos clasificados con demoras en la ejecución y por los que se pidieron informes especiales de situación figuran en el anexo I, y los proyectos con temas pendientes figuran en el anexo II del presente documento.

Recomendaciones

6. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota de:

i) Los informes de situación y de proyectos con demoras en la ejecución de los organismos bilaterales y de ejecución presentados a la 81ª reunión y que figuran en el documento PNUMA/OzL.Pro/ExCom/81/10;

ii) Que los organismos bilaterales y de ejecución informarán a la 82ª reunión sobre tres proyectos con demoras en la ejecución y sobre siete proyectos para los que se recomienda la presentación de informes adicionales de situación, tal como se indica en los anexos I y II, respectivamente, del presente documento; y

b) Aprobar las recomendaciones sobre los proyectos en curso con cuestiones específicas que figuran en la última columna del anexo II del presente documento.

PARTE II: INFORMES RELACIONADOS CON LOS PGEH

7. En nombre de los Gobiernos de Brasil, Cuba, Indonesia, Irán (la República Islámica de), Kenia, Kuwait y Viet Nam, los organismos bilaterales y de ejecución pertinentes presentaron informes sobre la marcha de las actividades de ejecución de proyectos con requisitos específicos de presentación de informes que se encontraban en la etapa I o II de los PGEH.

8. El informe del PGEH de Kuwait presentado por el PNUMA, en su calidad de organismo director de ejecución, se remitió a la ejecución del segundo tramo de dicho plan e incluyó una petición para ajustar el periodo de ejecución de la etapa I por las demoras imprevistas en la conversión de las empresas de fabricación de espumas. En fechas posteriores, el PNUMA, en nombre del Gobierno, pidió la retirada de la presentación, lo que permitiría avanzar en la conversión demorada de tales empresas productoras de espumas e indicó que la solicitud de financiación para el tercer tramo se presentaría a la 82ª reunión.

Etapa I del PGEH para Brasil (uso provisional de sistemas de polioles (polialcoholes) de HFC de elevado PCA) (PNUD y el Gobierno de Alemania)

Antecedentes

9. En la 80ª reunión, el PNUD, en su calidad de organismo director de la ejecución, presentó el informe anual sobre la marcha de las actividades de ejecución del programa de trabajo conexo al quinto tramo del plan de gestión para la eliminación de los HCFC (PGEH)[2] [3].

10. El PNUD explicó que dos proveedores de sistemas (Shimtek y U-Tech) habían solicitado poder hacer uso de sistemas de polioles (polialcoholes) de HFC con un elevado potencial de calentamiento atmosférico (PCA), ante la imposibilidad de poder obtener hidro-fluoro-olefinas (HFO) en volúmenes comerciales en el país. Ambos proveedores de sistemas habían firmado su compromiso de dejar de emplear provisionalmente mezclas de HFC en el momento en que los HFO pudieran obtenerse comercialmente y los sistemas se hubieran desarrollado y optimizado sin por ello incrementar el costo para el Fondo Multilateral.

11. Tras una deliberación, el Comité Ejecutivo pidió al PNUD continuar asistiendo a Shimtek y a U-Tech con objeto de asegurar el suministro de las tecnologías alternativas seleccionadas, dándose por entendido que todo costo adicional de explotación no se pagaría hasta haberse introducido la tecnología alternativa o cualesquiera otra tecnología de bajo PCA que se hubiera seleccionado originalmente. Se pidió también al PNUD que informara, en cada reunión, sobre la situación en que se emplea la tecnología interina seleccionada por los proveedores de sistemas, hasta haberse introducido totalmente la tecnología originalmente seleccionada o cualesquiera otra de bajo PCA (decisión 80/12 e)).

12. De conformidad con la decisión 80/12 e), el PNUD notificó que ambos proveedores de sistemas se encontraban a día de hoy desarrollando polioles con HFO.

Observaciones

13. La Secretaría tomó nota de los esfuerzos desplegados por el PNUD para asistir a los dos proveedores de sistemas a asegurar el suministro de agentes espumantes de bajo PCA para la producción de espuma por inyección. Como respuesta a una petición de la Secretaría, el PNUD confirmó que el agente espumante específico es el HFO-1233zd y que, si bien puede obtenerse comercialmente en Brasil más fácilmente que en años anteriores, sigue siendo todo un reto conseguirlo en grandes cantidades. El PNUD continuará notificando sobre todo avance adicional que logren Shimtek y U-Tech.

Recomendaciones

14. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, del informe facilitado por el PNUD y de los esfuerzos efectuados para facilitar el suministro de tecnología de bajo potencial de calentamiento atmosférico (PCA) a los proveedores de sistemas Shimtek y U-Tech en Brasil; y

b) Pedir al PNUD que siga asistiendo al Gobierno del Brasil para asegurar el suministro de tecnologías alternativas de bajo PCA y que informe, en cada reunión, sobre la situación en que se encuentra la conversión de los proveedores de sistemas, hasta haberse

[2] El tramo quinto y definitivo de la etapa I del PGEH se aprobó en la 75ª reunión por un costo total que ascendió a 2 035 094 $EUA, cifra compuesta de 1 470 700 $EUA, más gastos de apoyo al organismo por un monto de 110 313 $EUA para el PNUD, y de 409 091 $EUA, más gastos de apoyo al organismo por un monto de 45 000 $EUA para Alemania.

[3] UNEP/OzL.Pro/ExCom/80/34.

introducido totalmente la tecnología originalmente seleccionada o cualquiera otra de bajo PCA.

<u>Uso provisional de una tecnología de alto PCA por parte de empresas que han realizado la conversión a tecnología de bajo PCA en Cuba</u> (PNUD)

Antecedentes

15. En la 77ª reunión, el Gobierno de Cuba presentó una solicitud para la aprobación de la financiación del tercer tramo de la etapa I de su PGEH[4] y señaló que si bien dos empresas productoras de espumas de poliuretano (PU) (a saber, Friarc e IDA) habían recibido asistencia para efectuar la conversión a tecnología de espumación acuosa (una tecnología de bajo PCA), en la actualidad se encontraban utilizando provisionalmente una tecnología de alto PCA (una mezcla de HFC-365mfc y HFC-227ea), dado que la tecnología seleccionada no estaba disponible ni proporcionaba las prestaciones aislantes necesarias. Al aprobar la financiación del tramo, el Comité Ejecutivo pidió, entre otras cosas, que el PNUD siguiera prestando asistencia al Gobierno a la hora de asegurar el suministro de tecnología de bajo PCA, y que presentara, en cada reunión, informes sobre la situación del uso de la tecnología provisional hasta que se hubiera introducido plenamente la tecnología escogida en un principio u otra tecnología con un bajo PCA, y las empresas hubieran realizado la conversión (decisión 77/50 b)).

16. De conformidad con la decisión 77/50 b), el PNUD informó que Friarc había mantenido conversaciones sobre arreglos comerciales con miras a la compra de una máquina de inyección de espuma que trabaja con hidrocarburos (HC), y que se había dirigido a un proveedor de sistemas con miras al suministro de sistemas PU con HFO. El PNUD ha notificado además que una segunda empresa, IDA, y la Dependencia Nacional del Ozono se han dirigido a ese mismo proveedor regional, el cual había enviado ya muestras de tales sistema de PU con HFO a las dos empresas con objeto de realizar las pruebas pertinentes.

Observaciones

17. La Secretaría destacó el esfuerzo del PNUD por asistir a las dos empresas a fin de garantizar el suministro de tecnología de bajo PCA.

18. Tras pedirse una mayor claridad, el PNUD indicó que Friarc había: identificado a un proveedor de máquinas productoras de espumas capaz de gestionar sistemas con HC; efectuado un estudio de viabilidad técnica y financiera para la adquisición de equipos; y solicitado a la dirección del grupo industrial los fondos necesarios para adquirir los nuevos equipos. Al disponer de tiempo para obtener una financiación adicional, en sintonía con el compromiso subscrito por el Gobierno para adoptar una alternativa sin PAO y de bajo PCA, la empresa en cuestión se encuentra actualmente sometiendo a ensayos los sistemas con HFO. En el caso de IDA, si bien la empresa no se ha comprometido definitivamente a una decisión final sobre la tecnología, está sopesando utilizar sistemas con HFO.

19. El PNUD ha indicado también que informará a la Secretaría al respecto de la selección definitiva de tecnología. En caso de seleccionarse la tecnología con HFO, las dos empresas asumirán el mayor costo de los sistemas. Dado lo limitado de la financiación aprobada para la conversión del sector de espumas, el PNUD prevé disponer de flexibilidad respecto a la selección de una tecnología de bajo PCA y poder hacer uso de los fondos disponibles. Una vez seleccionada la tecnología, y de que el PNUD haya notificado sobre el costo de su introducción, la Secretaría estará en condiciones de poder evaluar su costo adicional. A pesar de no haberse introducido aún la tecnología definitiva, el Gobierno ya ha prohibido el consumo de HCFC-141b, en sintonía con el compromiso al que se ha obligado.

[4] UNEP/OzL.Pro/ExCom/77/39.

Recomendaciones

20. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, del informe presentado por el PNUD, y los esfuerzos por facilitar el suministro de tecnología de bajo potencial de calentamiento atmosférico (PCA) a las empresas Friarc e IDA de Cuba; y

b) Pedir al PNUD que siga asistiendo al Gobierno de Cuba para garantizar el suministro de tecnología de bajo PCA y que presente a la 82ª reunión un informe sobre la situación en que se encuentra la conversión de las dos empresas del sector productor de espumas, incluyendo un análisis pormenorizado de los costos adicionales de capital y de explotación, en caso de decidirse por una tecnología diferente a la seleccionada cuando se aprobó el proyecto.

Indonesia: etapa I del PGEH: actualización sobre la conversión de tecnología por parte de las empresas (PNUD, ONUDI, Banco Mundial, y el Gobierno de Australia)

Antecedentes

21. En nombre del Gobierno de Indonesia, el PNUD, en su calidad de organismo de ejecución principal, ha presentado un informe sobre la situación en que se encuentran las empresas que están fabricando provisionalmente equipos de refrigeración y de climatización con un alto PCA que ya habían recibido con anterioridad financiación para convertirse a alternativas de bajo PCA de conformidad con la decisión 77/35.

22. La etapa I del PGEH incluyó la conversión de 48 empresas del sector de fabricación de equipos de refrigeración y climatización a tecnologías de bajo PCA. No obstante, en el transcurso de la implantación, 28 de las empresas (16 del sector de climatización y 12 del de refrigeración comercial) decidieron pasarse a una tecnología de alto PCA con sus propios recursos y devolvieron 3 134 216 $EUA más gastos de apoyo a los organismos al Fondo Multilateral.

23. De las 20 empresas, solo una (Panasonic) fabrica actualmente climatizadores con tecnología de HFC-32. Ocho empresas de media y gran envergadura han fabricado equipos de prototipo con HFC-32, mientras que otras ocho son ensambladores de pequeño tamaño que trabajan en pedidos personalizados; a fechas de hoy, no se han recibido pedidos de equipos con HFC-32. Otras tres empresas seguían a la espera de que el mercado de equipos con HFC-32 mejorara antes de emprender su conversión.

24. Las razones de las demoras en la conversión y fabricación de equipos de refrigeración y de climatización con la tecnología acordada por pate de 19 empresas son: la limitada disponibilidad comercial de compresores con HFC-32 y de componentes a precios asequibles; la falta de demanda de equipos con HFC-32 en el mercado local; y el más elevado costo de los equipos con HFC-32 en comparación con otros que pueden obtenerse en el país (por ejemplo, los de R-410A como refrigerante).

25. A fin de posibilitar que estas empresas empiecen a fabricar con la tecnología para la que se aprobó la financiación, la Dependencia Nacional del Ozono, conjuntamente con el PNUD, llevaron a cabo actividades de concienciación y acometieron en China una gira de estudio en octubre de 2017. De la gira de estudio las empresas aprendieron que los fabricantes de compresores de China estaban esperando la aparición de una norma de seguridad (que se había anticipado para junio de 2018) a fin de iniciar la producción en masa de compresores comerciales con HFC-32; algunos fabricantes indicaron que, aunque estaban listos para exportar, no sería económicamente viable hacerlo por la escasa demanda del mercado. Algunas de las empresas indonesias mostraron interés en iniciar conversaciones con los fabricantes chinos

de compresores al respecto de los pormenores de los diseños, pruebas, análisis del desempeño y fijación de precios.

26. El PNUD indicó además que en el mes de Julio de 2018 se celebrará una reunión de análisis con las empresas productoras de equipos de refrigeración y de climatización con el fin de estimar los calendarios de producción de equipos con la tecnología de bajo PCA seleccionada. Tras la celebración de dicha reunión, el PNUD estaría en condiciones de facilitar una actualización de la situación.

Observaciones

27. La Secretaría solicitó una mayor información sobre las medidas que se estaban tomando para facilitar la conversión de las empresas a la tecnología de bajo PCA seleccionada. El PNUD indicó que el Gobierno de Indonesia y el PNUD se encontraban continuando sus actividades para fomentar la introducción de tecnología con HFC-32 y confirmó que los costes adicionales de explotación no se abonarán hasta haberse verificado que las empresas están fabricando con la tecnología aprobada de conformidad con la decisión 77/35.

28. En lo tocante a lo limitado del suministro de compresores con HFC-32 a Indonesia, el PNUD explicó que el Comité Nacional para la Administración de la Normalización de China publicó una norma nacional de seguridad para los sistemas de refrigeración y las bombas de calor (GB/T9237-2017), por la que se especifica que el umbral para utilizar refrigerantes combustibles tendrá que ejecutarse y entrar en vigor el 1 de julio de 2018. Si bien la norma de seguridad no impide la exportación de compresores con HFC-32, lo más probable es que la producción en masa de compresores en China solo se iniciará una vez esté en vigor y funcionamiento la norma pertinente. Lo más probable es que dicha producción en masa de compresores con HFC-32 esté disponible a precios competitivos para su exportación al mercado de Indonesia. El PNUD hizo hincapié en que la capacidad de las empresas de Indonesia para fabricar a gran escala con HFC-32 no solo depende de la disponibilidad de los compresores con HFC-32, sino también en un espectro de factores más amplio que afecta a la aceptación del mercado, incluyendo el que el equipo sea percibido como seguro, de consumo energético eficiente y de funcionamiento seguro y de fiar.

29. La Secretaría tomó nota de que las empresas de Viet Nam consideran que no tendrán problemas para abastecerse de compresores con HFC-32. Al tiempo que resaltó que las empresas de Indonesia mantienen buenas relaciones con sus actuales proveedores de componentes, el PNUD indicó también que, como preparativo para la reunión de julio de 2018 con las empresas fabricantes de equipos de refrigeración y climatización, investigará otros proveedores potenciales de compresores con HFC-32, incluyendo a un fabricante de compresores de Tailandia que está listo para fabricar compresores de capacidad similar a la empleada por las empresas de Indonesia.

30. La Secretaría tomó nota de que, de conformidad con la decisión 77/35 a) vi), los costos adicionales de explotación aprobados por las empresas de fabricación no se pagarán hasta haberse verificado que las empresas se encontraban fabricando equipos con la tecnología aprobada y que, de conformidad con la decisión 76/47 d), el informe de terminación de proyecto para la etapa I del PGEH se presentaría a la primera reunión de 2019. Por ende, y a la espera de los resultados que resulten del examen que tenga lugar en julio de 2018 conjuntamente con las empresas, puede que sea necesario considerar una prórroga limitada para poder terminar las actividades del sector de equipos de refrigeración y de climatización de la etapa I y la presentación del informe de terminación del proyecto. Se acordó mantener conversaciones para ver esta posibilidad tras celebrarse el examen en julio de 2018 junto con las empresas y durante el examen del informe sobre la marcha de las actividades de ejecución de la etapa I que se presente a la 82ª reunión.

Recomendaciones

31. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota de la actualización acaecida en la conversión tecnológica de empresas en la etapa I del PGEH para Indonesia, presentada por el PNUD;

b) Tomar nota, con reconocimiento, de los esfuerzos desplegados por el Gobierno de Indonesia y por el PNUD para facilitar la introducción de tecnología de bajo potencial de calentamiento atmosférico seleccionada por las empresas productoras de equipos de refrigeración y de climatización financiados en el marco de la etapa I del PGEH; y

c) Pedir al PNUD que siga presentando, en cada reunión, un informe sobre la situación en que se encuentra la conversión de las empresas productoras de equipos de refrigeración y de climatización hasta que se encuentren fabricando equipos fundamentados en la tecnología alternativa acordada.

Etapa I del PGEH para Irán (República Islámica de) (informe anual sobre la marcha de las actividades de ejecución) (PNUD)

Antecedentes

32. En nombre del Gobierno de la República Islámica de Irán, el PNUD, en su calidad de organismo principal de ejecución, ha presentado el informe anual sobre la marcha de las actividades de ejecución del programa de trabajo del cuarto tramo de la etapa I del PGEH[5] del país, de conformidad con la decisión 74/43 b).

Consumo de HCFC

33. La República Islámica de Irán notificó en su informe de ejecución del programa de país para 2017 que el consumo había sido de 3 144,67 tm (229,28 toneladas PAO) de HCFC. Dicho consumo fue un 39,7 por ciento inferior al consumo básico de referencia de HCFC y un 33 por ciento inferior al objetivo de consumo anual para 2017 (342,45 toneladas PAO) prescrito en virtud del Acuerdo entre el Gobierno de la República Islámica de Irán y el Comité Ejecutivo. El sistema de concesión de cuotas y licencias sigue en vigor y funcionando eficazmente.

Informe sobre la marcha de las actividades de ejecución del cuarto tramo del PGEH

Actividades en el sector de fabricación

34. Las actividades ejecutadas incluyen:

a) La conversión de ocho empresas productoras de espumas de poliuretano (PU) del sector de paneles continuos (Gobierno de Alemania) (30,7 toneladas PAO): Siete empresas han finalizado su conversión a tecnología de hidrocarburos, eliminando 27,8 toneladas PAO de HCFC-141b. Otra empresa distinta dejó, voluntariamente, de consumir 2,9 toneladas

[5] La financiación del cuarto y último tramo de la etapa I del PGEH lo aprobó la 74ª reunión por un costo total de 885 977 $EUA, cifra compuesta de 250 430 $EUA, más gastos de apoyo al organismo de 18 872 $EUA para el PNUD, 274 827 $EUA, más gastos de apoyo al organismo de 20 612 $EUA para la ONUDI, y de 288 582 $EUA, más gastos de apoyo al organismo de 32 744 $EUA para el Gobierno de Alemania.

PAO de HCFC-141b, y la financiación pertinente se reembolsará al Fondo Multilateral deduciendo el monto del correspondiente segundo tramo de la etapa II del PGEH, de conformidad con la decisión 80/21;

b) La conversión de 11 empresas de espumas de producción de poliuretano rígido (ONUDI) (88,7 toneladas PAO): diez empresas han finalizado su conversión a la nueva tecnología de hidrocarburos, con lo cual se eliminaron 54,6 toneladas PAO de HCFC 141b. La conversión de la única empresa que queda pendiente (a la que corresponden 34,1 toneladas PAO) quedará plenamente acabada en septiembre de 2018, aunque ya se encuentra fabricando espumas mediante ciclopentano; y

c) Las actividades en el sector de equipos de climatización (PNUD): el proyecto finalizó en 2015, con lo que se eliminaron 29,3 toneladas PAO de HCFC 22. Se introdujo la tecnología de HFC-410A.

Actividades en el sector de servicio y mantenimiento de equipos de refrigeración y de climatización (Gobierno de Alemania y PNUMA)

35. Las actividades en el sector de servicio y mantenimiento de equipos de refrigeración y de climatización han culminado, y en el transcurso de los últimos años se han celebrado: talleres de formación adicional sobre buenas prácticas de servicio y mantenimiento en varias provincias; talleres de incremento de la concienciación sobre consumo energético eficiente y buenas prácticas de trabajo en equipos de refrigeración y de climatización; distribución de publicaciones técnicas a partes interesadas; y supervisión de los resultados de efectuar modificaciones en sistemas precintados de los sistemas de refrigeración de dos cadenas de supermercados.

Volumen de desembolso de fondos

36. A fechas de marzo de 2018, de los 9 994 338 $EUA aprobados, 9 205 837 $EUA ya se habían desembolsado, como se indica en el Cuadro 1.

Cuadro 1. Informe financiero de la etapa I del PGEH para la República Islámica de Irán

Organismo	Aprobados ($EUA)	Desembolsados ($EUA)	Tasa de desembolso (%)
PNUD	4 340 246	4 340 246	100
ONUDI	2 506 277	2 009 372	80
Gobierno de Alemania	2 885 815	2 885 815	100
PNUMA	262 000	262 000	100
Total	**9 994 338**	**9 497 433**	**95**

Observaciones

37. La Secretaría toma nota de: la presentación de un informe completo; que el sistema de concesión de cuotas y licencias se ha ejecutado y fortalecido mediante el sistema en línea; y que las actividades adicionales de la etapa I se han terminado. El último proyecto de inversión en el sector de producción de espumas se finalizará en septiembre de 2018 y el saldo remanente de 496 905 $EUA se desembolsará antes de finales de 2018. El PNUD ha confirmado que la fecha de terminación de las operaciones de la etapa I es el 31 de diciembre de 2018 como se prescribe en el Acuerdo. Por ende, el informe final sobre la marcha de las actividades de ejecución y el informe de terminación del proyecto se presentarán a la 83ª reunión.

Recomendaciones

38. El Comité Ejecutivo puede estimar oportuno tomar nota del informe de 2017 sobre la marcha de las actividades de ejecución de la etapa I del PGEH para la República Islámica de Irán presentado por el PNUD.

Etapa I del PAGEH para Kenya (informe de desembolsos atinente a la oficina de gestión del proyecto) (Gobierno de Francia)

Antecedentes

39. En la 80ª reunión, el Comité Ejecutivo aprobó el quinto y último tramo de la etapa I del PGEH para Kenya[6] y, entre otras cosas, pidió al Gobierno de Francia que presentara un informe ante la 81ª reunión en el que se recogieran pormenorizadamente las actividades que se han realizado y se siguen realizando por parte de la oficina de gestión del proyecto para la etapa I del PGEH (decisión 80/68 d)).

40. El Gobierno de Francia presentó un informe sobre las actividades acometidas por dicha oficina durante la implantación de la etapa I del PGEH hasta fechas del mes de marzo de 2018. Como explicó el Gobierno de Francia, esta oficina juega un papel importante en las actividades de coordinación y supervisión del proyecto atinentes a la coordinación con otras instituciones del Gobierno, especialmente con las Autoridades Nacionales de Gestión del Medio Ambiente (NEMA) y con las Autoridades del Ministerio de Hacienda de Kenya (KRA) en lo tocante a la supervisión y vigilancia de las importaciones y exportaciones de SAO; capacitación de funcionarios de aduanas y técnicos de refrigeración; actividades de concienciación de las partes interesadas, incluyendo la participación en talleres y consultas sobre materias conexas al PGEH; procesos de coordinación sobre la verificación del consumo, preparación del informe sobre la marcha de las actividades de ejecución del PGEH; y respaldando a la Dependencia Nacional del Ozono en lo que respecta a procedimientos de adquisición y contabilidad relativos a proyectos.

41. A fechas de marzo de 2018, del total ajustado de financiación que ascendía a 196 610 $EUA para la oficina de gestión, 187 610 $EUA ya se habían desembolsado. El saldo de 9 000 $EUA se desembolsará en octubre de 2018.

Observaciones

42. La Secretaría tomó nota, con reconocimiento, de los esfuerzos realizados por el Gobierno de Kenya para reducir los costos de la oficina de gestión, lo que incluye la reducción en los costos de alquiler, el arreglo de costos compartidos de la plantilla de personal de dicha oficina, y la reducción de otros desembolsos operativos para el funcionamiento de la susodicha oficina. El Gobierno de Francia indicó que continuarían esforzándose en reducir los costos en los que incurra dicha oficina de gestión, siempre que ello fuera posible, durante la ejecución de las etapas I y II del PGEH.

43. La Secretaría tomó nota también de que el Director de los Acuerdo Multilaterales sobre el Medio Ambiente del Gobierno de Kenya había presentado una carta oficial a la Secretaría en diciembre de 2017 confirmando el compromiso al que se había obligado el Gobierno para acelerar y eliminar totalmente el consumo de HCFC para el 1 de enero de 2030, a lo más tardar, en línea con la decisión 80/58 g).

44. El Gobierno de Francia aclaró también que la etapa I del PGEH finalizaría en octubre de 2018, y que se presentaría un informe sobre los desembolsos reales de la oficina de gestión conexos a la etapa I una vez presentada la solicitud de financiación del segundo tramo de la etapa II del PGEH.

[6] UNEP/OzL.Pro/ExCom/80/41.

Recomendaciones

45. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, del informe sobre las actividades y desembolsos efectuados por la oficina de gestión de proyectos al respecto de la etapa I del PGEH para Kenya;

b) Pedir al Gobierno de Francia que presente un informe de desembolsos por las actividades de la oficina de gestión de proyectos sobre el PGEH de Kenya (etapa I) al presentar la solicitud de financiación del segundo tramo de la etapa II del PGEH de Kenya.

<u>Viet Nam: plan de gestión para la eliminación de los HCFC (PGEH) (etapa II) – Cambio de tecnología en Midea Consumer Electric (Viet Nam) Co. Ltd.)</u> (Banco Mundial y Gobierno del Japón)

Antecedentes

46. En la 76ª reunión, el Comité Ejecutivo aprobó en principio, la etapa II del PGEH para Viet Nam[7] para el periodo de 2016 a 2022 a fin de reducir el consumo de HCFC en un 35 por ciento de su consumo básico de referencia, por un monto que ascendía a 15 683 990 $EUA (14 411 204 $EUA, más gastos de apoyo al organismo de 1 008 784 $EUA para el Banco Mundial, y 233 630 $EUA, más gastos de apoyo al organismo de 30 372 $EUA para el Gobierno del Japón).

47. La etapa II del PGEH incluye la conversión de cuatro empresas productoras de equipos de climatización. Tres de ellas (a saber, Hoa Phat, Nagakawa y REE) decidieron convertirse a HFC-32, mientras que la cuarta, Midea Consumer Electric (Viet Nam) Co. Ltd. (Midea Viet Nam), decidió convertir dos líneas de producción a R-290 partiendo de la experiencia de la conversión de la empresa Midea de China que recibió financiación del Fondo Multilateral para convertirse y pasarse al mismo tipo de tecnología. La financiación facilitada a Midea Viet Nam para la conversión a la tecnología de R-290 ascendió a 837 017 $EUA.

48. Durante los preparativos para implantar el proyecto, Midea Viet Nam envió una petición oficial al Gobierno de Viet Nam solicitando cambiar la tecnología alternativa a HFC-32 y alegando para ello las siguientes razones, a saber: preocupaciones sobre la aceptación del mercado de las unidades de climatización con R-290; falta de regulación o de normas que faciliten la venta de equipos con R-290 en el país; retos para proveer la suficiente capacitación al sector de servicio y mantenimiento para manipular con seguridad los equipos de R-290 en fechas posteriores al periodo de garantía y durante los contratos de servicio, a diferencia de HFC-32, para el que varias empresas comenzaron a impartir talleres de servicio de capacitación en manipulación segura de este refrigerante ya en 2014; y una mejor paridad con los importadores y fabricantes locales de equipos de climatización en lo que respecta a las condiciones del mercado y a cómo abordar las preocupaciones de seguridad y las cuestiones reglamentarias potenciales. Midea Viet Nam se remitió también a las circunstancias actuales en el mercado del sureste asiático en el que los fabricantes de mayor envergadura (por ejemplo, Daikin, Hitachi, LG y Panasonic) se encontraban comercializando equipos de climatización con HFC-32. Por último, la empresa observó que la Sede Social de Midea (en China) tiene en vigor una producción sostenible de equipos con HFC-32. Midea Viet Nam considera que puede beneficiarse directamente de esa experiencia.

49. De conformidad con el párrafo 7 a) v) del Acuerdo entre el Gobierno de Viet Nam y el Comité Ejecutivo, el Gobierno de dicho país, por mediación del Banco Mundial, ha presentado una solicitud para cambiar la tecnología de Midea Viet Nam pasando de R-290 a HFC-32.

[7] UNEP/OzL.Pro/ExCom/76/55.

50. Los costos adicionales de capital y de explotación se han revisado conforme a como se recoge en el Cuadro 2. Las partidas de costos conexos a los prototipos de ensayos y certificación, las pruebas oficiales destinadas a la clasificación y etiquetaje, así como a la asistencia técnica, no se facilitaron para la conversión a la tecnología con R-290 puesto que Midea China ya había recibido anteriormente financiación del Fondo Multilateral para la conversión a dicha tecnología. A día de hoy se pide financiación para convertirse a la tecnología con HFC-32. La reducción de emisiones a la atmósfera se vio incrementada en 40 801 tm CO_2-eq. como consecuencia del mayor valor potencial de calentamiento atmosférico de HFC-32.

Cuadro 2. Costo adicional revisado de la conversión de Midea Viet Nam a la tecnología con HFC-32 ($EUA)

Partidas de costos	R-290	HFC-32	Diferencia
Rediseño de modelos, investigación, desarrollo, ensayos internos	50 000	66 000	16 000
Prototipos para ensayos y certificación		10 800	10 800
Ensayos oficiales para clasificación y etiquetaje		5 000	5 000
Asistencia técnica		25 000	25 000
Capacitación	5 000	5 000	-
Equipo de carga	104 000	120 000	16 000
Bombas de vacío		33 600	33 600
Detectores de fugas	4 000	4 000	-
Medidas de seguridad, ventilación, instalaciones eléctricas	70 000	50 000	(20 000)
Almacenamiento de refrigerante, bombas de transferencia y conductos	50 000	20 000	(30 000)
Imprevistos (10 por ciento)	28 300	33 940	5 640
Instalación y servicio y mantenimiento	55 000	55 000	-
Total de costos adicionales de capital	366 300	428 340	62 040
Total de costos adicionales de explotación	470 717	341 419	(129 298)
Suma total de costos	837 017	769 759	(67 258)

Observaciones

51. La Secretaría tomó nota de que el acuerdo entre el Gobierno de Viet Nam y el Banco Mundial no se había firmado y que, por lo tanto, la solicitud de financiación para el segundo tramo de la etapa II del PGEH no podría presentarse a la 81ª reunión. El Banco Mundial aclaró que la firma del acuerdo se ha visto demorada aún más, en otros seis meses, debido a los nuevos procedimientos internos de autorización del Gobierno.

52. Al margen de no haberse firmado el Acuerdo, la Secretaría tomó nota de que había empezado la preparación para la ejecución de la etapa II, y que Midea Viet Nam querría comenzar la conversión de sus líneas de producción a la tecnología con HFC-32 inmediatamente de haberse firmado el acuerdo entre el Gobierno de Viet Nam y el Banco Mundial. La Secretaría estima que, habida cuenta de las circunstancias, y a fin de evitar ulteriores demoras en la ejecución de la etapa II, sería beneficioso que la petición de cambio de tecnología se considerara en el marco de la 81ª reunión y no de la 83ª reunión que es cuando está prevista que se presente la solicitud de financiación del segundo tramo.

53. La Secretaría recordó el proyecto de demostración para la conversión de HCFC-22 a R-290 en Midea (China) aprobado en la 61ª reunión, y que también se habían convertido otras dos líneas de producción a R-290 en el marco de la etapa I del PGEH en China. La Secretaría tomó nota además de que los equipos de climatización con R-290 del tipo dividido fabricados en Midea obtuvieron recientemente la ecoetiqueta *Blue Angel*. La Secretaría entiende que aunque Midea sigue comprometida para convertirse a R-290 en el sector de climatización de habitaciones de China, sigue también una estrategia de una diversidad de refrigerantes, en función del modelo, del tipo y del mercado.

54. La Secretaría recordó que además de la experiencia de la empresa matriz de Midea con R-290, la razón de la elección de R-290 se vio también influenciada por la distribución de los equipos fabricados

por la empresa. Un 60 por ciento aproximadamente de los equipos de climatización fabricados por Midea Viet Nam tienen una capacidad de refrigeración (TR) de 0,75 toneladas, y que también aproximadamente un 25 por ciento son de 1 TR, de lo que se desprende que aproximadamente el 85 por ciento de los equipos fabricados por la empresa son de 1 TR o menos. Estos sistemas pequeños tienen consecuentemente una carga menor y con frecuencia han sido el objetivo de proyectos de conversión a R-290 que es el caso de equipos de mayor capacidad. Por el contrario, REE solo fabrica unidades de mayor envergadura que 4 TR; mientras que la producción de Hoa Phat y Nagakawa incluyen también una considerable proporción de equipos de 1 TR o capacidad inferior, y también fabrican más equipos de 2 TR o más. Al margen de los equipos que fabrique Midea Viet Nam, la empresa prefiere converger a HFC-32.

55. La Secretaría cuestionó la disponibilidad de la composición de HFC-32 en Viet Nam observando que las empresas de equipos de climatización de Indonesia se habían convertido a HFC pero que aún no estaban fabricando equipos con esta tecnología por dificultades en el abastecimiento de compresores con HFC-32. El Banco Mundial indicó que no había problemas en el abastecimiento de compresores con HFC-32 en Viet Nam, y que los planes de conversión destinados a las tres empresas que originalmente preveían convertirse a la tecnología HFC-32 seguían vigentes.

56. En lo tocante a los costos adicionales para la conversión a tecnología con HFC-32 en Midea Viet Nam, el Banco Mundial aclaró que la reducción de los costos adicionales de explotación se debía al menor costo de los compresores con HFC-32 en comparación con los de R-290. Se acordó ajustar la capacitación a un monto de 4 000 $EUA, lo que es consecuente con la financiación facilitada a otras tres empresas que se convertirán a la tecnología HFC-32. Otros costos adicionales de la propuesta revisada del Banco Mundial son congruentes con los acordados en la 76ª reunión para las otras tres empresas que decidieron convertirse a la tecnología HFC-32. Una vez así acordado, el costo total de la conversión se acordó en 768 659 $EUA, de lo que resulta la devolución de 68 358 $EUA, más gastos de apoyo al organismo de 4 785 $EUA para el Banco Mundial, a reembolsar al Fondo Multilateral. El Acuerdo entre el Gobierno de Viet Nam y el Comité Ejecutivo se enmendará para reflejar esta devolución cuando se presente la solicitud de financiación del segundo tramo de la etapa II del PGEH.

57. Por último, la Secretaría tomó nota de que si el Comité Ejecutivo aprueba el cambio solicitado de tecnología, la futura admisibilidad de la empresa para recibir financiación en virtud de la reducción del consumo de HFC sería de conformidad con el párrafo 18 de la decisión XXVIII/2, observando que una aprobación tendría lugar tras la adopción de la Enmienda de Kigali.

Recomendaciones

58. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota de la solicitud de financiación presentada por el Banco Mundial en nombre del Gobierno de Viet Nam para cambiar de tecnología en Midea Consumer Electric (Viet Nam) Co. Ltd., pasando de R-290 a HFC-32, en el marco de la etapa II del plan de gestión para la eliminación de HCFC (PGEH);

b) Aprobar la solicitud de financiación para el cambio de tecnología destinado a Midea Consumer Electric (Viet Nam) Co. Ltd., pasando de R-290 a HFC-32, por una cuantía que asciende a 768 659 $EUA, más gastos de apoyo al organismo de 53 806 $EUA para el Banco Mundial, de lo que se derivaría la devolución a la 81ª reunión de 68 358 $EUA, más gastos de apoyo al organismo de 4 785 $EUA para el Banco Mundial, que éste tendría que reembolsar al Fondo Multilateral; y

c) Tomar nota de que el Acuerdo entre el Gobierno de Viet Nam y el Comité Ejecutivo para la etapa II del PGEH se enmendaría a fin de reflejar el reembolso de financiación indicado en el inciso b) a la hora de presentarse la solicitud de financiación del segundo tramo de la etapa II del PGEH.

PARTE III: PROYECTOS DE DEMOSTRACIÓN PARA ALTERNATIVAS DE BAJO POTENCIAL DE CALENTAMIENTO ATMOSFÉRICO (PCA) A LOS HCFC Y ESTUDIOS DE VIABILIDAD DE LOS SISTEMAS DE REFRIGERACIÓN URBANA (DECISIÓN 72/40)

Antecedentes

59. En las reuniones 74ª , 75ª y 76ª , el Comité Ejecutivo aprobó tres estudios de viabilidad para sistemas de refrigeración de edificios urbanos (es decir, refrigeración centralizada de edificios urbanos) (Egipto, Kuwait y República Dominicana) y 17 proyectos para demostrar tecnologías de bajo PCA de conformidad con la decisión XXV/5 y la decisión 72/40, entre los que se incluyeron: siete proyectos en el sector de refrigeración y aire acondicionado y el subsector de ensamblaje (Arabia Saudita [dos], China, Colombia, Costa Rica, un proyecto mundial (Argentina y Túnez) y un proyecto regional (Asia occidental[8]); seis proyectos en el sector de espumas (Arabia Saudita, Colombia, Egipto, Marruecos, Sudáfrica y Tailandia); y tres proyectos en el sector de servicio y mantenimiento de refrigeración (Maldivas, la región de Europa y Asia Central y un proyecto mundial [regiones de África Oriental y el Caribe]).

60. En la 80ª reunión, el Comité Ejecutivo sopesó información actualizada sobre la situación de la ejecución de proyectos de demostración de alternativas de bajo PCA que no han sido finalizados. En posteriores debates, el Comité Ejecutivo convino en cambiar las fechas de terminación de cada uno de tales proyectos de demostración en curso y tres estudios de viabilidad de refrigeración centralizada de edificios urbanos y, entre otras cosas, pidió a los organismos de ejecución que presentaran a la 81ª reunión una actualización sobre la marcha de las actividades de ejecución de todos los proyectos de demostración en curso y de los tres estudios de viabilidad sobre refrigeración centralizada de edificios urbanos, tales como aquellos con requisitos específicos de presentación de informes; y reiteró que los organismos de ejecución habrán de atenerse a las decisiones del Comité Ejecutivo sobre los requisitos de presentación de informes y presentar los mismos conforme a como los pida la Secretaría (decisión 80/26).

61. De conformidad con la decisión 80/26, los informes finales de los proyectos de demostración para Colombia (dos proyectos), Costa Rica, Maldivas, y Sudáfrica; y los informes pormenorizados sobre la marcha de las actividades de ejecución de los proyectos aprobados para Egipto (refrigeración centralizada de edificios urbanos), Kuwait (refrigeración centralizada de edificios urbanos), Marruecos y el proyecto regional de Asia occidental (PRAHA-II), se han presentado a la 81ª reunión. Además, los sumamente sucintos informes sobre la marcha de las actividades de ejecución de proyectos de demostración para Arabia Saudita (tres proyectos), China, Egipto, la República Dominicana y Tailandia (refrigeración centralizada de edificios urbanos), presentados a la 81ª reunión, se recogen en el Cuadro 3.

[8] El proyecto de demostración en Asia occidental para el fomento de refrigerantes alternativos para países con elevada temperatura ambiente, denominado “PRAHA-II”.

Cuadro 3. Informes de los estudios de viabilidad sobre refrigeración centralizada de edificios urbanos y proyectos de demostración de bajo PCA que no se presentaron a la 81ª reunión

País (organismo)	Título del proyecto	Fecha de terminación	Información sobre la marcha de las actividades de ejecución notificada a la 81ª reunión
China (PNUD)	Proyecto de demostración de compresores de tornillo semiherméticos con convertidor de frecuencia para equipos de refrigeración a base de amoniaco en el sector de la refrigeración industrial y comercial, en Fujian Snowman Co., Ltd.	Jun-18	El proyecto ha venido avanzando bien y se celebró una reunión de puesta en servicio. De conformidad con la decisión 80/26 a), se presentará un informe final a la 82ª reunión.
Egipto (PNUD)	Demostración de opciones de bajo costo para la conversión de tecnologías sin SAO en la producción de espumas de poliuretano a muy pequeña escala.	Dec-18	El proyecto recibió la autorización y visto bueno del Gobierno; se han asignado presupuestos con planes específicos de adquisición que se han avanzado de fecha para optimizar los modelos de los equipos que se buscan. De conformidad con la decisión 80/26 e), se presentará un informe final a lo más tardar a la 83ª reunión.
Arabia Saudita (ONUDI)	Proyecto de demostración para promover el uso de refrigerantes con tecnología HFO con bajo PCA en el sector de aire acondicionado en lugares con elevadas temperaturas ambiente.	Dec-18	Se ha firmado el contrato con el proveedor. El desarrollo de los prototipos está en curso. Se han entregado los componentes (por ejemplo, compresores) para realizar ensayos. Queda pendiente la visita de los técnicos del proveedor de los equipos y la entrega del equipo de producción y la producción de las primeras unidades con HC-290. De conformidad con la decisión 80/26 g), se presentará un informe final a lo más tardar a la 83ª reunión.
Arabia Saudita (Banco Mundial)	Proyecto de demostración en fabricantes de equipos de aire acondicionado para el desarrollo de equipos de aire acondicionado de ventana e integrados que usan refrigerantes con bajo potencial de calentamiento atmosférico.	Sep-18	El proceso administrativo para iniciar la ejecución se culminó en febrero de 2018. La entrega del diseño del prototipo está prevista para junio de 2018 con la producción de dicho prototipo comenzando en agosto de 2018. El informe final se presentará a la 82ª reunión.
Arabia Saudita (ONUDI)	Proyecto de demostración para la eliminación de los HCFC mediante el uso de HFO como agente espumante en aplicaciones de espuma pulverizada en lugares con elevadas temperaturas ambiente	Dec-18	En febrero de 2018 se organizó la presencia de una misión in situ. Los ensayos del nuevo sistema de producción de espumas con HFO-1233zd se llevó a cabo; los ensayos demostraron la relación de costo a eficacia y propiedades físicas similares del nuevos sistema en comparación con los de tecnología de HCFC-141b. De conformidad con la decisión 80/26 i), se presentará un informe final a lo más tardar a la 83ª reunión.
Tailandia (Banco Mundial)	Proyecto de demostración en proveedores de sistemas para espumas para formular polioles premezclados para aplicaciones de espumas de poliuretano pulverizado utilizando un agente espumante con bajo potencial de calentamiento atmosférico.	Sep-18	Se firmaron los Acuerdos con ambos proveedores en noviembre de 2017. Ambos proveedores de sistemas han iniciado la adquisición de los equipos, y se encuentran a la espera de recibirlos. De conformidad con la decisión 80/26(k), el informe final se presentará a lo más tardar a la 83ª reunión.
República Dominicana (PNUD)	Estudio de viabilidad para sistemas de refrigeración centralizada de edificios urbanos en Punta Cana.	Dec-17	El PNUD ha informado que este proyecto se consideró terminado desde la 79th reunión. No obstante, un informe final no se ha presentado según se prescribe en virtud de la decisión 80/26 m).

* Esta cifra no incluye los fondos para la preparación de proyecto ni los gastos de apoyo al organismo.
** El proyecto se terminará hacia mayo de 2018, pero no se ha firmado aún el documento de proyecto para la ejecución y no se ha ejecutado aún ninguna actividad.

Recomendaciones

62. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota de los informes sobre la marcha de las actividades de ejecución de los proyectos de demostración presentados por los organismos de ejecución, conforme a lo que se recoge en el Cuadro 3 del presente documento;

b) Instar al PNUD a presentar el informe final sobre la asistencia técnica para un estudio de viabilidad sobre refrigeración centralizada de edificios urbanos en la República Dominicana a lo más tardar a la 82ª reunión; e

c) Instar a los organismos de ejecución a presentar una actualización sobre los proyectos de demostración para Arabia Saudita, China, Egipto y Tailandia a la 82ª reunión y los informes finales de conformidad con la decisión 80/26.

<u>Colombia: informe final sobre el proyecto de demostración para la eliminación del consumo de HCFC-22 en la fabricación de equipos de climatización comercial en Industrias Thermotar Ltda.</u> (PNUD)

Antecedentes

63. En la 75ª reunión, el Comité Ejecutivo aprobó el proyecto de demostración para usar R-290 (propano) como refrigerante alternativo en la fabricación de equipos de climatización comercial en Industrias Thermotar Ltda., en Colombia[9] por el monto de 500 000 $EUA, más gastos de apoyo al organismo de 35 000 $EUA para el PNUD (decisión 75/40).

64. El proyecto se aprobó para demostrar el uso seguro del R-290 como refrigerante de bajo potencial de calentamiento atmosférico (PCA) en el sector de fabricación de equipos de climatización comercial en gamas comprendidas entre 3,5 kW (una tonelada de refrigeración (TR)) y 17,5 kW (cinco TR); posibilitar la fabricación de equipos con hidrocarburos (HC) de buen desempeño y con un costo adicional de explotación mínimo; y demostrar la manipulación segura y la gestión de riesgo adecuada para introducir refrigerantes combustibles en el sector de climatización comercial de Colombia, con objeto de fomentar la posible adopción por parte de otros países que operan al amparo del artículo 5.

65. En nombre del Gobierno de Colombia, el PNUD ha presentado el informe final del proyecto de demostración (dicho informe se adjunta al anexo III del presente documento). El proyecto se llevó a cabo en Industrias Thermotar Ltda., una empresa que fabrica equipos herméticos y acondicionadores de aire tipo dividido con conducto condensador y refrigerante de HCFC-22, con una producción media anual de 4 100 unidades, y que consume aproximadamente el 60 por ciento del consumo total de HCFC-en el sector de equipos de climatización comercial. La conversión a la tecnología R-290 ya se ha culminado, de lo que se deriva una eliminación de 13,27 tm (0,73 toneladas PAO) de HCFC-22.

66. Colombia se enfrentó a dos impedimentos a la fabricación comercial de equipos de climatización con R-290: una falta de información técnica sobre el diseño, ingeniería y fabricación de equipos con R-290 como refrigerante, y los limitados conocimientos técnicos del personal instalador y de servicio y mantenimiento de este tipo de equipos.

67. Cabe señalar las siguientes conclusiones:

a) Reducción del diámetro del tubo del termointercambiador (condensador): se definieron dos modelos para ambos tipos de equipos de climatización, a saber,

[9] UNEP/OzL.Pro/ExCom/75/42 y Add.1.

termointercambiadores con microcanal de aluminio y termointercambiadores con tubo de cobre de 8 mm. A los modelos de mayor envergadura (5 TR) se les aplicaron los diseños y ensayos ya desempeñados, dado que pueden reproducirse en el resto de los modelos;

b) Reducción de la carga de refrigerante R-290: la carga que se estimó fue de 1,00 kg para los equipos tipo dividido con conducto condensador (5 TR) con una tubería de 5 metros; la carga para un equipo condensador hermético fue de 0,95 kg. Hubo algunos casos en los que las reducciones de las cargas superaron el 50 por ciento en comparación con los modelos con refrigerante de HCFC-22;

c) Modificación de la estructura metálica (armarito) de los condensadores: la estructura metálica de ambos tipos de equipos se modificó, y los cajetines de conexiones eléctricas se dispusieron individualmente o bien se aislaron;

d) Modificación de la estructura metálica de la unidad de manipulación: se modificó la estructura metálica de la unidad de manipulación (parte del condensador dividido) con objeto de aislar el cajetín de conexiones eléctricas y todo el conjunto del marco, principalmente la zona de admisión de aire, a fin de impedir la acumulación de R-290 dentro de una caja cerrada en caso de producirse fugas;

e) Instalación del ciclo de recogida: el condensador dividido y la unidad hermética tienen un ciclo de "recogida", en el que se recolecta y confina la mayor parte del refrigerante del condensador (fuera del equipo). Esto tiene lugar una vez se detecten variaciones de presión mediante dos presóstatos situados en el equipo de climatización;

f) Sensor de ultrasonidos: la unidad de manipulación dispone de un sensor de ultrasonidos para la detección de fugas, a guisa de característica adicional de seguridad para prevenir que en el interior de un espacio cerrado se acumulen elevados niveles de R-290 en caso de producirse fugas; y

g) Consumo energético: la empresa llevó a cabo ensayos comparativos conexos al consumo energético entre los equipos con R-410A y con R-290 (5 TR). Los de tecnología R-290 consumen un 15 por ciento menos energía que los de tecnología HCFC-22 y un 13 por ciento menos que los de R-410A.

68. Las medidas de seguridad necesarias en la nueva línea de producción y en todo el conjunto de la empresa se definieron mediante la evaluación de seguridad efectuada por una empresa de seguros independiente, la cual certificó que Industrias Thermotar Ltda. Había implantado todas las recomendaciones resultantes del estudio de análisis de riesgos conexas a la nueva línea de producción con R-290.

69. Se efectuaron actividades de capacitación bajo la supervisión de asesores internacionales, lo que continuará en el plano nacional. Se crearon documentos técnicos para actualizar las normas nacionales (NTC 6828) fundamentándose en la norma ISO 5149[10], y se elaboró un plan de apoyo que se centró en el usuario final y en el sector de servicio y mantenimiento. Los resultados y las conclusiones del proyecto de demostración se presentaron en eventos locales e internacionales.

[10] La norma ISO 5149-1:2014 especifica los requisitos relativos a la seguridad de las personas y de la propiedad, aporta directrices para la protección del medio ambiente y establece procedimientos a seguir para realizar operaciones, tareas de mantenimiento y reparación de sistemas de refrigeración y de recuperación de refrigerantes.

Observaciones

70. La Secretaría tomó nota de que la etapa II del PGEH para Colombia incluye un número de actividades en el sector de servicio y mantenimiento que complementarían esta conversión al permitir el uso y el servicio y mantenimiento de equipos con R-290, incluyendo la creación de un centro de capacitación en refrigerantes naturales; la creación y el desarrollo de reglamentos y normas relativos a los refrigerantes combustibles; y registros cronológicos en línea en el sector de servicio y mantenimiento de equipos de climatización. Además, el proyecto para fomentar cambios en los hábitos de consumo de los usuarios finales de sistemas de refrigeración y de climatización comercial, incluyendo la adopción de exención del impuesto del valor añadido para los usuarios finales de sistemas de enfriamiento que apliquen criterios de consumo energético eficiente y de impacto medioambiental bajo, habrá de fomentar la entrada al mercado, al igual que debería ocurrir por la inclusión de estrategias similares de empresa destinadas a utilizar equipos de consumo energético eficiente y de bajo PCA.

71. La empresa ofrece un plan de mantenimiento básico para los seis primeros meses y un contrato preventivo, que incluye un mínimo de tres visitas anuales. Además, todos los equipos que dicha empresa fabrique tienen una garantía de un año. Las tareas de servicio y mantenimiento las ejecuta el propio departamento de servicio técnico de la empresa o los proveedores de servicio formados y capacitados por Thermotar y el Servicio Nacional de Aprendizaje (SENA). Todos los equipos los instalará el propio servicio técnico de la empresa o distribuidores conexos capacitados y formados por la empresa.

72. La Secretaría tomó nota de que la empresa no ha podido aún vender ningún equipo con R-290. El PNUD indicó que no hay obstáculos comerciales que lo justifiquen, y que la empresa está a la espera de las primeras existencias de compresores con R-290 y de culminar la capacitación y formación profesional de los técnicos de servicio. En lo tocante a la posibilidad de que la empresa compensaría por la línea de producción de R-290 que permanece inactiva incrementando para ello la fabricación de equipos con alto PCA, el PNUD indicó que la empresa ha aumentado ligeramente el nivel de fabricación de equipos con refrigerante de alto PCA, si bien dicho incremento se debe a las tendencias del mercado y no a la conversión de la línea de producción.

Recomendaciones

73. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, del informe final del proyecto de demostración de R-290 (propano) a guisa de refrigerante alternativo en la fabricación de equipos comerciales de climatización en Industrias Thermotar Ltda., en Colombia, presentado por el PNUD; e

b) Invitar a los organismos bilaterales y de ejecución a tener en cuenta el informe final del proyecto de demostración mencionado en el inciso a) antedicho, a la hora de asistir a los países que operan al amparo del artículo 5 como preparativo en los sectores de equipos de climatización.

<u>Colombia: informe final del proyecto de demostración para validar el uso de hidro-fluoro-olefinas (HFO) para paneles cortados en partes que operan al amparo del artículo 5 mediante el desarrollo de formulaciones eficientes respecto de sus costos (PNUD)</u>

Antecedentes

74. En la 76ª reunión, el Comité Ejecutivo aprobó el proyecto de demostración para validar el uso de hidro-fluoro-olefinas (HFO) para la producción de tableros cortados en países que operan al amparo del

artículo 5 mediante el desarrollo de formulaciones eficientes respecto de sus costos en Colombia[11], por un volumen de 248 380 $EUA, más gastos de apoyo al organismo de 22 354 $EUA para el PNUD (decisión 76/29).

75. El proyecto se aprobó para validar formulaciones de poliuretano (PU) destinadas a la producción de tableros cortados con menor cantidad de HFO (es decir, HFO-1233zd(E) y HFO 1336mzz(z)); optimizar el equilibrio costo/desempeño para lograr un desempeño térmico similar al de las formulaciones con HCFC-141b; y realizar un análisis de costos de las diferentes formulaciones HFO/agua en comparación con los sistemas con HCFC-141b. En concreto, el proyecto se diseñó para evaluar dos HFO como agentes coespumantes en asociación con CO_2 derivado de la reacción agua-isocianato: se compararon HFO-1336mzz(Z) y HFO-1233zd(E). El tratamiento de la espuma y las propiedades físicas obtenidas con estas substancias, junto con sus costos de formulación respectivos se compararon con los de los sistemas con HCFC-141b. Espumlatex, el mayor proveedor de sistemas de PU 100 por cien de propiedad colombiana, equipado con 18 tanques de mezcla y con un laboratorio certificado de control de calidad, sirvió como anfitrión técnico local para coordinar la demostración, las aplicaciones de la espuma y las actividades de los ensayos.

76. En nombre del Gobierno de Colombia, el PNUD ha presentado el informe final del proyecto de demostración (el informe final se adjunta en el anexo IV del presente documento). Las conclusiones del proyecto de demostración son como sigue:

a) Se desarrollaron formulaciones con HFO, habiéndose reducido la concentración del agente espumante entre un 61 y un 64 por ciento por peso (equivalente a una reducción de HFO del 60 por ciento en las células de gas). Estas formulaciones no plantean ninguna cuestión adicional de tipo medioambiental, de seguridad ni de higiene industrial;

b) En comparación con las formulaciones con HCFC-141b, las de concentraciones reducidas de HFO arrojaron un mayor flujo de la espuma (es decir, una menor relación de flujo entre la densidad de subida libre y la densidad mínima de llenado); un factor-*k* inicial[12] un 7 por ciento más elevado en el laboratorio (inyecciones Brett; se reprodujo también en el plano de planta), y valores de factor-*k* similares medidos un mes después de la inyección; y valores de laboratorio y de planta de producción similares de la resistencia a la compresión, la estabilidad dimensional y la adhesión a los metales;

c) La capacidad de manipulación y de tratamiento en la planta de producción de la formulación con HFO reducida fueron similares a las de HCFC-141b;

d) No se observó diferencia alguna (estadísticamente hablando) entre el desempeño de las espumas de ambos tipos de HFO, (HFO-1233zd(E) y HFO-1336mzz(Z));

e) En el caso de condiciones de un clima cálido, los sistemas con HFO-1233zd(E) podrían necesitar unas condiciones de almacenamiento por las que se enfríen los polioles formulados y almacenados, y el depósito de almacenamiento diurno de los polioles formulados a temperaturas comprendidas entre 20 y 25 grados Celsius;

f) En el caso de tableros cortados y de otras aplicaciones de espumas rígidas, los moldes habrán de equiparse con controles de la temperatura para garantizar un buen desempeño;

[11] UNEP/OzL.Pro/ExCom/76/26.
[12] La conductividad térmica, es decir, el factor-*k*, es el cómputo de la capacidad de un material dado para transferir calor. Los materiales que transfieren calor sin problemas tienen factores-*k* elevados; cuánto más bajo el valor de *k*, más elevadas serán las propiedades de aislamiento del material.

g) A día de hoy, el precio de los sistemas con HFO reducido es de 16,4 a 33,2 por ciento más caro; no obstante, ello podría bajar en un futuro; y

h) Se acometieron las tareas iniciales para investigar las formulaciones de espumas con reducción del 80 por ciento en la concentración de HFO. Los resultados fueron prometedores, si bien se sugirió realizar más ensayos.

Observaciones de la Secretaría

77. La Secretaría tomó nota, con reconocimiento, del informe que evaluó plenamente el desempeño y los costos de sistemas con concentración de HFO reducida, empleó el diseño de los experimentos para facilitar resultados estadísticos significativos, y demostró la tecnología en el marco de un fabricante de espumas (Ingeniería de Refrigeración Industrial Rojas Hermanos S.A). Los resultados son congruentes con los informes recogidos en los relatos y en los informes técnicos anteriores.

78. El PNUD hizo hincapié en el considerable trabajo acometido por el proveedor de sistemas para desarrollar la formulación, amén de no describirse en el informe el grado de complejidad, en parte por las restricciones de confidencialidad. El PNUD resaltó también la importancia de los moldes calentados; el hecho de que algunos de los productos químicos se suministraron a costos favorables para el proyecto de demostración; y el que los resultados del informe habrán de verse como un punto inicial para el ulterior desarrollo de los sistemas de HFO en países que operan al amparo del artículo 5.

79. El informe arroja un costo total en términos de $EUA/kg del sistema PU. La Secretaría convirtió estos costos en costos adicionales de explotación como se recoge en el Cuadro 4. Los costos adicionales de explotación para HFO-1233zd(E) varían entre 9,17 $EUA/kg para HCFC-141b y 3,48 $EUA/kg para HCFC-141b, mientras que los costos adicionales de explotación para HFO-1336mzz(Z) varían entre 21,60 $EUA/kg para HCFC-141b y 8,14 $EUA/kg para HCFC-141b.

Cuadro 4. Costos del sistema de producción de PU con HFO-1233zd(E) y con HFO-1336mzz(Z)

	HCFC-141b	Reducción del 0%	Reducción del 20%	Reducción del 40%	Reducción del 60%
Costo de sistemas de PU con HFO-1233zd(E)					
Costo total del sistema ($EUA/kg del sistema)	2,73	3,91	3,59	3,32	3,18
Costo adicional de explotación ($EUA/kg para HCFC-141b)	n.c.	9,17	6,66	4,53	3,48
Costo de sistemas de PU con HFO-1336mzz(Z)					
Costo total del sistema ($EUA/kg del sistema)	2,73	5,52	4,75	4,32	3,78
Costo adicional de explotación ($EUA/kg para HCFC-141b)	n.c.	21,60	15,68	12,33	8,14

80. Los costos adicionales de explotación que se muestran en el Cuadro 4 se fundamentan en los costos de los HCFC-141b y los HFO como se indica en el informe[13]. De las recientes tendencias parece deducirse que el precio HCFC-141b ha subido, por lo que una reducción de la producción de la sustancia puede derivar en más incrementos del costo. De los datos incluidos en las recientes presentaciones de planes de gestión para la eliminación de los HCFC se deduce que lo más corriente son costos de HCFC-141b más elevados. Así mismo, el precio notificado de los HFO varía considerablemente, siendo común el que haya costos superiores a los recogidos en el informe. A juzgar por algunos de los informes, la cifra de la producción comercial de HFO en uno de los grandes países productores que operan al amparo del

[13] Los costos por unidad que se recogen en el informe son, a saber: HCFC-141b: 2,97 $EUA/kg; HFO-1233zd(E): 12,00 $EUA/kg; HFO-1336mzz(Z): 20,00 $EUA/kg, mezcla de polioles: 2,16-2,42 $EUA/kg; aditivos (catalizadores, tensioactivos, aditivos): 1,47-1,61 $EUA/kg.

artículo 5, está prevista que se publique a mediados de 2019, arrojando una ya prevista reducción correspondiente de los costos, aunque el momento en que acaezca esta reducción es incierto.

81. Con objeto de facilitar información pertinente para la penetración de tecnología en el mercado, la Secretaría evaluó la variación en los costos adicionales de explotación, fundamentándose en las formulaciones aportadas, el incremento del precio de HCFC-141b, y la reducción de los precios de los HFO. Los Cuadros 5 y 6 muestran los costos adicionales de explotación para la formulación con una reducción del 60 por ciento cual una función del precio de HCFC-141b y de los HFO. A título de referencia, cuando el costo de los HFO es de 10 $EUA/kg, los costos adicionales de explotación son cero al llegar el costo de HCFC-141b a 5,65 $EUA/kg, en el caso del HFO-1233zd(E), y de 7,85 $EUA/kg en el caso de HFO-1336mzz(Z). El PNUD resaltó que los costos de los productos químicos en otros países que operan al amparo del artículo 5 podrían ser diferentes a los presentados en este informe, lo que podría influir en los costos adicionales de explotación.

Cuadro 5. Costo adicional de explotación ($EUA/kg) para formulaciones con una reducción del 60 por ciento a guisa de función del precio de HCFC-141b y de HFO-1233zd(E)

Precio de HCFC-141b ($EUA/kg)	Precio de HFO-1233zd(E)		
	14 $EUA/kg	12 $EUA/kg	10 $EUA/kg
2,97 $EUA/kg	4,18	3,43	3,08
3,5 $EUA/kg	3,65	2,9	2,15
4,5 $EUA/kg	2,65	1,90	1,15
5 $EUA/kg	2,15	1,40	0,65

Cuadro 6. Costo adicional de explotación ($EUA/kg) para formulaciones con una reducción del 60 por ciento a guisa de función del precio de HCFC-141b y de HFO-1336mzz(Z)

Precio de HCFC-141b ($EUA/kg)	Precio de HFO-1336mzz(Z) ($EUA/kg)		
	20 $EUA/kg	15 $EUA/kg	10 $EUA/kg
2,97 $EUA/kg	8,14	5,62	3,1
3,5 $EUA/kg	7,61	5,09	2,57
4,5 $EUA/kg	6,61	4,09	1,57
5 $EUA/kg	6,11	3,59	1,07

Recomendaciones de la Secretaría

82. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, del informe final del proyecto de demostración con objeto de validar el uso de hidro-fluoro-olefinas (HFO) para la producción de tableros cortados, por aquellas partes que operan al amparo del artículo 5, mediante el desarrollo de formulaciones de relación eficiente respecto de sus costos, efectuado en Colombia y presentado por el PNUD; e

b) Invitar a los organismos bilaterales y de ejecución a tener en cuenta el informe final del proyecto de demostración antedicho en el inciso a) indicado *supra*, a la hora de asistir a los países que operan al amparo del artículo 5 como preparación de los proyectos de producción de espumas con espumantes de HFO.

Costa Rica: demostración de la aplicación de un sistema de refrigeración formado por amoniaco/dióxido de carbono en sustitución de HCFC-22 para un productor de calibre medio y un almacén de venta al por menor de Premezclas Industriales, S.A. (PNUD)

Antecedentes

83. En la 76ª reunión, el Comité Ejecutivo aprobó la financiación del proyecto para demostrar la aplicación de un sistema de refrigeración compuesto de amoniaco/dióxido de carbono en sustitución de HCFC-22 para un productor de calibre medio y un almacén de venta al por menor de Premezclas Industriales, S.A. (PNUD) en Costa Rica[14] por un monto de 524 000 $EUA, más gastos de apoyo al organismo de 36 680 $EUA para el PNUD (decisión 76/23).

84. El proyecto se aprobó para demostrar el uso del sistema[15] de refrigeración bietápico compuesto de amoniaco (NH_3)/dióxido de carbono (CO_2) en almacenes de venta al por menor como repuesto viable para un sistema con HCFC-22, en la empresa Premezclas Industriales de Panadería S.A. (Premezclas), que trabaja con un sistema de almacenamiento en frío de 50 toneladas de capacidad (TR). El sistema que se propone reducirá la presión de trabajo y los costos del circuito secundario, así como el volumen de la carga de NH_3, lo que reducirá los riesgos para la salud y la seguridad.

85. En nombre del Gobierno de Costa Rica, el PNUD presentó el informe final del proyecto de demostración (informe que se adjunta al anexo V del presente documento).

86. La conversión al nuevo sistema de refrigeración en cascada comenzó en junio de 2017 y se terminó en enero de 2018. Representa el primer y único sistema refrigerante adoptado en el sector de la industria alimentaria que se usa actualmente en la región de América Central. Los resultados del proyecto de demostración son como sigue:

a) El uso de NH_3/CO_2 en cascada (recirculando una salmuera tipo CO_2), es una solución innovadora y viable a implementar en empresas de fabricación de calibre medio. Este sistema puede adoptarse en otras empresas nacionales y/o de la misma región, que necesiten encontrar una solución definitiva al reemplazamiento de los refrigerantes de HCFC o de HFC;

b) El nuevo sistema de enfriamiento de la cámara de producto ya acabado que se fundamenta en la tecnología de cascada, redunda en ahorros en el consumo de electricidad (es decir, durante los dos meses de funcionamiento del nuevo sistema, los costos de electricidad arrojaron una reducción del 10 por ciento). Con arreglo a la estimación efectuada, el nuevo sistema podría alcanzar reducciones de hasta el 20 por ciento en los costos de electricidad;

c) El nuevo sistema facilita menores costos de producción al reducir el consumo de electricidad, menos intervenciones para las labores de mantenimiento, no requiere que haya que comprar HCFC-22 para rellenar los sistemas como consecuencia de las fugas ocasionadas durante el funcionamiento, y permite usar refrigerantes naturales más económicos;

[14] UNEP/OzL.Pro/ExCom/76/28.
[15] El NH_3 es un sistema de alta temperatura y el CO_2 se encuentra en el circuito de baja temperatura cuya circulación impulsan las bombas, y en el que este CO_2 se emplea como fluido de transferencia de calor (salmuera).

d) La nueva tecnología adoptada y ejecutada pone de manifiesto que es posible vencer los obstáculos para aplicar gases naturales con niveles de toxicidad y combustibilidad, y elevadas presiones de trabajo. Lo que es más, contribuirá a que las empresas se comprometan con el objetivo de neutralidad en el consumo de carbono para 2021 prescrito por el Gobierno de Costa Rica;

e) Se facilitará una capacitación adicional para el personal técnico a medio plazo, de conformidad con la mayor experiencia en el funcionamiento, servicio y mantenimiento que se vaya acumulando con el nuevo sistema de funcionamiento en cascada; habrá también que desarrollar procedimientos para el servicio partiendo de la experiencia obtenida en el funcionamiento de este nuevo sistema;

f) La nueva tecnología tendrá que demostrarse ante técnicos en equipos de refrigeración, estudiantes e ingenieros, así como ante los responsables de la toma de decisiones de las empresas con el fin de fomentar que se produzca el cambio en sectores industriales similares;

g) Se necesita una supervisión y evaluación periódicos del funcionamiento del nuevo sistema, incluyendo el mantenimiento del historial de consumo de energía y los datos operativos.

Observaciones

87. La Secretaría tomó nota de la ejecución con éxito del proyecto, el cual demostró que el potencial de ahorro en el consumo energético de este nuevo tipo de sistema de refrigeración en cascada formado de NH_3/CO_2 (hasta la fecha una reducción del 10 por ciento en las facturas de electricidad), puede alcanzar una gama de temperaturas más amplia (con temperaturas tan bajas como de hasta -18 grados Celsius), un menor costo de explotación consecuencia de un menor mantenimiento y de refrigerantes más económicos, y la eliminación de 900 kg de HCFC-22 instalados en el sistema de refrigeración que se ha sustituido.

88. Esta tecnología podría potencialmente darse en una serie de aplicaciones del sector alimentario, incluyendo tahonas, lecherías, carnecerías, pescaderías y productos congelados. Se necesitaría un mayor grado de análisis de la viabilidad económica de la tecnología para entender mejor su capacidad de reproducción. Se prevén ahorros de hasta el 20 por ciento en las facturas de electricidad y una reducción de los costos de explotación, siendo el costo de capital de la instalación de 943 000 $EUA.

89. Un tema aparte, sujeto a un mayor grado de análisis, es el de los aspectos de salud e higiene de la instalación, operación, mantenimiento y eliminación de sistemas con este tipo de tecnología. Tanto el CO_2 como el NH_3 exigen mayores pericias y conocimientos por parte de los instaladores y técnicos de lo que se necesita en el caso del sistema con HCFC-22. Un mayor uso de esta tecnología en pequeños sistemas necesitaría una revisión de la capacidad de los técnicos locales para gestionar el CO_2 y el NH_3 así como el tipo de reglamentos, normas y códigos de prácticas aplicables.

Recomendaciones

90. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, del informe final del proyecto para demostrar la aplicación del sistema de refrigeración con amoniaco/dióxido de carbono en sustitución del HCFC-22 para los productores de calibre medio y para los almacenes de venta al por menor de Premezclas Industriales, S.A., en Costa Rica, que presentó el PNUD; e

b) Invitar a los organismos bilaterales y de ejecución a que compartan el informe final del proyecto de demostración mencionado en el inciso a) indicado *supra*, a la hora de asistir a los países que operan al amparo del artículo 5, como preparativo para reemplazar el HCFC-22 utilizado en los sistemas de refrigeración comercial de productores de calibre medio y de almacenes de venta al por menor.

Maldivas: proyecto de demostración de alternativas sin HCFC y de bajo PCA para la refrigeración en el sector de pesquerías (PNUD)

Antecedentes

91. En la 76ª reunión, el Comité Ejecutivo aprobó la financiación del proyecto de demostración de alternativas sin HCFC y de bajo PCA para la refrigeración en el sector de pesca en las Maldivas[16], por un monto de 141 000 $EUA, más gastos de apoyo al organismo de 12 690 $EUA (decisión 76/34).

92. El proyecto se aprobó para identificar tecnologías alternativas de bajo PCA a los HCFC para utilizarse en los equipos de refrigeración con una carga de 150 kg a 200 kg de refrigerante en el sector de pesca. Ello incluía la conversión de los equipos de refrigeración con HCFC-22 de tres buques pesqueros para utilizar tecnologías de bajo PCA, evaluando el desempeño de tecnologías alternativas, y evaluando también la idoneidad de la tecnología seleccionada partiendo del costo de retroadaptación y manteniendo el mejor desempeño posible del equipo. Partiendo de la evaluación, las tecnologías más idóneas se distribuirán en el marco del sector de pesca.

93. En nombre del Gobierno de las Maldivas, el PNUD ha presentado el informe final del proyecto de demostración (informe final que se adjunta al anexo VI del presente documento). En el transcurso de la ejecución del proyecto se desarrollaron los criterios para la selección del refrigerante alternativo, tal y como se resume seguidamente:

a) La combustibilidad, un criterio crucial de seguridad que hay que examinar antes de seleccionar un refrigerante idóneo. Tanto el R-444B[17] como el L40/D8[18] son ligeramente combustibles, mientras que el R-448A[19] no es combustible;

b) El costo de retroadaptar los sistemas de refrigeración utilizados en los buques pesqueros, que sean viejos (de aproximadamente 20 años y frágiles por los años en servicio), y que requieran modificaciones, sería elevado. Como consecuencia de los años en servicio, no es posible asegurar que los sistemas de refrigeración (es decir, los equipos y las tuberías) se mantengan a prueba de fugas. Lo que es más, los sistemas de refrigeración se confinan en espacios muy limitados y reducidos del interior del buque. Así pues, la retroadaptación con refrigerantes R-444B y/o L40/D8 sigue siendo un riesgo al ser ambos ligeramente combustibles, y la conversión conllevaría costos significativos; y

c) El desempeño de los sistemas de refrigeración, allí donde parezca que el R-448A es el refrigerante más idóneo, puede emplearse sin que repercuta significativamente en el desempeño del equipo.

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[16] UNEP/OzL.Pro/ExCom/76/40.

[17] R-444B: 41,5 por ciento de HFC-32, 10 por ciento de HFC-152a, y 48,5 por ciento of HFO-1234ze(E), con un valor de PCA de 295.

[18] L40/D8: 40 por ciento de HFC-32, 10 por ciento de HFC-152a, 20 por ciento de HFO-1234yf y 30 por ciento de HFO-1234ze(E), con un valor de PCA inferior a 300.

[19] R-448A: 26 por ciento de HFC-32, 26 por ciento de HFC-125, 21 por ciento de HFC-134a, 7 por ciento de R-1234ze y 20 por ciento de HFO-1234yf, con un valor PCA de 1 273.

94. Partiendo del criterio anterior y respaldándose en el estudio teórico acometido, se encontró que el R-448A sigue siendo el mejor refrigerante de relleno total o parcial para reemplazar al HCFC-22 empleado en los sistemas de refrigeración seleccionados instalados en los buques de pesca de las Maldivas. El desempeño del refrigerante parece ser idóneo para retroadaptar los sistemas, sin que ello parezca afectar a su desempeño, y mediante una modificación limitada del sistema y con el apoyo técnico del que se dispone, es idóneo también para proceder a la retroadaptación partiendo de refrigerante original. Se observó también que el personal que participó en la reparación y operaciones cotidianas de los sistemas de refrigeración de los buques de pesca no se encuentra plenamente capacitado ni profesionalmente formado, lo que dificulta el abordar las complejas tareas de retroadaptación de los equipos.

95. En el transcurso de la ejecución del proyecto, el PNUD se coordinó con el Consejo de Ministros de los Países Nórdicos (como se sugirió previamente), para realizar pesquisas sobre el informe de alternativas a los HCFC y los HFC de alto PCA en los buques de transporte marítimo; el informe está pendiente de acabarse. Se tomó nota de que en la publicación de las Autoridades Noruegas del Medio Ambiente, titulada "Estudio sobre el medio ambiente y las repercusiones sobre la salud humana de los refrigerantes de HFO" (diciembre de 2017)[20], se recoge que las mezclas de HFO, R-448A, R-449A, R-450A y R-452A pueden obtenerse comercialmente, siendo el R-448A y el R-449A los más utilizados.

Observaciones

96. La Secretaría pidió información adicional sobre la evaluación del desempeño de R-448A. El PNUD aclaró que partiendo del examen técnico, el R-448A puede considerarse idóneo como refrigerante, con una limitada repercusión negativa en el desempeño del equipo y de cambios en los sistemas de refrigerantes de los buques. Fundamentándose en la evaluación técnica, la disponibilidad actual del R-448A, y en las pericias y conocimientos técnicos de los técnicos de servicio, así como en la retroadaptación positiva del equipo de que goza el país, el R-448A puede considerarse la alternativa más viable.

97. Tras una petición de aclaración sobre la situación en que se encuentra la evaluación técnica del R-448B (como refrigerante A2L), el PNUD mencionó mientras se ejecutaba dicha evaluación, que el sector de pesca se mostraba reacio a adoptar la sustancia dado que es un refrigerante ligeramente combustible y existen riesgos potenciales en el uso de dicho refrigerante en los buques de pesca.

Recomendaciones

98. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, del informe final del proyecto de demostración de alternativas sin HCFC y de bajo PCA para refrigeración en el sector de pesca de las Maldivas que presentó el PNUD;

b) Pedir al Gobierno de las Maldivas y al PNUD que incluyan en el informe de la marcha de las actividades de la ejecución de la etapa I del plan de gestión de los HCFC, un informe pormenorizado de las actividades acometidas al retroadaptar los tres sistemas de refrigeración con HCFC-22 en los buques pesqueros con el refrigerante alternativo que se haya seleccionado, y la situación en que se encuentra la conversión de los sistemas de refrigeración con HCFC-22 en los buques de pesca de las Maldivas;

c) Pedir al PNUD que continúe explorando otras alternativas de bajo PCA para el sector de pesca de las Maldivas, de conformidad con la decisión 80/26 p); e

[20] http://www.miljodirektoratet.no/Documents/publikasjoner/M917/M917.pdf.

d) Invitar a los organismos bilaterales y de ejecución a compartir el informe final del proyecto de demostración mencionado en el inciso a) indicado *supra*, al asistir a países que operan al amparo del artículo 5 como preparativo a los proyectos de conversión de sistemas de refrigeración con HCFC-22 en buques de pesca.

Marruecos: demostración del uso de tecnología de bajo costo, con pentano como agente espumante, para la conversión de tecnologías sin SAO en la producción de espumas de poliuretano en empresas PIME (ONUDI)

Antecedentes

99. En la 75ª reunión, el Comité Ejecutivo aprobó la financiación del proyecto de demostración sobre el uso de tecnología de bajo costo, con pentano como agente espumante, para la conversión a tecnologías sin SAO en la producción de espumas de poliuretano en empresas PIME de Marruecos[21], por una cuantía que ascendía a 280 500 $EUA, más gastos de apoyo al organismo de 19 635 $EUA para la ONUDI (decisión 75/41).

100. El proyecto se aprobó para explorar la posibilidad de reducir el costo inicial de capital al diseñar una máquina de producción de espumas, sencilla, compacta, normalizada y fácil de manejar capaz de funcionar con pentano, de forma que tanto los equipos como los sistemas móviles de ventilación sirvieran para la producción de varios productos. La tecnología podría considerarse como una solución para las empresas que no tienen un elevado régimen productivo, ni tampoco la necesidad periódica de producir espumas.

101. En la 80ª reunión, el Comité Ejecutivo tomó nota de la actualización facilitada por la ONUDI respecto de la marcha de las actividades de ejecución en el proyecto de demostración y prorrogó la fecha de terminación del proyecto hasta el 31 de diciembre de 2018, dándose por entendido que no se permitiría pedir otra prórroga, y pidió a la ONUDI que presentara el informe final a la 83ª reunión a lo más tardar (decisión 80/26 f)).

102. En nombre del Gobierno de Marruecos, la ONUDI presentó el informe sobre la marcha de las actividades de ejecución del proyecto de demostración. Se visitó al proveedor de sistemas Pumex, México, en septiembre de 2017, como proveedor potencial de polioles (polialcoholes) premezclados con ciclopentano para las PIME. En octubre de 2017 se visitaron varios fabricantes de equipos para la producción de espumas, manteniéndose conversaciones sobre los aspectos técnicos y de seguridad conexos al uso de los equipos con pentano por parte de las PIME. Se redactó un mandato pormenorizado para el suministro de una línea de producción de espumas, incluyendo en ello el equipo de seguridad y los sistemas de control; el sistema de seguridad y la asistencia técnica; y la capacitación de técnicos, operadores y personal de mantenimiento. Se prevé que el equipo se instale en el tercer trimestre de 2018; en el cuarto trimestre se celebrará un taller; y a principios de 2019 se presentará un informe pormenorizado del proyecto.

Observaciones

103. La Secretaría pidió una información detallada de cómo se prevé alcanzar los ahorros en costos a la hora de ejecutar el proyecto, tal y como se concibió durante la presentación del mismo. La ONUDI informó de que una importante reducción del coste se logra al usar polialcoholes previamente mezclados con ciclopentano en vez de efectuar la mezcla de ciclopentano en las propias empresas; el diseño de una máquina compacta para la producción de espumas idónea para las PIME también derivaría en una reducción de los costos. La puesta en servicio y sometimiento a pruebas de la planta/equipo daría lugar a recomendaciones sobre cómo optimizar más los costos.

[21] UNEP/OzL.Pro/ExCom/75/58.

104. Tras una petición de aclaración sobre cuándo se presentaría el informe final del proyecto y de tomarse nota de que el proyecto terminaría en diciembre de 2018, la ONUDI aclaró que el informe final del proyecto se presentaría a primeros de 2019.

Recomendaciones

105. El Comité Ejecutivo puede estimar oportuno tomar nota del informe sobre la marcha de las actividades de ejecución del proyecto de demostración del uso de tecnología de bajo costo con pentano, para la producción de espumas, con fines a la conversión de tecnologías sin SAO en la producción de espumas de poliuretano en empresas PIME, implantado en Marruecos y presentado por la ONUDI.

Sudáfrica: proyecto de demostración de las ventajas técnicas y económicas de la inyección asistida por vacío en las plantas de producción de tableros cortados que se hayan retroadaptado pasando de consumir HCFC-141b a consumir pentano (ONUDI)

Antecedentes

106. En la 76ª reunión, el Comité Ejecutivo aprobó la financiación del proyecto de demostración sobre las ventajas técnicas y económicas de la inyección asistida por vacío en las plantas de producción de tableros cortados que se hayan retroadaptado en Sudáfrica[22], pasando de consumir HCFC-141b a consumir pentano, por una cuantía que ascendía a 222 200 $EUA, más gastos de apoyo al organismo de 19 998 $EUA para la ONUDI (decisión 76/32).

107. El proyecto se aprobó para evaluar las ventajas de la inyección asistida por vacío en el proceso de producción de tableros cortados, cuando se consuma ciclopentano como agente espumante, y para demostrar la seguridad de las operaciones de producción de espuma en una empresa que fabrica equipos de refrigeración comercial.

108. En la 80ª reunión, el Comité Ejecutivo tomó nota de la actualización facilitada por la ONUDI sobre la marcha de las actividades de ejecución del proyecto de demostración y prorrogó la fecha de terminación del proyecto hasta el 31 de diciembre de 2017, dándose por entendido que no se pediría ninguna otra prórroga en la ejecución del proyecto, y pidió a la ONUDI que presentara el informe final en la 81ª reunión a lo más tardar (decisión 80/26 j)).

109. En nombre del Gobierno de Sudáfrica, la ONUDI presentó el informe final del proyecto de demostración (informe final que se recoge en el anexo VII del presente documento). Como ya informó la ONUDI en el transcurso de la 80ª reunión, hubo un cambio de beneficiario. El proyecto estaba en un principio destinado a ejecutarse en Dalucon Refrigeration Products; en vez de ello, la tecnología de inyección asistida por vacío la instaló Panel World; en dicha tecnología, antes de las operaciones de producción de espumas, se aplica controladamente un cierto grado de vacío entre las planchas de la prensa en las que el tablero previamente ensamblado está situado. La presión reducida se aplica durante la inyección, tras lo que la expansión de la espuma facilita el llenado del tablero, mejorándolo.

110. Se realizaron varias pruebas en las líneas operativas de producción en las que la máxima pérdida de ciclopentano por evaporación fue del 5 por ciento del contenido de mismo; la pérdida se produce también durante la fase de expansión de la espuma en los primeros 90 segundos, tras el vertido. La densidad de la espuma puede verse reducida en hasta el 5 por ciento de ahorro en el consumo de poliuretano (PU). En todos los tableros sometidos a ensayos, la espuma no presentó ninguna pauta de cambio irregular en la resistencia a la compresión ofrecida a lo largo de la longitud de dicho tablero. Durante la reacción química mostró un buen flujo del producto químico, viéndose ayudada por el vacío, sin signo alguno de estrechamiento de la espuma o de elongación de las células, así como una resistencia

[22] UNEP/OzL.Pro/ExCom/76/48.

equilibrada en la compresión de la espuma. La espuma de todos los tableros superó la prueba de estabilidad. La conductividad térmica fue buena y similar en todos los tableros. Los tableros se fueron llenando a una densidad relativamente baja. Al aplicarse el vacío la distribución de la densidad es excelente, lo que representa una mejora significativa en comparación con la ausencia del mismo. La adhesión mejoró; percibiéndose una estabilidad dimensional superior y una apariencia de mejora calidad.

111. La ventilación de la prensa tiene la ventaja añadida de eliminar los vapores del ciclopentano y los compuestos orgánicos volátiles de la zona de trabajo, los que están presentes si la producción tiene lugar sin la inyección asistida por vacío. La succión directa por vacío en el interior del tablero de la expansión del PU resulta en la extracción total del vapor del ciclopentano y del isocianato, lo que deriva en una producción más segura y menos perjudicial para los operadores. Dado el incremento en la reactividad-viscosidad de la espuma, la tecnología reduce la fuga de espuma por los puntos de ventilación del tablero, manteniendo así más limpia la zona de trabajo.

112. El tiempo necesario para el desmolde se ha reducido en un 40 por ciento; si se considera el ciclo total de producción (es decir, de carga/descarga y preparación), se estimó que la prensa puede producir el mismo número de tablero en un 25 por ciento menos de tiempo, lo que permite a la empresa ahorrar en el consumo de energía.

Observaciones

113. La Secretaría tomó nota de que las espumas con espumante de ciclopentano producidas con tecnología de inyección asistida por vacío muestra una excelente estabilidad dimensional; permite una reducción en la densidad de la espuma de hasta el 5 por ciento, lo que redunda en considerable ahorros en términos del consumo de PU; elimina los vapores de ciclopentano y de isocianato de la zona de trabajo, reduciendo así el perjuicio a la salud y la seguridad del trabajador; y logra valores-*k* similares (entre 20,12 y 20,54 mW/mK) a las espumas con espumante de HCFC-141b (20,4 mW/mK). Además de todo ello, se producen ahorros en el consumo de energía y se reduce el tiempo de desmolde.

114. Al tomar nota de los prometedores resultados, la Secretaría observó que el informe no incluía información sobre los costos de la tecnología en cuestión, sobre los desembolsos para el proyecto, ni tampoco sobre las lecciones aprendidas, ni sobre si la tecnología podría reproducirse en otros países que operan al amparo del artículo 5. En su respuesta, la ONUDI informó de que los costos de capital del juego de inyección por vacío y por las necesarias modificaciones al equipo actual ascendía a 425 000 $EUA, y que dos juegos de perfiles laterales ascendían a un costo de 30 000 $EUA; el costo de los perfiles dependerá del número y tamaño de los juegos, lo que irá en función de las necesidades del cliente (véase el addendum al informe final que se recoge en el anexo VII del presente documento). La financiación facilitada por el Fondo Multilateral, junto con la de contraparte, fue suficiente para sufragar los objetivos del proyecto de demostración. La ONUDI considera que la tecnología podría aplicarse universalmente en nuevas instalaciones, retroadaptaciones, y mejoras de actualización, y sugirió que los futuros costos comerciales de la tecnología de inyección por vacío podrían verse reducida al incrementarse la admisión de dicha tecnología en el mercado. El Cuadro 7 recoge los costos del proyecto de demostración.

Cuadro 7. Costos del proyecto ($EUA)

Partida	Costos aprobados	Financiación actual		Costos actuales
		Fondos de donaciones	Fondos de contraparte	
Modificaciones de la prensa para la inyección por vacío, juego de vacío	80 000	181 200	244 000	425 200
Juego de perfiles laterales	20 000	30 000		30 000
Auditoría sobre seguridad	2 000	Incluido más arriba		
Transferencia de tecnología, servicios, asesoría y capacitación	25 000	Incluido más arriba		0
Instalación, puesta en servicio, inicio y pruebas y ensayos de la tecnología y de los productos finales	75 000	11 000 y 64 000 Incluido más arriba		11 000
Total	222 200*	222 200	244 000	466 200

* Incluye 20 200 $EUA para imprevistos.

115. La Secretaría toma nota de que los ahorros identificados *supra*, incluidos los que se derivan de la menor densidad de la espuma y del tiempo del desmolde, en combinación con el menor costo de la mano de obra y la mejora en las condiciones de salud y seguridad laboral para el trabajador, muy probablemente aportarán ahorros que podrían compensar los costos iniciales de capital conexos a la tecnología. Asumiendo que en el informe final del proyecto de demostración se recojan costos y formulaciones comparables que validen el uso de hidro-fluoro-olefinas (HFO) para la producción de tableros cortados en países que operan al amparo del artículo 5 mediante el desarrollo de formulaciones con buenas relaciones de costo a eficacia en Colombia[23], la reducción del 5 por ciento en la densidad de la espuma se traduce en ahorros anuales de aproximadamente 21 200 $EUA para una empresa que consuma 20 tm de agente espumante. Puede estimarse que la reducción del 40 por ciento en el tiempo de desmolde y el incremento del 25 por ciento en la productividad derivará en ahorros adicionales de aproximadamente 50 000 $EUA anuales en menores costos laborales, asumiendo una plantilla de aproximadamente diez trabajadores con un sueldo anual de 20 000 $EUA, incluyendo los costos fijos. Los demás beneficios, tales como la mejora en la salud y seguridad del trabajador serían contribuciones adicionales que compensarían la inversión de capital inicial necesaria para la tecnología de inyección asistida por vacío.

Recomendaciones

116. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota del informe final del proyecto de demostración presentado por la ONUDI sobre las ventajas técnicas y económicas de la inyección asistida por vacío, implantado en Sudáfrica, en la producción de tableros cortados en plantas retroadaptadas para consumir pentano en vez de HCFC-141b; e

b) Invitar a los organismos bilaterales y de ejecución a tener en cuenta el informe final del proyecto de demostración mencionado en el inciso a) indicado *supra*, a la hora de asistir a países que operen al amparo del artículo 5 como preparativo para proyectos de producción de espumas con ciclopentano como espumante.

[23] Párrafos 74 a 82 y anexo IV del presente documento.

Egipto: estudio de viabilidad para la refrigeración centralizada de edificios urbanos in Nuevo Cairo (PNUMA y ONUDI)

117. En la 75ª reunión, el Comité Ejecutivo aprobó la solicitud de financiación del estudio de viabilidad para la refrigeración centralizada de edificios urbanos en Nuevo Cairo, Egipto, el cual incluiría un modelo de negocio[24], con el correspondiente componente para el PNUMA, por un monto de 27 223 $EUA, más gastos de apoyo al organismo de 3 539 $EUA (decisión 75/33), y el correspondiente componente para la ONUDI por un monto de 63 521 $EUA más gastos de apoyo al organismo de 5 717 $EUA (decisión 75/35).

118. El estudio de viabilidad vinculará la posibilidad de hacer uso de una refrigeración centralizada de edificios urbanos en la Capital Nuevo Cairo que se está diseñando a día de hoy; se centrará en un distrito de la nueva capital, el cual se seleccionará antes de proceder al estudio, e incluirá a unos 21 distritos de viviendas y otros sin espacio de viviendas; y simulará el perfil de las cargas dinámicas de enfriamiento en todo el marco del distrito elegido. Se considerará el diseño, simulación y optimización de una diversidad de aportaciones energéticas alimentadas por gas natural, energía térmica solar y sumideros/disipadores de calor por medio de agua dulce.

119. Los resultados previstos del estudio de viabilidad determinarán la tecnología más idónea para la refrigeración centralizada de edificios urbanos (mezcla híbrida de gas natural o enfriador alimentado por calor con asistencia de energía solar); la identificación de las fuentes de energía renovable, los mecanismos de ahorro en el consumo energético, los beneficios medioambientales, y los impedimentos jurídicos a la ejecución; el desarrollo de una estructura financiera y el programa para el Gobierno y los mecanismos de cofinanciación; así como la culminación de una propuesta completa para lograr un sistema de refrigeración centralizada de edificios urbanos en la Capital Nuevo Cairo, lo que realzará la estrategia de ejecución, los incentivos financieros y las evaluaciones.

120. En la 80ª reunión, el Comité Ejecutivo tomó nota de la actualización facilitada por el PNUMA y la ONUDI sobre la marcha de las actividades de ejecución del estudio de viabilidad destinado a la refrigeración centralizada de edificios urbanos en el Nuevo Cairo, Egipto, y convino en prorrogar la fecha de terminación del proyecto hasta el 30 de junio de 2018, dándose por entendido que no habría de solicitarse ninguna otra prórroga en la ejecución del proyecto, y pidió a los organismos de ejecución que presentaran el informe final a la 82ª reunión a lo más tardar (decisión 80/26 n)).

121. En nombre del Gobierno de Egipto, el PNUMA y la ONUDI han presentado el informe sobre la marcha de las actividades de ejecución del estudio de viabilidad. Todas las actividades han terminado y el informe final está siendo sometido a día de hoy al último análisis por parte del comité local del proyecto, así como por parte del PNUMA y de la ONUDI. Lo que se indica *infra* es un resumen de las actividades ya culminadas:

a) Creación de un Comité Nacional en el marco del “Centro Nacional de Investigaciones sobre Edificios y Viviendas” del Ministerio de la Vivienda y Nuevos Asentamientos de Egipto, Comité que gestionará el proyecto;

b) Se han seleccionado dos emplazamientos para realizar el estudio, a saber: la ciudad del Nuevo El Alamein y la ciudad de Capital One. Fundamentándose en la información técnica de diferentes tecnologías de refrigeración, se eligió el sistema de refrigeración por el mar profundo para la ciudad del Nuevo El Alamein; eligiéndose la planta de refrigeración centralizada de edificios urbanos para ciudad de Capital One en la que se

[24] UNEP/OzL.Pro/ExCom/75/30 y ExCom/75/31.

emplean sistemas de refrigeración alternativos (produciendo el 60 por ciento de la capacidad de carga de refrigeración) auxiliados por refrigeración convencional en la que se emplean enfriadores por absorción con gas natural;

c) El análisis financiero de ambos emplazamientos, incluyendo los costos de capital y los de explotación, en comparación con los de las tecnologías convencionales, ya se han efectuado;

d) Se está creando un marco institucional y reglamentario en el plano nacional para la refrigeración centralizada de edificios urbanos en Egipto, teniendo en cuenta las considerables experiencias acumulada en las aplicaciones con refrigeración centralizada de edificios urbanos de varios países; y

e) Se ha celebrado un congreso internacional sobre refrigeración centralizada de edificios urbanos y desarrollos urbanos[25], en el que han participado expertos de más de 20 países. Se prevé celebrar reuniones auxiliares que traten de los resultados del proyecto en un periodo de sesiones del Grupo de Trabajo de composición abierta a celebrar en julio de 2018[26], estando prevista la celebración de un último taller de extensión final para agosto de 2018.

Observaciones

122. La Secretaría tomó nota de que el proyecto ha sido terminado y de que el informe final seguía estando en fase de análisis. No obstante, a día de hoy aún no se ha recibido.

Recomendaciones

123. El Comité Ejecutivo puede estimar oportuno tomar nota del informe sobre la marcha de las actividades de ejecución del estudio de viabilidad para la refrigeración centralizada de edificios urbanos en Nuevo Cairo, Egipto, que presentaron el PNUMA y la ONUDI.

Kuwait: estudio de viabilidad para la comparación entre tres tecnologías alternativas para climatización centralizada (PNUMA y ONUDI)

124. En la 75ª reunión, el Comité Ejecutivo aprobó la solicitud de financiación del estudio comparativo de viabilidad entre tres tecnologías alternativas para el sistema de climatización centralizado de Kuwait, lo que incluiría un modelo de negocio[27], la partida correspondiente del PNUMA por un monto de 27 223 $EUA, más gastos de apoyo al organismo de 3 539 $EUA (decisión 75/34), y la correspondiente partida para la ONUDI por un monto de 63 521 $EUA más gastos de apoyo al organismo por valor de 5 717 $EUA (decisión 75/36).

125. En el estudio de viabilidad se recogerá un análisis comparativo completo de tres tecnologías alternativas, a saber: sistemas de refrigeración gratuita por las aguas abismales, por absorción del calor residual y por absorción de agua enfriada con asistencia solar, a fin de determinar cuál de ellos puede ser la opción más prometedora que emplear en los sistemas de climatización centralizada. Se incluirán las actividades que se indican seguidamente en un compendio y recopilación de relatos sobre la situación en que se encuentran actualmente las tres tecnologías alternativas o no convencionales; un análisis de las fuentes de energía renovable, los impedimentos jurídicos, los mecanismos de consumo energético eficiente, los beneficios para el medio ambiente; y el desarrollo de una estructura y programa financieros

[25] Los documentos de la Conferencia pueden encontrarse en http://www.ozonactionreunións.org/international-conference-district-energy-urban-development-sharm-el-sheikh-Egipto-21-22-september-4.
[26] Viena, Austria, 8 a 14 de julio de 2018.
[27] UNEP/OzL.Pro/ExCom/75/30 y ExCom/75/31.

tanto para el Gobierno, y los mecanismos de cofinanciación, como para los proveedores privados de energía.

126. En la 80ª reunión, el Comité Ejecutivo tomó nota de la actualización aportada por el PNUMA y la ONUDI sobre la marcha de las actividades de ejecución del estudio de viabilidad en comparación con tres tecnologías alternativas de posible aplicación en el sistema de climatización centralizada de Kuwait, acordó prorrogar la fecha de terminación del proyecto hasta el 30 de junio de 2018, dándose por entendido que no habría de solicitarse ninguna otra prórroga en la ejecución del proyecto, y pidió a los organismos de ejecución que presentaran el informe final a la 82ª reunión a lo más tardar (decisión 80/26 o)).

127. En nombre del Gobierno de Egipto, el PNUMA y la ONUDI han presentado el informe sobre la marcha de las actividades de ejecución del estudio de viabilidad. El primer proyecto del "Estudio comparativo del estudio técnico para analizar los tres sistemas de refrigeración más prometedores para Kuwait" se presentó a la ONUDI en febrero de 2018; los criterios para la selección del emplazamiento ya se han culminado. El Gobierno ha elegido tres sitios (a saber, una escuela, una mezquita y un hospital), y se han contratado ya a los asesores para terminar las evaluaciones técnicas y financieras.

128. Se prepararán diseños conceptuales para dos emplazamientos. Cada uno de estos diseños se regirá por el principio de conservación de la energía, adoptándose tecnologías alternativas, quizás auxiliadas por otras tecnologías convencionales de refrigeración. En el tercer trimestre de 2018 se celebrará un taller final para explicar los estudios comparativos de las tres tecnologías, así como todo lo referente a los criterios seguidos en la elección de los tres emplazamientos.

Observaciones

129. La Secretaría tomó nota de los avances logrados en este proyecto, incluyendo la confirmación de la ONUDI de que todas las actividades del mismo se terminarán en junio de 2018 y de que el informe final se presentará a la 82ª reunión.

Recomendaciones

130. El Comité Ejecutivo puede estimar oportuno tomar nota del informe sobre la marcha de las actividades de ejecución del estudio de viabilidad, en el que se comparan tres tecnologías de sustitución, para utilizarse en la refrigeración centralizada de edificios urbanos en Kuwait, presentado por el PNUMA y la ONUDI.

Fomento de refrigerantes de bajo potencial de calentamiento atmosférico (PCA) destinados a los sectores de climatización de países con elevadas temperaturas ambiente (ETA) en Asia occidental (PNUMA y ONUDI)

131. En la 69ª reunión, el Comité Ejecutivo aprobó la financiación para el proyecto de fomento de refrigerantes de bajo potencial de calentamiento atmosférico (PCA) destinados a los sectores de climatización de países con elevadas temperaturas ambiente (ETA) en Asia occidental, y le asignó 155 000 $EUA, más gastos de apoyo al organismo de 20 150 $EUA para el PNUMA, y de 365 000 $EUA, más gastos de apoyo al organismo de 25 550 $EUA para la ONUDI. El proyecto tenía por objeto facilitar la transferencia de tecnología y el intercambio de experiencias conexas a las alternativas de bajo PCA para el sector de climatización de países con elevadas temperaturas ambiente, con objeto de ayudarles en la eliminación del consumo de los HCFC.

132. El PNUMA y la ONUDI han presentado a la 81ª reunión un informe sobre la marcha de las actividades de ejecución del proyecto. Se han ejecutado varias actividades, incluyendo la creación de capacidad en las instalaciones locales de investigación y desarrollo de los países con elevadas

temperaturas ambiente (ETA) apoyándose en los sectores industriales más avanzados. En lo tocante a la tecnología con HFC-32, se efectuaron actividades en cooperación con la Asociación japonesa de los sectores de equipos de refrigeración y de climatización y demás sectores industriales del Japón; en lo concerniente a la tecnología con R-290, se efectuaron actividades en cooperación con la Asociación china de aparatos eléctricos del hogar y demás sectores industriales de China; en lo tocante a la tecnología con HFO, se celebraron actividades conjuntamente con el Instituto de equipos de refrigeración, calefacción y climatización y con los proveedores de tecnología de refrigerantes a los fabricantes de compresores y de refrigerantes. Se ejecutaron también actividades de evaluación de riesgos con miras al diseño, desarrollo y examen de un modelo de evaluación de riesgos idóneo para las pautas de empleo y las condiciones de elevadas temperaturas ambiente; estas actividades, incluyendo el desarrollo de modelos, se adecúan a las necesidades locales de los países con elevadas temperaturas ambientales y se culminarán en octubre de 2018. Las actividades conexas a los ensayos y optimización mediante prototipos ya desarrollados anteriormente en el marco del proyecto PRAHA-I, no se han iniciado por haberse cambiado de contratista. Estas actividades se culminarán en noviembre de 2018.

Observaciones

133. La Secretaría examinó el informe sobre la marcha de las actividades de ejecución y tomó nota de que la mayoría de las actividades de los proyectos se terminarían en octubre/noviembre de 2018.

Recomendaciones

134. El Comité Ejecutivo puede estimar oportuno tomar nota del informe sobre la marcha de las actividades de ejecución del proyecto en Asia occidental en el que se fomenta el uso de refrigerantes alternativos para países con elevadas temperaturas ambiente (PRAHA-II).

PARTE IV: ELIMINACIÓN DEL CONSUMO Y DE LA PRODUCCIÓN DE CTC EN LA INDIA

Antecedentes

135. En la 75ª reunión, el Comité Ejecutivo estudió un informe sobre el proyecto de eliminación acelerada de la producción de CFC en la India, así como de la eliminación del consumo y la producción de CTC en dicho país[28], en el que se recogía que el Acuerdo entre el Gobierno de la India y el Banco Mundial (cual organismo de ejecución seleccionado por el Gobierno para ambos proyectos) había caducado, y los fondos remanentes estaban sin desembolsar a los productores de CFC quienes habían dejado de producirlo en 2008, y que había actividades de asistencia técnica pendientes en el proyecto de eliminación de la producción y consumo de CTC en el que el Banco Mundial es el organismo director de la ejecución y el Japón es el organismo bilateral.

136. En lo tocante a la propuesta sobre el CTC, se tomó nota de que se había asignado un cierto volumen de financiación al fortalecimiento del sistema de supervisión y vigilancia de la producción de CTC para fines de materias primas y demás actividades conexas a la adopción de alternativas a dicho CTC en 2016. Tras la deliberación, el Comité Ejecutivo aprobó, entre otras cosas, el plan de acción correspondiente al resto de las actividades conexas con la eliminación del consumo y producción de dicho CTC, habiéndose revisado la fecha de terminación que quedó fijada para finales de 2016, señalándose que todo fondo remanente habría de reembolsarse al Fondo Multilateral en la primera reunión del Comité Ejecutivo en 2017. El Comité pidió además al PNUD acometer un estudio sobre el uso que el país hace del CTC y que destina a las aplicaciones de materias primas, y poner los resultados del estudio a disposición del Comité Ejecutivo para finales de 2016 (decisión 75/19 b)).

[28] UNEP/OzL.Pro/ExCom/75/20 y Add.1.

137. En la 77ª reunión, el Comité Ejecutivo examinó el Informe Refundido sobre la marcha de las actividades de ejecución al 31 de diciembre de 2015[29], el cual incluía un informe sobre la situación en que se encontraban el consumo y la producción de CTC en la India. Respecto de este proyecto, el Comité Ejecutivo tomó nota de que una de las partidas del plan de eliminación de CTC aprobadas en la 75ª reunión se culminaría en diciembre de 2016 y que todo saldo remanente se reembolsaría en diciembre de 2017 (decisión 77/8 b) i), prorrogando la fecha de terminación de dos partidas de asistencia técnica aprobadas en la 45ª reunión hasta fechas de noviembre de 2017 (decisión 77/8 c) i)).

Observaciones

138. La Secretaría tomó nota con preocupación de que el estudio sobre el uso de CTC que hace el país para sus aplicaciones de materias primas, cuya presentación ante el Comité Ejecutivo estaba prevista para finales de 2016 (decisión 75/19 b) iv)), ni tampoco el informe de terminación de proyecto, cuya presentación estaba prevista ante la 81ª reunión (decisión 75/19 b) iv) y decisión 77/8 c) i)), se hubieran presentado.

Recomendaciones

139. El Comité Ejecutivo puede estimar oportuno:

a) Pedir al PNUD que presente a la Secretaría el estudio sobre el consumo de CTC en el país para aplicaciones de materia prima, a la mayor brevedad posible, y a lo más tardar a la 82ª reunión; y

b) Pedir al Banco Mundial que, con los Gobiernos de Francia, Alemania y el Japón, y conjuntamente con el PNUD y la ONUDI como organismos cooperantes de ejecución, presente a la 82ª reunión del Comité Ejecutivo el informe de terminación de proyecto sobre la eliminación de la producción y consumo de CTC.

PARTE V: PROYECTOS DE ELIMINACIÓN DE DESECHOS DE SAO

Antecedentes

140. En la 79ª reunión, el Comité Ejecutivo pidió a los organismos bilaterales y de ejecución, entre otras cosas, presentar los informes finales de los proyectos piloto de eliminación de SAO que hubiera pendientes[30], aparte de los de Brasil y Colombia, y reembolsar a la 82ª reunión los saldos remanentes de proyectos cuyos informes no hayan sido presentados a la 80ª ni a la 81ª reunión (decisión 79/18 d)).

141. Los organismos bilaterales y de ejecución pertinentes presentaron, en nombre de los Gobiernos de China, Colombia, Nigeria y Turquía, informes sobre la ejecución de los proyectos de eliminación de desechos de SAO. Estos informes se resumen más adelante. Al anexo VIII del presente documento se adjuntan los informes completos.

142. De conformidad con la decisión 79/18 e), a la 82ª reunión se presentará un informe de síntesis sobre los proyectos piloto de eliminación de SAO terminados hasta la fecha, recopilando las lecciones aprendidas, e incluyendo cuestiones conexas al diseño de proyectos, sinergia con otros proyectos, oportunidades para la movilización de recursos y la relación de costo a eficacia de los proyectos.

[29] UNEP/OzL.Pro/ExCom/77/11.

[30] Los informes finales de los proyectos piloto de Georgia, Ghana y Nepal se presentaron a la 79ª reunión y los de México y la región de Europa y Asia Central (ECA) se presentaron a la 80ª reunión.

China: informe final del proyecto de demostración piloto sobre gestión y eliminación de desechos de SAO (Gobierno del Japón y ONUDI)

143. El objetivo del proyecto piloto de demostración es el de explorar el tratamiento al que se someten los desechos de SAO recolectados, establecer un modelo sostenible para la destrucción de los desechos de SAO, y la eliminación de 192,0 toneladas métricas (tm) de desechos de SAO, especialmente de los bancos de CFC.

144. El Reglamento sobre la Gestión de SAO, que entró en vigor en junio de 2010, constituye la base del reciclaje de las SAO. En él se prescribe, entre otras cosas, que las empresas especializadas en las tareas de servicio y mantenimiento, y de convertir en chatarra los equipos de refrigeración, sistemas de refrigeración y de lucha contra incendios que contengan SAO, habrán de registrarse en virtud de los Burós provinciales y municipales de protección del medio ambiente (BPMA) y recolectarán, reciclarán o transferirán las SAO a empresas especializadas en su recogida, reciclaje y destrucción para así tratar debidamente tales SAO.

145. El monto total de CFC destruidos se incrementó hasta alcanzar 194 793 tm, volumen formado por 11 788 tm de refrigerantes con CFC, 172,005 tm de CFC en forma de desechos de espumas, y 11 tm de CFC-11 empleado como agente espumante. Todos los desechos recolectados se incineraron en hornos giratorios. Los costos de la eliminación de los refrigerantes y de los desechos de espumas conexos a las SAO incluyeron los costos directos y los indirectos. Los costos directos incluyeron los atinentes al consumo energético, incluyendo la electricidad y el gas, al agua y demás materiales para el ensayo y tratamiento de los gases de escape. Los costos indirectos incluyeron la inversión compartida de los bienes fijos, costos fijos, gestión y demás (por ejemplo, impuestos). Si bien los costos varían de una provincia a otra, el costo medio de la destrucción osciló entre 8,00 $EUA/kg y 12,50 $EUA/kg.

146. El proyecto de demostración ha servido para validar que la tecnología de incineración en hornos giratorios es eficiente para destruir espumas con CFC-12, CFC-11 y CFC-11, aunque el costo de la operación es relativamente elevado. Se recomienda optimizar el proceso de destrucción a fin de mejorar la eficiencia y de reducir los costos. Si bien en algunas provincias se dispone de instalaciones para la eliminación de desechos peligrosos, tales instalaciones trabajan a plena capacidad tratando otros desechos sólidos. Tras considerar los desechos de SAO potenciales procedentes de productos con HCFC y HFC en los próximos años, cabe dentro de lo posible que haya que crear más instalaciones adicionales en un futuro.

Colombia: informe final del proyecto de demostración sobre la gestión y destrucción de SAO al final de su vida útil (PNUD)

147. El objetivo del proyecto piloto es el de demostrar un planteamiento sostenible respecto de la gestión de los desechos de SAO, desde el punto de recogida hasta el de su destrucción, fortaleciendo para ello las capacidades de destrucción de las instalaciones nacionales e integrándolas en el marco de iniciativas más amplias de consumo energético eficiente y de desecho de sustancias peligrosas. Se propone abordar la eliminación de 114 tm de desechos de SAO, destruyéndolos; tomar medidas para respaldar la sostenibilidad del proyecto habida cuenta de los desechos de SAO que se recogerán mediante el sector de servicio y mantenimiento de equipos de refrigeración, y se respaldarán por las iniciativas de política-normativa que actualmente se están implantando.

148. El proyecto de eliminación de desechos de SAO se ejecutó en un marco de política-normativa más amplio, incluido en un planteamiento integrado atinente a la gestión de desechos peligrosos, el consumo energético eficiente, la gestión de emisiones de gases de efecto invernadero y el compromiso de cumplir con las obligaciones contraídas en virtud del Protocolo de Montreal. Todo esto llevaba una prioridad adjuntada a la gestión racional del medio ambiente de SAO al final de su vida útil, que nació como resultado de las iniciativas nacionales de políticas-normativas en la esfera de la refrigeración y la

climatización. Vino también respaldado por un Programa de Responsabilidad Ampliada del Productor, que era sostenible, y que comenzó en 2013, tras lo que evolucionó desde una fase piloto voluntaria a convertirse en un sistema de obligado cumplimiento.

149. Las tareas de incineración de la prueba de demostración arrojaron que la capacidad nacional era válida, en principio, para destruir las SAO y, en concreto, las espumas con CFC-11 y HCFC-141b y los productos químicos con CFC-11 y CFC-12, hasta un cierto y definido límite de contenido de cloro en las materias primas. Si bien la instalación de destrucción cumplía con los requisitos de eficiencia destructiva, había limitaciones respecto de las emisiones de aire, especialmente gases ácidos (ácido clorhídrico (HCl) y ácido fluorhídrico), lo que limita el contenido de cloro y de flúor de las materias primas y, a su vez, repercute en la productividad y en la relación de costo a eficacia de los ensayos de destrucción. La relación de costo a eficacia para la destrucción de los productos químicos con CFC-11 y CFC-12 se estimó ser de la mitad de la relación de costo a eficacia especificada por el Fondo Multilateral (es decir 13,20 $EUA/kg). Sin embargo, en el caso de la destrucción de espumas, la relación de costo a eficacia se estimó en, aproximadamente, cuatro veces el umbral, por ende, inasequible. Partiendo de esta situación, la opción vigente es la de tratar puertas y armaritos de refrigeradores en los hornos de arco eléctrico de las acerías, o bien incinerarlos en un horno de cemento comercial, de forma que se destruyan las espumas y el potencial refrigerante de las SAO. Según la opción que se seleccione, las estimaciones del costo general oscilan entre 6,40 $EUA y 12,30 $EUA por refrigerador.

Nigeria: proyecto de informe final del proyecto de demostración piloto para la eliminación de las SAO indeseadas (ONUDI)

150. El objetivo del proyecto piloto es el de demostrar un modelo de negocio sostenible para la gestión de los desechos de SAO, desde la recogida hasta la eliminación, sirviéndose de la asistencia del Fondo Multilateral en forma de capital nodriza para destruir las actuales existencias de las SAO indeseadas y generar derechos de emisión de carbono. Tales créditos se emplearían para establecer un Programa de Sustitución de Aparatos (para reemplazar los actuales refrigeradores y climatizadores de las viviendas por otros de consumo energético más eficiente), con objeto de sostener el sistema vigente de recogida y recuperación de SAO, y con miras a incorporarle otros refrigerantes en un futuro. El proyecto preveía destruir los futuros desechos SAO sirviéndose de las instalaciones de incineración municipales y provinciales, cuya capacidad se fomentaría mediante los ingresos obtenidos de los mencionados créditos de emisión de carbono. Los resultados que se preveía obtener de este proyecto era la destrucción de 84,0 tm de CFC-12 que ya se habían notificado como recolectadas de fuentes industriales, y especialmente, de refinerías petrolíferas, en el transcurso de la preparación del proyecto.

151. En noviembre de 2013 se celebró un taller de iniciación, en el que participaron organismos del Gobierno, empresas de servicio y mantenimiento, empresas de gestión de desechos y usuarios finales. Se contrataron los servicios de un contratista local para acumular los desechos de SAO del país; se facilitó un taller de capacitación para técnicos en el que se impartieron conocimientos sobre la recogida segura, el transporte y almacenamiento de los desechos de SAO, incluyéndose los procedimientos de verificación, etiquetaje correcto y documentación; y celebrándose en junio de 2014 un taller dedicado a la creación de capacidad para la recogida y acumulación de SAO. Se contactó a las empresas y a los usuarios finales identificados durante la fase preparatoria para efectuar pesquisas respecto de sus existencias de SAO. No obstante, en la mayoría de los casos las existencias de SAO notificadas no se encontraron. El volumen total de SAO recolectado ascendió meramente a 1,5 tm de CFC-12. Las actividades de recogida se interrumpieron al no encontrarse nuevas existencias de CFC-12 y las nuevas pesquisas una y otra vez se dirigieron a los Halones (que se encuentran almacenados en organismos gubernamentales).

152. Los Reglamentos Revisados sobre las SAO (2016) disponen la destrucción obligatoria de desechos, directrices para la destrucción de instalaciones, incluyendo límites a las emisiones, y amplían e imputan la responsabilidad por los equipos de desecho al final de su vida útil a los productores/proveedores. Los Reglamentos sobre la Responsabilidad Ampliada del Productor están en

vigor y funcionando en lo atinente a los sectores de electricidad/electrónica; así pues, en el caso de los nuevos refrigeradores, la futura recuperación de sus refrigerantes al llegar al final de su vida útil será responsabilidad del sector privado. Se impartieron también sesiones de capacitación sobre la recogida y gestión de residuos/desechos de chatarra electrónica.

153. Los funcionarios del Ministerio del Medio Ambiente y de la ONUDI inspeccionaron cuatro instalaciones de eliminación e invitaron a dos de ellas a pujar por la eliminación de los CFC. La empresa seleccionada presenta un historial bien demostrado de gestión de desechos peligrosos para empresas multinacionales y de experiencia en la gestión de los desechos de CFC, específicamente desde la recogida hasta el reciclaje. La pureza de las existencias recolectadas de desechos de CFC se verificó en las instalaciones de almacenamiento antes de proceder a su transporte hacia la instalación de destrucción situada en Port Harcourt, Nigeria. El proceso de destrucción utilizado por la instalación contratada es el de incineración en horno giratorio. A fechas de la redacción del presente informe, la ONUDI había notificado que el proceso de eliminación seguía en curso. Los desechos se eliminan lote a lote y el proyecto de informe se actualizará tan pronto como dicho proceso se termine.

154. Del total de los fondos aprobados que ascendieron a 911 724 $EUA, solo se habían desembolsado 219 288 $EUA. Partiendo de este volumen de desembolso, el costo actual de destrucción de este proyecto fue de 146 $EUA/kg en el caso de los desechos de SAO. El informe final se actualizará tras terminarse la destrucción, habiéndose abonado todos los pagos pendientes. El saldo de fondos se reembolsará a la 82ª reunión.

<u>Turquía: informe final sobre el proyecto de demostración para la eliminación de SAO indeseadas</u> (ONUDI)

155. El objetivo del proyecto piloto fue el de demostrar un modelo de negocio sostenible e integrado para la gestión eficiente de los desechos de SAO, sirviéndose de medidas institucionales que permitirían organizar los sistemas actuales de recogida y recuperación del país formando así un sistema integrado y eficiente de recogida, validación y evaluación.

156. Turquía ya había recolectado un cierto volumen de desechos de SAO utilizando los centro de recuperación y regeneración autorizados por el Gobierno y establecidos en tres ciudades, Ankara (TUHAB), Estambul (ISISO) y Izmir (ESSIAD); el volumen de desechos de SAO que se previó destruir fue de 103,72 tm de CFC-12. No obstante, y durante la implantación, se encontró que los desechos de SAO disponibles eran en muchos casos mezclas de todos tipo de refrigerantes, por lo que el volumen disponible para su destrucción fue de 9,162 tm de CFC-12.

157. El proyecto preveía exportar los desechos de SAO a los Estados Unidos de América para su destrucción; sin embargo, al no materializarse los ingresos que se preveía obtener de los mercados de cuotas de emisiones de sustancias que contienen carbono, y ante los pequeños volúmenes de desechos de SAO a destruir, los hechos forzaron a rediseñar la estrategia de eliminación. Se decidió destruir en Europa el desecho recolectado, sirviéndose de un proceso de licitación internacional.

158. A fin de que las operaciones fueran más rentables, los desechos de SAO procedentes de Turquía se combinaron con los desechos de SAO procedentes de Montenegro; estos últimos formaban parte del proyecto regional de demostración del proyecto piloto para la eliminación de SAO de la región de Europa y Asia Central (EAC), también financiado por el Fondo Multilateral. Otras actividades, tales como la impartición compartida de lecciones aprendidas y el incremento del grado de concienciación se llevaron también a cabo en estrecha colaboración con la región EAC.

159. El resultado del proyecto fue la destrucción de 9,162 tm de CFC-12, notificándose un desembolso de 598 345 $EUA del total aprobado de 1 076 250 $EUA, más gastos de apoyo al organismo, todo lo que derivó en una relación de costo a eficacia de 65 $EUA/kg de desechos de SAO destruidos. El informe

financiero se actualizará una vez que se termine la destrucción y se hayan efectuado todos los pagos pendientes. Los saldos de los fondos se reembolsarán a la 82ª reunión.

Observaciones

160. La Secretaría tomó nota de que en los informes finales de China, Colombia, Nigeria y Turquía se habían incluido los siguientes aspectos de la decisión 58/19, a saber:

a) El volumen estimado de SAO que llegó a destruirse en el marco del proyecto;

b) La descripción de los sistemas de recogida, especialmente cuando los proyectos del Fondo Multilateral mostraban sinergia con otros proyectos;

c) Las medidas pormenorizadas tomadas en el proceso en su conjunto; y

d) Los principales retos encontrados y cómo se abordaron, junto con las lecciones aprendidas hasta el momento en la implantación de proyectos piloto.

161. La Secretaría tenía una serie de observaciones que hacer al respecto de los informes finales, incluyendo los bajos volúmenes de desechos SAO notificados como destruidos en algunos proyectos, en comparación con todo a lo que se habían obligado durante la aprobación, retos en la acumulación de materiales de desecho en las instalaciones de recogida u otros métodos, entre otras cosas.

162. De conformidad con la decisión 79/18 e), la Secretaría presentará un informe de síntesis sobre los proyectos piloto de destrucción de SAO ejecutados hasta el momento, recopilando las lecciones aprendidas, e incluyendo las cuestiones conexas al diseño de los proyectos, la sinergia con otros proyectos, las oportunidades para la movilización de recursos, y la relación de costo a eficacia de los proyectos y lo presentará a la 82ª reunión. Los saldos de todos los desechos de SAO de los proyectos de eliminación habrán de reembolsarse a la 82ª reunión.

Recomendaciones

163. El Comité Ejecutivo puede estimar oportuno:

a) Tomar nota, con reconocimiento, de cada uno de los informes finales de los proyectos piloto de gestión y eliminación de desechos SAO para China, presentado por la ONUDI y el Gobierno del Japón; para Colombia, presentados por el PNUD; para Nigeria y Turquía, presentados por la ONUDI;

b) Invitar a los organismos bilaterales y de ejecución a tener en cuenta, donde proceda, las lecciones aprendidas de los proyectos piloto de eliminación de SAO mencionados en el inciso a) indicado *supra*, con miras al diseño, concepción e implantación de proyectos similares en un futuro;

c) Tomar nota de que el informe final del proyecto piloto de eliminación de SAO para el Líbano, que está pendiente de entrega, no se presentó a la 81ª reunión, y pedir a la ONUDI que reembolse los saldos sin desembolsar correspondientes a este proyecto, haciéndolo a la 82ª reunión, de conformidad con la decisión 79/18 d); y

d) Tomar nota ulteriormente de que, de conformidad con la decisión 79/18 e), una síntesis del informe sobre los proyectos piloto para la eliminación de SAO, que recopile y compendie las lecciones aprendidas, e incluya las cuestiones conexas al diseño de proyectos, sinergia con otros proyectos, oportunidades para la movilización de recursos, y la relación de costo a eficacia de los proyectos se presentará ante la 82ª reunión y que los saldos de todos los proyectos de eliminación de desechos SAO se devolverán a dicha 82ª reunión.

PARTE VI: PROYECTOS EN MARCHA SOBRE ENFRIADORES

Antecedentes

164. En el Cuadro 8 se recoge un resumen de la actualización de los informes de situación correspondientes a los cuatro proyectos de enfriadores en marcha.

Cuadro 8. Informe de situación de los proyectos de enfriadores en marcha

País	Título del proyecto	Organismo	Reunión	Fondos aprobados ($EUA)	Fecha de terminación planificada	Situación de la marcha de las actividades de ejecución
Brasil	Proyecto de demostración para la gestión integrada del subsector de enfriadores centrífugos, centrándose en la aplicación de tecnologías de alta eficiencia energética sin CFC para sustituir los enfriadores con CFC.	PNUD	47	1 000 000	Enero de 2017	El PNUD presentó el informe de terminación del proyecto. La información se incluirá en el informe sobre todos los proyectos de enfriadores previstos para presentar a la 82ª reunión.
Región de África	Proyecto de demostración estratégica para la conversión acelerada de enfriadores de CFC en cinco países africanos (Camerún, Egipto, Namibia, Nigeria y Sudán)	Francia	48	360 000	Diciembre de 2017	La presentación del informe de terminación de proyecto está prevista para octubre de 2018. El informe final se presentará a la 82ª reunión.
		Japón	48	700 000	Diciembre de 2017	
Mundial	Proyecto mundial de la sustitución de enfriadores	Banco Mundial	47	6 884 612	Diciembre de 2017	El proyecto incluyó a Argentina, China, India, Indonesia, Jordania, Malasia, Filipinas y Túnez. No se iniciaron actividades relativas a proyecto alguno en China, Malasia y Túnez. De conformidad con la decisión 79/19 b) i), el informe de terminación de proyecto habrá de presentarse en fechas de diciembre de 2018 a lo más tardar, y los saldos de los fondos habrán de reembolsarse en junio de June 2019 a lo más tardar.

Observaciones

165. La Secretaría examinó el informe de terminación de proyecto presentado sobre el proyecto del enfriador para Brasil. La información pertinente de dicho informe se incluirá en el informe pormenorizado sobre todos los proyectos de enfriadores que está previsto se presenten a la 82ª reunión.

Recomendaciones

166. El Comité Ejecutivo puede estimar oportuno tomar nota del informe sobre la marcha de las actividades de ejecución de los proyectos en línea sobre enfriadores implantados por los Gobiernos de Francia y el Japón, el PNUD y el Banco Mundial.

Anexo I

PROYECTOS CLASIFICADOS COMO "CON ALGUNOS PROGRESOS" CUYA SUPERVISIÓN SE RECOMIENDA CONTINUAR

País	Organismo	Título del proyecto
China	ONUDI	Plan sectorial para la eliminación del consumo de CFC en el sector de inhaladores de dosis medida (CPR/ARS/56/INV/473
Egipto	ONUDI	Eliminación del consumo de CFC en la fabricación de inhaladores de dosis medidas en aerosol (EGY/ARS/50/INV/92)
República Árabe Siria (la)	ONUDI	Eliminación de HCFC-22 y HCFC-141b en la fabricación de equipos de aire acondicionado unitarios y paneles aislantes de poliuretano rígido en Al Hafez Group (SYR/REF/62/INV/103)

Anexo II

PROYECTOS PARA LOS QUE SE PIDIERON INFORMES DE SITUACIÓN ADICIONALES PARA SU PRESENTACIÓN A LA 81ª REUNIÓN

País	Organismo	Título/código del proyecto	Recomendación
República Centroafricana (la)	PNUMA	Plan de gestión de la eliminación de los HCFC (etapa I, primer tramo) (CAF/PHA/64/TAS/22)	Pedir a la 82ª reunión un informe sobre la situación de la marcha de las actividades de ejecución a fin de vigilar la reanudación de las actividades en el país.
República Centroafricana (la)	ONUDI	Plan de gestión de la eliminación de los HCFC (etapa I, primer tramo) (CAF/PHA/64/INV/21)	Pedir a la 82ª reunión un informe sobre la situación de la marcha de las actividades de ejecución a fin de vigilar la reanudación de las actividades en el país.
Guyana	PNUMA	Plan de gestión de la eliminación de los HCFC (etapa I, segundo tramo) (GUY/PHA/74/TAS/24)	Pedir a la 82ª reunión un informe sobre la situación de la marcha de las actividades de ejecución a fin de vigilar un régimen de desembolso bajo de los fondos aprobados y firmar el Acuerdo, tomando nota de que el primer desembolso no se ha producido todavía.
Iraq	ONUDI	Plan de gestión de la eliminación de los HCFC (etapa I, segundo tramo) (sector de servicios de mantenimiento de equipos de refrigeración) (IRQ/PHA/74/INV/23)	Pedir a la 82ª reunión un informe sobre la situación de la marcha de las actividades de ejecución para vigilarla ante las condiciones de seguridad.
Libia	ONUDI	Plan de gestión de la eliminación de los HCFC (etapa I, primer tramo) (sector de las espumas) (LIB/PHA/75/INV/36)	Vigilar los progresos de la aplicación y la tasa de desembolso de los fondos aprobados habida cuenta de las condiciones de seguridad.
Mozambique	PNUMA	Plan de gestión de la eliminación de los HCFC (etapa I, segundo tramo) (MOZ/PHA/73/TAS/25)	Pedir a la 82ª reunión un informe sobre la situación de la marcha de las actividades de ejecución a fin de vigilar la firma del Acuerdo ante los cambios estructurales y administrativos que acaecen en el país.
Saint Kitts y Nevis	PNUD	Plan de gestión de la eliminación de los HCFC (etapa I, primer tramo) (STK/PHA/64/TAS/16)	Pedir a la 82ª reunión un informe sobre la situación de la marcha de las actividades de ejecución a fin de vigilar un régimen de desembolso bajo de los fondos aprobados.

INDUSTRIAS THERMOTAR LTDA. - DEMONSTRATIVE PROJECT FOR HCFC-22 PHASE OUT IN THE MANUFACTURING OF COMMERCIAL AIR CONDITIONING EQUIPMENT

UNDP REPORT

APRIL 2018

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Executive Summary

This demonstrative project was developed as response to the decision 75/40 by the Multilateral Fund Executive Committee in November 2015, and its aim was to demonstrate the safe use of HC-290 (propane) as an alternative refrigerant in the production of commercial air-conditioning (AC) equipment[1] at Industrias Thermotar ltda.

The HCFC-22 consumption in Colombia for the manufacture of commercial air-conditioning and refrigeration equipment is equivalent to 3% of the country's total HCFC-22consumption . This corresponds to the refrigerant charge of about 5,600 units manufactured per year. Currently, the the commercial air-conditioning models developed and manufactured are ducted split vertical condensing units and ducted package-type systems.

The project was carried out at Industrias Thermotar Ltda, a company that is responsible for great part of the country production of ducted split condensing units and package-type equipment with HCFC-22 . Thermotar average production is 4,100 units per year, about 17 to 20 units per day. This company consumes 60% of the total HCFC-22 consumption in the commercial air-conditioning sector. The company also manufactures the heat exchangers and the structure (metal-mechanics), and performs the electrical and other components installation, as well the refrigerant charging or precharging to the DACS.

In total, the company has eliminated 0.73 ODP tons (13.27 tons of HCFCs) through this project, which is essential for Colombia to comply with the HCFC phase out strategy for 2020. According to Decision XIX/6 this project applies proven non-ODS, negligible GWP technology. According to Thermotar environmental policy the company decided to switch from HCFC-22 to HC-290, considering the very low GWP[2] of HC-290, and LFL[3] equals to 2.1 % volume.

The country faced two main barriers to manufacture commercial AC equipment with hydrocarbon (HC-290) as an alternative refrigerant: The lack of knowledge and information of the sector on the technical aspects to be taken into account in the design engineering and manufacture of HC-290 AC equipment, and the technical weakeness of the personnel that provides the installation and maintenance services for these types of equipment devices. Therefore, the project included the participation of an international expert and the expertise of international supplier companies that work in the manufacturing of refrigeration and air-conditioning equipment with hydrocarbons.

In order to face the barriers mentioned above, the outcomes of the project were mainly based on demonstrating the safe use of HC-290 in the manufacture of commercial air-conditioning equipment between the ranges from 1 to 5 TR[4] (3.5 kW to 17.5 kW), and ensuring the safe and proper management of risks associated with the introduction of flammable refrigerants in the commercial air-conditioning sector,.

[1] DACS: Packaged and centralised ducted air-conditioning systems (Ducted split condensing units and ducted package-type units)
[2] Global Warming Potential, GWP, of HC-290 = 5
[3] Lower Flammable Limit. HC-290 = 0.039 kg/m3
[4] TR = Tons of Refrigeration

The demonstrative project consisted of five phases:

- Engineering design of AC equipment, which required a safety assessment of air-conditioning units considering the use of HC-290 (development of the explosion-protection features and quantitative risk assessment of new designs),
- Production line change installing new equipment in the manufacturing process (acquisition and installation of a leak-proof system, leak testing equipment, a storage station and feeding line for HC charging, a charging station for HC and a leak testing system for HC-charged equipment),
- Safety assessment of the production line (risk assessment and approvals from a third party),
- Training for the service area (training and qualification of staff in safe hydrocarbon refrigerant handling and management
- Organization of dissemination workshops.

Each of the above phases comprised the development of the following activities: Experiment or methodology design, recording of results, analysis of results (including lessons learned) and conclusions.

The following conclusions can be pointed out:

Through the demonstrative project condensing units and ducted package-type systems that work with HC-290 refrigerant were designed,. Different leakage and ignition tests were performed mainly on large-size prototypes (5 Tons of Refrigeration or 17.5 kW, prototype with a greater charge of HC-290 refrigerant). Among the technical and safety features of the new models, the following are highlighted:

- Reduction of the heat exchanger tube diameter (condenser): Two models of DACS were defined for both types of equipment; they differ in the material and diameter used in the manufacture of the condensing unit heat exchanger. (Aluminium microchannel heat exchangers and 8 mm copper tube heat exchangers). It should be noted that the designs and tests performed were applied to the largest model (5 TR), because these designs are replicable to the rest of HC-290 based DACS models.

- Reduction of HC-290 refrigerant charge: the estimated charge was 1,000 grams for ducted split condensing unit (5 TR) with five (5) meter pipe. The charge for the package-type condenser unit was 950 grams. The reduction in some cases was greater than 50% compared against the same HCFC-22 model.

- Modification of the metal structure (cabinet) of condensing units: The metal structure for both types of equipment were modified, similarly, the electrical boxes were individualized or insulated.

- Modification of the handling unit metal structure: The metal structure of the handling unit that is part of the split condensing unit was modified to insulate the electrical box and the entire frame, mainly the location of the air-intake area. This safety measure prevents high concentration levels of HC-290 inside an enclosure whenever an unexpected leak occurs.

- Pump Down cycle installation: The split condensing unit and the package-type unit have a "Pump Down" cycle, which collects the largest amount of refrigerant on the outside of the AC equipment specifically in the condensing unit. This occurs once pressure variations are detected through two pressure switches located in the air-conditioning system.

- Ultrasonnic sensor: The handling unit or equipment that is part of the split condensing unit has an ultrasonnic sensor for leak detection. This is an additional safety feature that prevents high levels of HC-290 concentration inside an enclosure, when an unexpected leak occurs.

- Power consumption: The Company carried out comparative tests related to energy consumption. A comparision between R-410A and HC-290 AC equipment (5 TR) was developed. The input power of the R-410A equipment compressor was 4,350 W and the input power for the new design with HC-290 was 3,780 W.

An adecuate conversion of the manufacturing line was made for HC-290 based DACS. The former HCFC-22 manufacturing line had the following stages: manufacture of the metal structure and heat exchangers, assembly of components and welding, vacuum, HCFC-22 charging, final leak test, quality control and packaging. A new manufacture line was installed to produce the HC-290 AC, and it is used for both types of air-conditioning (DACS). The new line has a manufacturing stage of heat exchangers and cabinets (these stages that did not change), assembling process, and an isolated main chamber with the necessary security measures for its operation. The tightness, pre-vacuum, vacuum, charge and leak tests are carried out in the chamber, as well as the reprocessing of non-conforming AC equipment. Similarly, as in the previous process with HCFC-22, the last stages are quality control and packaging of manufactured AC equipment. It must be noted that twenty (20) units are produced per day.

The security measures required by the new manufacture line and for the entire company were defined through the security assessment carried out by the insurance company contracted by Industrias Thermotar Ltda. In essence, the insurance company certified that Industrias Termothar LTDA implemented all the recommendations that arose during risk analysis study for the new HC-290 production line. Which means that new line has the protection measures that the foresaid line must have in order to guarantee its correct operation before, during and after each activity related to charging DACS with HC-290.

Training and coaching activities were carried out under supervision of the international consultant. This activities will continue at national level due to it has been included in programs related to training and education in the refrigeration and air-conditioning servicing sector. Additionally, as an integral part of this phase was generated technical document for updating of national standars (NTC 6828) based on ISO 5149, and a support plan was prepared focusing on the end user and the servicing sector.

And finallly the results and conclusions of the demonstrative project were presented in international and local events.

1. INTRODUCTION

The implementation of the demonstrative project for the use of HC-290 (propane), as an alternative refrigerant in the manufacture of air-conditioning equipment, was performed under the provisions of the UNDP PRODOC project 00097648, which considers the folloing topics:

- challenges for project implementation,
- strategy for project development,
- cooperation with other institutions,
- project management,
- results framework,
- monitoring and evaluation,
- multi-year work plan,
- management and governance arrangements
- and legal context and risk management issues.

The demonstrative project was carried out at Industrias Thermotar Ltda., a company that manufactures and consumes the largest amount of air-conditioning equipment and HCFC-22 refrigerant in the air conditioning sector in the country. According to the market data and company's production, the project focused mainly on the engineering design of ducted split vertical condensing units and ducted package-type units in the range from 1 to 5 TR (3.5 kW to 17.5 kW); two models were defined for each of these devices. These models differed in the material and tube diameter used in the manufacture of the heat exchanger of the condensing unit. (One aluminium microchannel exchanger model and an 8-mm copper heat exchanger model). It should be noted that the study and tests carried out by the international expert on the prototype concerning leakage and ignition, were developed for the prototypes that contain the highest refrigerant load: the split condensing units and the 5 TR package-type refrigeration equipment. This means that the design solutions adopted for these models were considered repeatable for the rest of the models contemplated in the project.

The phases and actions carried out during the project, within the framework of Stage II of the HPMP, are related to the elimination of the main barriers associated with the use of hydrocarbon refrigerants in the manufacture of commercial AC equipment, including training and certification of maintenance technicians and the establishment of technical standards for the management of hydrocarbons as a refrigerant in Colombia. Thus, the following objectives were established:

- to demonstrate the safe use of HC-290 (propane) as a refrigerant that has negligible global warming potential in the manufacture of commercial air-conditioning equipment,
- and to ensure the safe handling and good management of the risks associated with the introduction of flammable refrigerants in the commercial air-conditioning sector.

The present report details the development of the project implementation, including the completion the following activities: Tests and design procedures, recording of results, analysis of results (including lessons learned) and conclusions, as well as the integration of the products obtained in each phase, in order to meet the goal and objectives proposed in the demonstrative project.

The following are some the phases, activities and actions carried out during the project:

- Development of prototypes and safety assessment of AC units for HC-290 application. The activities developed in this phase make up to the preliminary and final engineering designs for the models of commercial air-conditioning equipment with HC-290, the manufacture of prototypes, leak and ignition tests, and equipment testing.
- Conversion and installation of equipment in the manufacturing line. The activities and actions developed in this phase are related to the civil works required in the companies' production plant, the acquisition and installation of equipment and/or components needed to handle HC-290 hydrocarbon properly in the manufacture line, and the training of operators in charge of the manufacture line.
- Risk assessment of the manufacture line at Industrias Thermotar Ltda. The activities developed in this phase were related to the risk assessment performed on the hydrocarbon air-conditioning manufacture line.
- Technical training for the service of air-conditioner maintenance and installation. The activities developed in this phase were the training and qualification of the male technicians in charge of the installation and maintenance of new equipment. The international expert supported this activity. Additionally, two aspects have been considered in this activity to strengthen this phase, namely, the development of a follow-up plan focused on the end users who purchase these types of hydrocarbon air-conditioning equipment, as well as generate inputs for updating the Colombian Technical Standard, NTC 6828 based on ISO-5149.
- Dissemination of results. The activities and actions developed in this phase were related to the dissemination workshops and academic events about the lessons learned in the demonstrative project; they have been carried out during the project closure.

The results obtained from the demonstrative project for the use of HC-290 as an alternative refrigerant in the manufacture of air-conditioning equipment were the total elimination of the consumption of HCFC-22 refrigerant used in the manufacture of commercial air-conditioning equipment, and the safe promotion of this replacement alternative in companies that use other refrigerant substances (such as R-410A) with high GWP and that are associated with higher energy consumption. These results are achievable provided that the safe and proper management of the risks associated with the introduction of flammable refrigerants in the commercial air-conditioning sector of the country is ensured.

2. PROJECT OBJECTIVES AND IMPLEMENTATION

According to the document submitted and approved in the 75th meeting of the Executive Committee of the Multilateral Fund held in Montreal in November 2015, the project objectives were:

1. To demonstrate the safe use of HC-290 as a low GWP refrigerant in the commercial production of air-conditioning with ranging from 3.5 kW to 17.5 kW (1 to 5 TR), thus contributing to the phase out of HCFC-22 use in the RAC manufacturing sector. The aim was to develop HC-based AC equipment with good performance with a minimum incremental operating cost.

2. To assure safe handling and good risk management for the introduction of flammable refrigerants in the commercial air-conditioning sector.

Industrias Thermotar Ltda. is the factory that manufactures the largest share of the total volume of HCFC-22-based condensing units for air-conditioning systems and packaged air-conditioning equipment. Their principal users are trade outlets and retails located in tropical areas. The company served as a local technical host to coordinate the activities included in the demonstrative project phases since the new designs of equipment were incorporated into the diffusion workshop made to present the general results.

The project started last week in October 2016. It was implemented as a joint effort of Industrias Thermotar Ltda, Daniel Colbourne (International Expert of UNDP), Moji Trading S.A.S. (Agramcow: supplier company), the National Ozone Unit (UTO) and UNDP, and the Emerson Company (Copeland) that provided the compressors to be used in the project. The following activities were carried out:

Phases/Activity	Period	Date		
		2016	2017	2018
Designs and prototypes: Controllers and electrical components. Design of the refrigerant circuit, construction and prototype testing.	November 01, 2016 to March 31, 2018			
Installation of equipment in the manufacturing process: Installation and implementation of new equipment for the manufacture line. (Selection of the stationary equipment supplier, training for the operation and maintenance of the production line.)	December 01, 2016 to April 30, 2018			
Safety audit: Safety audit on the new manufacture line (Industrias Thermotar Ltda).	January 01 to March 31, 2018			
Training for servicing in installation during guarantee, post-sales services. (Updated Release of Colombian Technical Standard NTC 6828 based on ISO-5149)	October 01, 2017 to June 30, 2018			
Dissemination activities. Workshop for dissemination.	September 01, 2017 to July 31, 2018			

The execution period for the phase related to training of the service sector and update of the Colombian Technical Standard, NTC 6828 based on ISO-5149, was the period defined during the project development (see above), but this activities will continue at national level due to it has been included in programs related to training and education in the refrigeration and air-conditioning servicing sector.

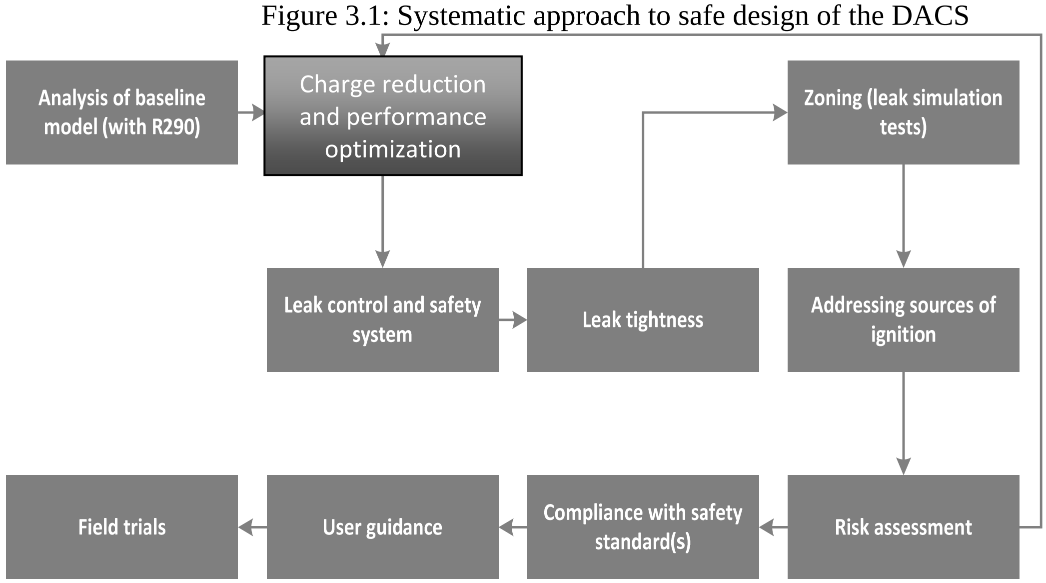
3. METHODOLOGY / EXPERIMENTAL

3.1 Experimental activities for safety assessment of HC-290 based DACS (see Annex A)

In order to place a product on the market – such as a DACS – it is necessary to ensure that it is safe and in compliance with applicable safety regulations. Whilst it is assumed that the baseline DACS designs (i.e., that currently use HCFC-22) already comply with the relevant requirements related to electrical, pressure and mechanical safety, an additional safety assessment is required for the use of flammable refrigerants . Therefore, it is necessary to re-assess whether any requirements of the DACS deviate from the HCFC-22 model due to the different properties and characteristics of the new refrigerant (HC-290) and its associated parts and components.

The work described in this report followed the sequence summarized in **Error! Reference source not found.** Essentially it was based on an iterative risk assessment/risk analysis approach, where each stage ultimately leads to a reassessment and refinement of the DACS design under development.

Figure 3.1: Systematic approach to safe design of the DACS



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

Several prototypes of both ducted split and rooftop units have been developed throughout this process, as summarized below:

Stage 1: HCFC -22 system charged with HC-290
Stage 2: Modifications to electrical components and enclosures/panels
Stage 3: Optimized condenser and inclusion of liquid line solenoid valve (LLSV[5]) and additional non-return valve (NRV[6])
Stage 4: Revised electrical components and enclosures/panels and AHU[7] return inlet construction
Stage 5: HC-290 compressor
Stage 6: Inclusion of leak detection system

The main task was to consider explosion protection in the design and construction of the unit. Additional measures were proposed for leak tightness in accordance with ISO 5149 and EN 1127-1 to ensure the system is technically tight. Further, tests were carried out to determine the releasable mass of refrigerant under various operating conditions. In addition to the general approach of safe design and construction, the unit is also assessed for compliance with NTC 6228, specifically for the requirements directly related to refrigerant flammability.

The DACS under consideration were packaged or centralized/split units mainly used for residential and commercial applications, where air-conditioning is supplied via ducting. The packaged unit is a single factory-sealed, pre-charged system. The centralized system comprises a separate indoor air handling unit (AHU) and an outdoor condensing unit.

The execution of this phase was carried out based on two activities: Development of the model designs for explosion protection and the quantitative risk assessments for these models.

3.1.1 Development of DACS designs for explosion protection

The design and construction of the DACS for explosion protection must be handled considering the risk minimization. Several basic principles, such as those as identified in EN 1127-1, focus on explosion prevention (as opposed to reduction of consequences). In principle, this requires:

- To reduce the amount of flammable.
- To avoid explosive atmospheres.
- To avoid all effective ignition sources.

The following aspects have been studied to fulfill of the above items:

a.) Leak tightness

Leak tightness is essential for risk reduction. A high level of leak tightness can be achieved through compliance with the following:

- Requirements for leak tightness testing in ISO 5149-2 clause 5.3.3 (and 5.3.2 for strength test).
- Ensuring the system is durably technically tight.
- Adopting additional design measures.

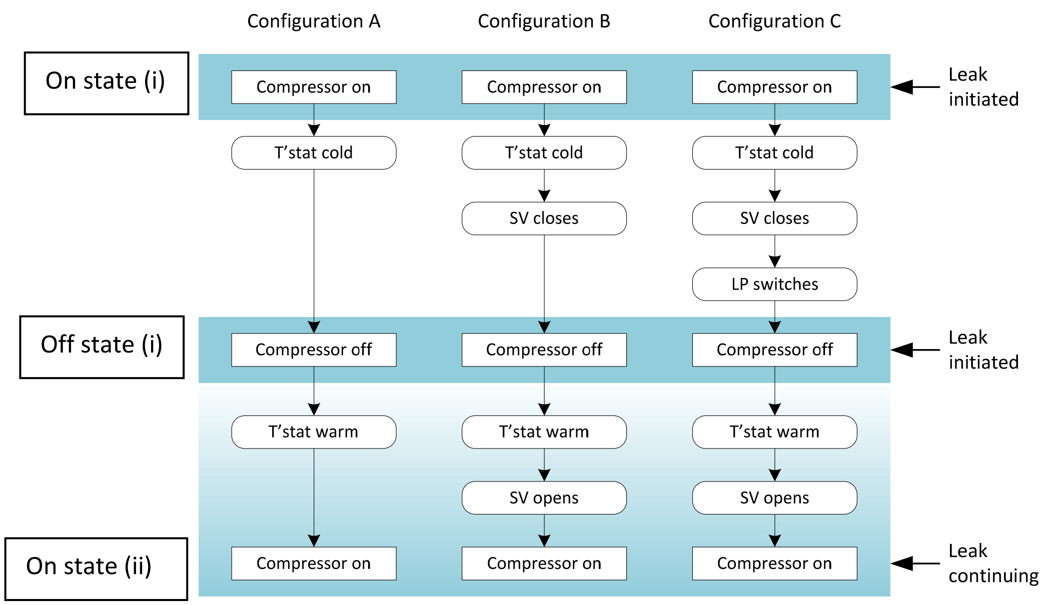
[5] SV: Solenoid valve – LLSV: Liquid line solenoid valve
[6] NRV: Non-return valve
[7] Air handling unit SEE COMMENT ABOVE ABOUT A LIST OF ABBREVIATURES

b.) Refrigerant charge minimisation: The redesign of the following parts was considered to minimise the refrigerant charge: Condenser, evaporator, compressor and overall system

c.) Releasable mass of refrigerant: It is important to establish how much refrigerant will be released from the system in the event of a leak and under different operating modes. Tests were conducted to quantify the refrigerant charge that could leak (released refrigerant mass):

Figure 3.2 presents the operating conditions and system configurations were considered to perform the refrigerant charge quantification tests.

Figure 3.2: Operating states for different system configurations



***Definitions**: T´stat cold: State of thermostat (cold). T´stat warm: State of thermostat (warm). LP switch: Low pressure switch. SV: Solenoid valve

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

It is important to point out that the system configurations used for the new DACS equipment were designed to locate the condenser unit (high side) on the outer part or outdoors.

The following procedures were developed with the methodology and arrangement used:

- To attache short, wide-bore hoses to chosen leak positions with the leak hole orifice at the end.
- To connect the outlet of the release orifice to a sealed collection bag.
- To operate the system for at least 30 minutes to achieve reasonably steady state conditions.
- To adjust the system operation to achieve the desired operating state and/or function
- To open valve to initiate the simulated leak.

The following devices and layouts were used:

- Ducted air-conditioners (ducted split and rooftop).
- 2.5 mm diameter (4.9 mm^2) leak orifice.
- Electronic pressure transducers.
- Electronic balance.
- Sealed collection bags.

d.) Characterization and avoidance of flammable concentrations: A release of refrigerant from either the internal or external parts of the DACS can form flammable mixtures. Ventilation, particularly mechanical ventilation, is known to provide risk reduction by assisting in the dispersion of a flammable refrigerant leak by increasing the entrainment rate and thus diluting the mixture below flammable limit rapidly.

The following methodology and arrangement were used to identify the location where flammable mixtures may form across various elements of the DACS and subsequently obtain the mass flow rate for certain leaks:

- To set up the room and equipment properly, including the placement of gas sensors at appropriate locations.
- To make sure all unintended sources of ventilation are removed.
- To initiate the release of refrigerant from the cylinder at the desired flow rate.
- To stop the flow once the released mass has been achieve.
- To wait as long as necessary until the end of test.

The following devices and layouts were used for the above:

- Ducted air conditioners (ducted split and rooftop) with fitted ducting, as required.
- Leak holes of various sizes (to suit specific leak conditions).
- HC-290 cylinder and hoses.
- Electronic balance.
- Electronic flow meter.
- Gas analysers with data logging.

e.) Removal of sources of ignition (SOI): The EN 1127-1 procedures were followed to remove these ignition sources. Here is a summary:

- To identify all possible points of leakage.
- To perform a hazardous area classification (zoning) exercise, as prescribed in IEC 60079-10-1.
- To check electrical (or non-electrical) components within zones with potential SOI.
- To remove those potential SOI from the zones, either by replacing them with non-SOI equivalent components or relocating existing components outside the hazardous area.

- Modifications to eliminate SOI.

This approach is included in the NTC 6228-2[8] draft and is intented for air-conditioning and refrigeration equipment. Accordingly, the leak simulation test method in the annex (NTC 6228-2) has been used for the zoning exercise.

f.) Limiting potential consequences and considering use and misuse limits: considers the activities that must be taken in account to limit the effects or consequences of an ignition event and those potentially hazardous situations associated to human interaction with an AC equipment or machine in accordance with EN ISO 12100, respectivily.

3.1.2 Quantitative risk assessment of AC new designs with HC-290

Quantitative Risk Assessment (QRA): The experimental model used in QRA was developed based on the operation (in-use) phase for the two DACS. Accordingly, the various equipment characteristics and environmental conditions that affect the likelihood of ignition of a flammable mixture are considered. This requires an analysis of the equipment and surroundings and integrating the findings into the basic methodology, namely:

- To select a range of leak hole sizes and determine the frequency of the occurrence of leak hole sizes.
- To estimate the average mass flow rate of release for each leak hole size.
- To identify each relevant operating mode (system on/off-cycle, fan on/off-mode; as applicable) and the external conditions (infiltration rates, presence of occupants, external SOI, etc.).
- To estimate the gas concentration within the unit compartment, flammable volume within unit compartment, gas concentration within room and flammable volume within room for each of the leak sizes, operating modes and sets of external conditions.
- To determine the probability of a flammable mixture within unit compartment and the probability of a flammable mixture within a room.
- To identify a set of potential sources of ignition (SOI) within the room and the unit compartment including their activation characteristics and location.
- To determine the probability of SOI and the corresponding frequency of ignition.
- To estimate the corresponding overpressure and thermal intensity for each circumstance that leads to an ignition event.
- To calculate overall risk values.

In order to carry out the calculations, it is first necessary to discretise the operation into segments according to the leak hole size, location of SOI, etc. A probability must be assigned to the occurrence of each event. Thus, the ignition frequency as well as the size of the consequent overpressure and thermal intensity can be estimated based on the estimated frequency of a release, size of flammable volumes and probability of active sources of ignition. These results then allow the calculation of risk values.

[8] NTC 6228 part 1 was updated and approved by the RAC sector and the part 2 exist as a draft which is being updated

After the quantification of all the elements discussed above, empirical data from field information, measurements and other validation techniques were used to improve the reliability of QRA results. The data, relevant parameters and DACS design and installation characteristics were based on discussions and measurements taken from previous studies (where relevant) and from technical literature.

The probability calculations used in normal operation are described in this section and include three main elements:

- Calculation of ignition frequency, consequence and risk for a given set of conditions.
- Calculation of the probability of occurrence for each set of conditions.
- Calculation of the overall ignition frequency and risk for the entire set of conditions.

These involve the estimation of contributing events, such as the occurrence of flammable concentrations and active sources of ignition and estimations of the probabilities of particular operating modes. In addition, the situation consists of two separate risks: a release into the condensing unit compartments and a release transferring into the room. Thus, the calculations are carried out according to:

- Ignition of a release within the applicable compartments within the DACS by an unintended potential SOI (i.e., a faulty or incorrectly fitted component).
- Ignition of a release within the room by other potential SOI normally present in the room.
- Ignition of a release surrounding the out-door parts of equipment caused by other potential SOI normally present outside.

A potential SOI is a device that may become a SOI under fault or failure conditions, but cannot ignite under normal operation, for example, a short circuiting in fan motor windings or a switch with a broken or incorrectly-fitted protective cover.

It is worth noting that event tree and fault tree analysis are used in the recording of results to determine the probability of each of these failure modes occurring and for each leak-hole size.

3.2 Methodology for the conversion and installation of equipment in the manufacturing line

The methodology used for the development of this phase was comparative, the expertise of different companies that execute the installation and assembly of these equipment lines worldwide was considered in the analysis.

The request for quotation form was drawn up for this purpose, which contained the technical specifications of the equipment and/or parts required for the new manufacture line, according to the country’s safety standards for the handling of flammable gases (refers to production lines used in the country's oil refineries). The systems required to convert the manufacture line are the following:

- A Helium leak test system with sniffer detector and helium recovery equipment
- Pre-vacuum system and vacuum pressure leak test.
- Evacuation equipment and flammable refrigerant charge (HC-290).
- Equipment for safe discharge and evacuation of flammable refrigerant (HC-290).
- HC-290 detector equipment for leakage testing in manufacturing and reprocessing areas.
- Additionally, the safety monitoring and control system for flammable gases (HC-290) was included, together with the ventilation system for flammable gases.

The companies that submitted their proposals in accordance with the request were: POLO SRL, VPC INGENIERIA S.A.S (Galileo); MOJI TRADING S.A.S. (Agramkow Fluid Systems A/S). The selection process favoured the Agramkow Fluid Systems A/S company, which defined a work plan including the following activities: Preparation of the equipment drawings for the manufacture line, determination of the civil works required in the delimited installation for the assembly of the acquired machines, restructuring of the supply system of oxyacetylene sources, dry air and electrical connections and the construction of the charging area and leakage test, by means of an aluminium profile cabin, which delimits the area for the handling processes of HC-290 flammable refrigerant gas.

3.3 Risk assessment of the manufacture line at Industrias Thermotar Ltda

Two reports were made in the development of this phase; a first report related to risk analysis for the implementation of HC-290 LPG[9] at Industrias Thermotar Ltda and a second report on the follow-up to the recommendations for the implementation of HC-290 LPG at Industrias Thermotar Ltda.

The experimental test was carried out based on the fulfilment of three objectives. First, determining the most significant risks that arise or can be identified, regardless of their characteristics; second, assessing those risks, that is, the probability of occurrence and level of impact in case they materialise; and the final objective is to determine how to handle those specific risks, that is, determine the path to be followed, through a loss control or risk reduction program.

A risk map of the process was prepared for the risk identification stage in the implementation of this new refrigerant. Also, the respective scales of probability of occurrence and level of impact applied to each risk —and therefore, to each one of the stages of the HC-290 charging process— were defined to assess those risks.

The evaluation took into account the expertise of the insurance company of Industrias Thermotar Ltda, who previously knew the manufacture line.

3.4 Training for servicing in installation during guarantee, post-sales services

[9] Pressurized Liquefied Gas

The training process included both theory and practice workshops, which were supported by the international expert that organized and formulated technical contents that focused on the safe handling of HC-290 refrigerant during the installation, maintenance and disassembly services of the new air-conditioning equipment.

Additionally, the guidelines and methodology established through the National Standardization Agency of Colombia INCONTEC (Colombian Institute of Technical Standards and Certification) were considered to generate inputs in order to update the NTC 6828. Likewise, in order to carry out this update, an interdisciplinary working group was formed among the different actors involved in safety and environmental requirements needed in refrigeration systems and heat pumps. It should be noted that the international expert consultant supported the update of the NTC.

Finally, while preparing the follow-up plan, Industrias Thermotar Ltda used its experience on preventive maintenance operations to develop a follow-up plan for the operation of the new air-conditioning equipment installed in the commercial sector (customers).

3.5 Workshops for dissemination of results

The dissemination workshops involved presenting or socializing the results obtained in each project phase to the interested public. Additionally, the dissemination and communication included the preparation of research papers or documents on the results obtained.

4. RESULTS

4.1 Prototypes and safety assessment of HC-290 based DACS

The DACS specifically addressed under this project are identified inTable 4.1, although it has mainly focused on the 17.5 kW units; if the safety issues associated with the largest units are met, applying HC-290 to the smaller units should be less of a challenge.

Table 4.1: Models to be addressed for HC-290 application

Capacity	Centralised ducted split	Packaged rooftop
7 kW (2TR)	CV024 + FCD024	EPAC-024
10.5 kW (3TR)	CV036 + FCD036	EPAC-036
17.5 kW (5TR)	CV060 + FCD060	EPAC-060

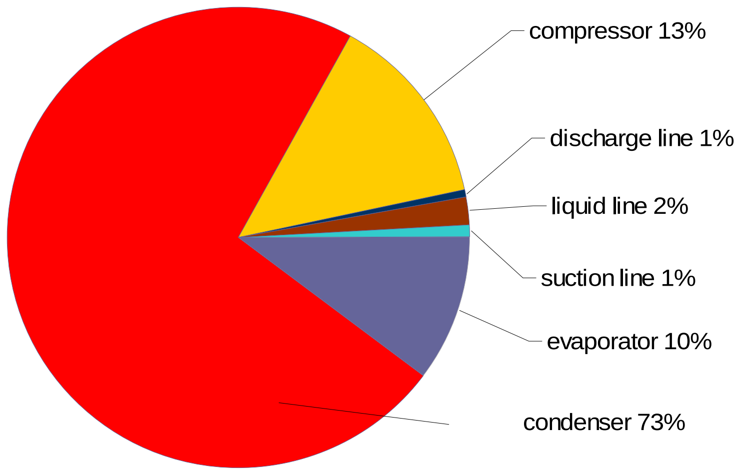
Source: Industrias Thermotar Ltda.

4.1.1 Development of the prototypes with design for explosion protection

a.) Leak tightness: Circuits and piping were examined and checked in the development of prototypes to minimize their vulnerability to leakage. Final design models were re-checked for compliance with leak-tightness requirements (ISO 5149-2 clause 5.3.3).

b.) Refrigerant charge minimisation: **Error! Reference source not found.** 4.1 shows the usual refrigerant charge distribution for an ACU[10]. This implies that most benefit for change reduction can be gained from addressing the condenser. Although the compressor can yield potential charge reduction, it depends on the efforts of the compressor manufacturer.

Figure 4.1: Typical refrigerant charge distribution in an air-conditioning system



Source: Prototype designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- Condenser: The most significant modification was to reduce the tube size from 9.5 mm diameter to 7.9 mm. In addition to the finned tube condenser, a parallel prototype has been developed with a micro-channel condenser which also provides charge reduction.
- Evaporate: The analysis and redesign of the evaporator coil have not been performed in this Project.
- Compressor: The compressors used within the new DACs are HC-290 compressors. These compressors have more appropriate electrical components. (compressors were provided by Copeland - Emerson.)
- Overall system: The refrigerant charge had been reduced from approximately 1,300 – 1,400 g HC-290 to about 1,000 g with the finned tube condenser in the ducted split and with the standard 3 m interconnecting piping. Table 4.2 provides the current and estimated charge sizes for the six models under consideration.

Table 4.2: Models with HCFC-22 and anticipated HC-290 charge sizes

Charasteristics	Rooftop			Ducted split		
Model number	EPAC-036-	EPAC-048-	EPAC-060-	CV036-	CV048-	CV060-
Nominal capacity	10.5 kW	14 kW	17.5 kW	10.5 kW	14 kW	17.5 kW
HCFC-22 charge	1300 g	1775 g	2210 g	1360 g	1815 g	2265 g
HC-290 charge	560 g	760 g	950 g	600 g	800 g	1000 g

Source: Industrias Thermotar Ltda.

[10] Air condenser unit

c.) Releasable mass of refrigerant: The final results were obtained with the prototypes including HC-290 compressors. These tests primarily focused on "pump-down" and "shut-down" conditions and should provide the actual releasable refrigerant amounts for the developed ("5TR") models. Three measurements were carried out for both ducted split and rooftop models, for the pump-down and shut-down cases.

The following observations can be made based on the results compilation of Table 4.3:

- The use of pump-down cycle is more effective to retain refrigerant in the system in the event of a leak from the low side.
- Relying on a LLSV only but without pump-down when compressor terminates in 3 – 4 times as much charge being released (than with pump-down).
- Relying on the LP[11] switch to close the system and prevent more refrigerant from leaking is not particularly effective, since more than half the charge will be released.
- Leak from the high side will release almost the entire charge (outside).
- Wherever a LLSV is used to limit the amount of refrigerant that may be released, average leak rates tend to be lower, with mass fluxes ranging 15 – 25 g/min per mm^2.
- Leak rates from the low side are approximately double when there is no closed LLSV, which is due to the driving force of the refrigerant migrating from the high-pressure side of the system.
- Releases from the high-pressure side result in average leak rates two to five times higher than those from the low side, mainly due to the higher pressure and the greater amount of refrigerant held locally.
- Mass flow rates in the boiling stage when the compressor is off are generally one and a half to two times the average mass flow, an expected result due to higher pressure during that stage and occasional liquid droplets.
- When a leak occurs whilst the compressor is on, mass flow in the boiling stage is almost the same as the average mass flow since the low-pressure side is continually replenished with liquid most of the leak period.
- There is a negligible boiling stage for leaks from the low side following pump-down due to the prior removal of most of the refrigerant.

[11] Low Pressure

Table 4.3: Summary of leak amount tests conditions and results

Test No.	Unit	Location	Mode	Charged (g)	Leaked mass (g)	Total leak mass (g)	Leaked fraction of charge (%)	Average leak rate (g/min)	Av. leak mass flux (g/m/mm^2)	Leak rate (boiling) (g/min)	Leak mass flux (boiling) (g/m/mm^2)
3	Duct split	low side	On --> off; LLSV closed	1009	395	934	93%	86	25	186	54
4	Duct split	high side	Off; remaining	1009	540			184	53	344	99
5	Duct split	low side	On --> off; LLSV closed	1050	434	957	91%	43	12	87	25
6	Duct split	high side	Off; remaining	1050	522			182	53	305	88
7	Duct split	low side	On --> off; LLSV closed + DNRV	1043	327	880	84%	82	24	156	45
8	Duct split	high side	Off; remaining	1043	554			190	55	321	93
9a	Duct split	low side	On; pump-down	1035	40	912	88%	31	9	n/a	n/a
9b	Duct split	low side	On; pump-down	1035	54			34	10	n/a	n/a
9c	Duct split	low side	On; pump-down	1035	51			33	9	n/a	n/a
10	Duct split	high side	Off; remaining	1035	767			231	67	371	107
11	Duct split	low side	Compr on; LPS --> off	1035	537	832	80%	44	13	47	14
12	Duct split	high side	Off; remaining	1035	295			141	41	328	95
13	Duct split	low side	Compr on; LPS --> off	1120	522	1076	96%	189	55	184	53
14	Duct split	high side	Off; remaining	1120	554			126	36	203	59
15a	Duct split	low side	Compr on; LPS --> off	1120	557	994	89%	134	39	130	38
15b	Duct split	low side	Off	1120	114			81	23	142	41
16	Duct split	high side	Off; remaining	1120	324			145	42	315	91
17a	Duct split	low side	On; pump-down	1400*	236	1366	98%	54	16	n/a	n/a
17b	Duct split	low side	On; pump-down	1400*	142			49	14	n/a	n/a

Test No.	Unit	Location	Mode	Charged (g)	Leaked mass (g)	Total leak mass (g)	Leaked fraction of charge (%)	Average leak rate (g/min)	Av. leak mass flux (g/m/mm^2)	Leak rate (boiling) (g/min)	Leak mass flux (boiling) (g/m/mm^2)
17c	Duct split	low side	On; pump-down	1400*	97			60	17	n/a	n/a
18	Duct split	high side	Off; remaining	1400*	892			212	61	304	88
19	Duct split	low side	On; pump-down	880	80	80	9%	63	13	n/a	n/a
20	Duct split	low side	On; pump-down	880	83	83	9%	66	13	n/a	n/a
21	Duct split	low side	On; pump-down	880	77	77	9%	61	12	n/a	n/a
22	Duct split	low side	On; shut-down	880	273	273	31%	115	23	237	48
23	Duct split	low side	On; shut-down	880	349	349	40%	125	25	218	45
24	Duct split	low side	On; shut-down	1010	352	352	35%	126	26	236	48
25	Duct split	low side	On; pump-down	1010	68	68	7%	51	10	n/a	n/a
26	Rooftop	low side	On; pump-down	1100	88	88	8%	69	14	n/a	n/a
27	Rooftop	low side	On; shut-down	1100	278	278	25%	83	17	122	25
28	Rooftop	low side	On; pump-down	1100	51	51	5%	40	8	n/a	n/a
29	Rooftop	low side	On; shut-down	1100	295	295	27%	80	16	145	30
30	Rooftop	low side	On; pump-down	1100	60	60	5%	31	6	n/a	n/a
31	Rooftop	high side	On; shut-down	1100	284	284	26%	83	17	157	32

* System overcharged; released quantities deemed to be higher than those obtained from a correctly charged system. Test No 1 and 2 were considered like proof

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne d.) Characterisation and avoidance of flammable concentrations: As mentioned above, the two main reasons for testing are: to determine the releasable charge under a given set of conditions and subsequently obtain a mass flow rate for leaks of a certain size.

– AHU enclosure: Concentrations within the ducted split AHU enclosure for the two leak positions are shown in Figure 4.2 and Figure 4.3. The results are similar in both cases; there is an initial rapid increase in local concentration and then a transition to a fairly steady value with further addition of refrigerant as the mixture migrates from the openings within the AHU envelope. Seconds after the leak stops, both sampling points fall towards zero. As expected, concentrations are higher at the base than at the top of the enclosure. Importantly, the concentration easily exceeds the LFL[12] with this leak size, demonstrating that the entire internal space is potentially flammable. Even with a fraction of the charge, the concentration would still exceed the LFL.

Figure 4.2: Leak position 1, 220 g, 50 g/min

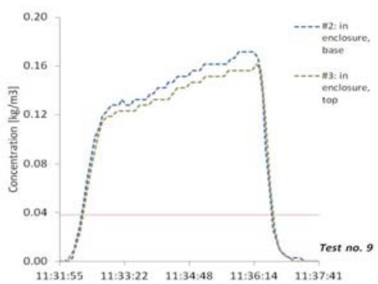
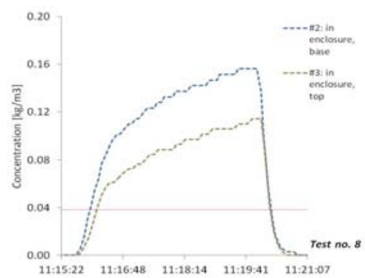


Figure 4.3: Leak position 2, 220 g, 50 g/min



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

With the blower on, the measured concentrations were negligible. Even with a release of 530 g at 135 g/min and the blower on "low" setting, the concentrations were below 0.005 g/m3 (on account that the sensors did not return a value). Dividing release mass flow rate by the blower volume flow infers an average concentration of 0.003 kg/m3 – about 7% of the LFL of HC-290.

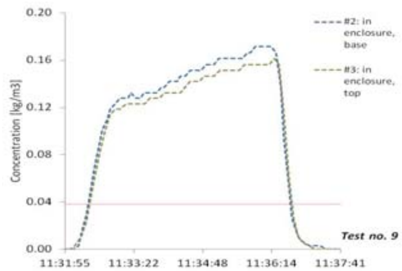
The behaviour is slightly different compared to the case of ducted split AHU enclosure in firstly, the initial jump in concentration is substantially higher with the rooftop AHU, likely due to a smaller internal volume. (The fact that a larger mass is used in the rooftop tests is not important since it does not affect the initial values.) Secondly, whereas concentration increased gradually over time with the ducted split AHU, those within the AHU reach equilibrium within a couple of minutes into the release. This is due to differences in the size of openings through which the mixture can flow out; whilst the rooftop AHU has a smaller internal volume, the gaps are larger (for example, comparing the internal volume) thus enabling a higher outflow rate.

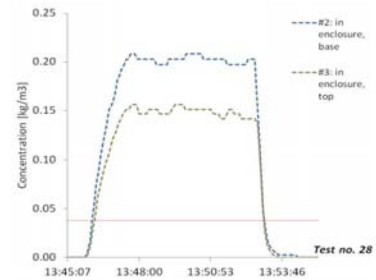
Concentrations within the rooftop AHU enclosure are shown in

Figure 4.4: Leak position 1, 380 g, 50 g/min

Figure 4.5: Leak position 2, 380 g, 50 g/min

[12] Lower flammable limit. HC-290 = 0.039 kg/m3





Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

4.4 and Figure 4.5 for the two leak positions. In both cases the results are similar, where there is an initial rapid increase in local concentration and these then transition to a fairly steady value with further addition of refrigerant as the mixture migrates from the openings within the AHU envelope. Within seconds of the leak stopping both sampling points fall towards zero. As would be expected, concentrations at the base are higher than at the top of the enclosure. Importantly, with this leak size, the concentration easily exceeds the LFL, demonstrating that the entire internal space is potentially flammable. Even with a fraction of the charge, the concentration would still exceed LFL.

Figure 4.4: Leak position 1, 380 g, 50 g/min

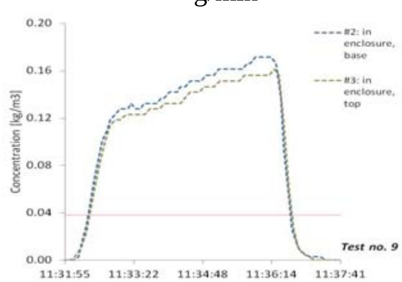
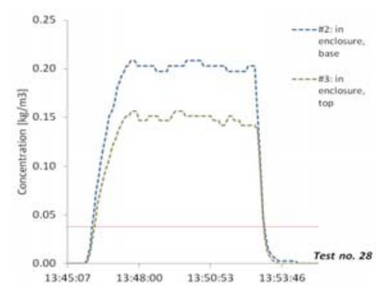


Figure 4.5: Leak position 2, 380 g, 50 g/min



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

As with the ducted split AHU, with the **blower on,** the measured concentrations were negligible. Using a release of 350 g at 230 g/min and the blower on "low" setting, the concentrations were below 0.005 g/m3 (on account that the sensors did not return a value). Dividing release mass flow rate by the blower volume flow infers an average concentration of just under 0.005 kg/m3 – about 12% of the LFL of HC-290.

– Condensing unit enclosure: Concentrations within the rooftop condensing unit enclosure are shown in Figure 4.6 and Figure4.7 for the two leak positions. As with the releases inside the rooftop AHU enclosure, there is an initial rapid increase in local concentration and these then transition to a relatively steady value as further refrigerant is released, although only at the lower sampling location. Despite the mass flow being 2.5 times greater than the AHU tests, this concentration equilibrium occurs due to the considerably larger free area in the housing, i.e., between condenser fins and the fan housing. The sampling locations towards the top of the enclosure are rather erratic and relatively low, due to rapid ingress of fresh air. Whilst at the base the concentrations exceed LFL, those at the top are comfortably lower than LFL.

Figure 4.6: Leak position [discharge pipe], 1000 g, 150 g/min

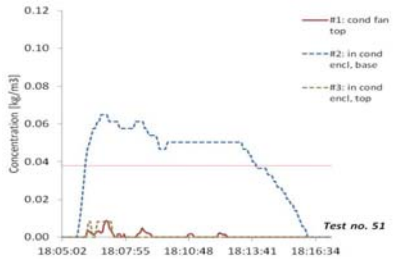
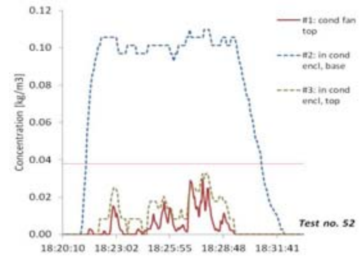


Figure 4.7: *Leak position [liquid line], 1000 g, 150 g/min*



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

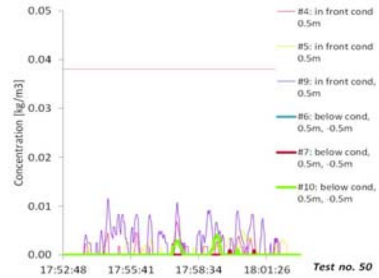
– Ducting: Provided that the velocity is high enough to cause turbulent flow within the ducting – which is the case in most applications (i.e., Reynolds number is several orders of magnitude higher than that at transition between laminar and turbulent flow) it is likely that any refrigerant travelling along the duct with forced airflow will become very well mixed. When the blower is off, high concentrations can be found at duct outlets, but this depends upon how much of the refrigerant can flow back through the return ducting or through the supply ducting. If duct outlets were elevated then any refrigerant flowing from the outlet will dilute to low concentrations within a fraction of a metre along its decent. Where duct openings are positioned at floor level, significant concentrations can be found and mitigations measures are recommended.

– Beyond condenser for DACS: Whilst releases from the condenser part of the rooftop unit, or the condensing unit of the ducted split unit are broadly of a lesser concern than leaks indoors, it is useful to understand how the refrigerant will distribute around the unit housing. In particular, this contributes to determine "separation distances" from the unit to other electrical equipment or fresh-air inlet ducts installed nearby.

  Measurements were made using the rooftop unit and condensing unit of the ducted split, positioned on an elevated board. This is intended to more accurately represent an outdoor installation, where a release is not confined by room walls. Measurements were carried out indoors, where airflow is limited; usually outside airspeed is substantially higher and therefore these results represent a very pessimistic case. Whilst only the rooftop unit was used for these tests, the results are deemed to represent the condensing unit since the construction of the condenser parts is almost identical.

Figure 4.8: Arrangement of the rooftop unit for surrounding concentration measurements

Figure 4.9: Concentrations surrounding the rooftop unit at 0.5 m and 0.5 m below plinth with 1000 g at 150 g/min from discharge pipe, with access panel open



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

e.) Removal of sources of ignition: Due to the relatively confined construction of the various DACS housings, a release from any point rapidly ensures any position within the housing would exceed 50% of the LFL. Therefore, it is necessary to position any potential SOI into an externally located panel.

Most electrical components (many of which could be a potential SOI) are located within inset electrical panels. Ordinarily this comprises (e.g., Figure 12): Mains relays, start capacitors, run capacitors, voltage transformers, timer/delay and terminal connections.

Of these, only the relay and timer/delay could be considered as a potential SOI (see below).

Figure 4.10: Typical contents of electrical panel

Figure 4.11: Example of evaporator fan motor

Figure 4.12: Example of fan blades

Source: Industrias Thermotar Ltda.

The evaporator fans are located within the AHU housing and are thus likely to come into sustained contact with refrigerant in the event of a leak. Therefore, significant attention should be paid to them in order to avoid ignition sources. Condenser fans are positioned at the top of the condensing unit and normally located in the open air. A leak of refrigerant is unlikely to accumulate around the condenser fan so limited attention may be paid to them.

Both condenser fan and evaporator fan motors are AC induction type and do not present a SOI under normal operation since they are brushless. They do use internal overload protectors.

All fan blades are aluminium, whilst the cowling is galvanised steel. Provided that the fan and cowling materials are not stainless-steel pairs or steel alloy and brass pairs, the possibility of sparking due to mechanical impact is negligible. The following must be complied with to ensure that the fan assembly has negligible risk of producing arcs and sparks:

– Rotational speed should be less than 40 m/s.

- Powder coating must not contain aluminium or iron oxides.
- All metal parts of the fan assembly and parts are earthed, which avoids the possibility of static build-up.
- Clearance distance between the fan blades and the casing shall be at least 1% of the diameter and no less than 2 mm.

The high and low-pressure switches are basic fixed-value encapsulated switches. They are likely to be suitable. However, several manufacturers are producing HC-290 approved components; these should be sought first before considering the use of HCFC-22 components. If HCFC-22 items are applied, then it is recommended they are checked for compliance against IEC 60079-15, e.g., for enclosed-break device.

With regard to compressor currently are used Copeland HC-290 scrolls. Whilst they comprise internal windings and thermal overloads; the only external electrical parts are terminals and wires and have nevertheless been certified against the applicable Standard. As such, they do not present as SOI under normal operation.

Figure 4.13: Example of pressure switch

Figure 4.14: Example of compressor (left) and electrical connection (right)

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

A normally-closed solenoid valve was installed within the liquid line to limit the releasable charge. Since solenoid valves do not arc or spark under normal operation, they are not considered SOI. However, it is advisable to select approved HC-290 SVs.

The electrical panel contains one 2/3-pole mains relay. Whilst it is intended to position the electrical panel external to the housing, it is desirable to check the construction of the used relays against the requirements for enclosed break device under IEC 60079-15 in order to provide additional confidence.

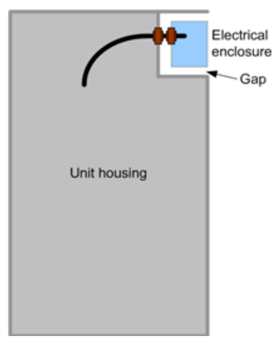
Figure 4.15: Example of mains relay employed

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

In response to the initial zoning exercise, several components needed to be relocated out of the zone 2 area (condenser unit). This was achieved by redesigning a panel located in an air-separated section; in this regard, even if the inset section is not sufficiently tight to prevent egress of leaked refrigerant, it should be unable to penetrate the second enclosure. A prototype is included in

Figure 4.16 along with a schematic.

Figure 4.16: Current (left) and proposed (right) electrical panel



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

By following the leak simulation test (zoning exercise) detailed in NTC 6228-2, it was demonstrated that the revised construction avoided contact with a concentration exceeding 50% of the LFL.

Separating the electrical panel ensures that if a technician inadvertently fits an unsuitable component after the units has been installed, there remains no residual risk that it could act as a SOI to a refrigerant leak.

f.) Limiting potential consequences and considering use and misuse limits: The preferred approach to avoiding or minimising the severity of consequences is prevention of ignition by removal of SOI and curtailing the formation of flammable mixtures. However, as long as flammable substances are being employed, their avoidance cannot be absolutely guaranteed. Therefore, additional consideration should be given to limiting the effects of such consequences. Typical approaches include:

- Physical barriers among potentially flammable mixtures, occupants and combustible materials.
- Non-combustible construction materials to avoid secondary combustion.
- Sufficient free openings or frangible sections for enclosures to allow overpressure relief.

These considerations are included within the operating manual of the new DACS designs, pursuant to NTC 6828.

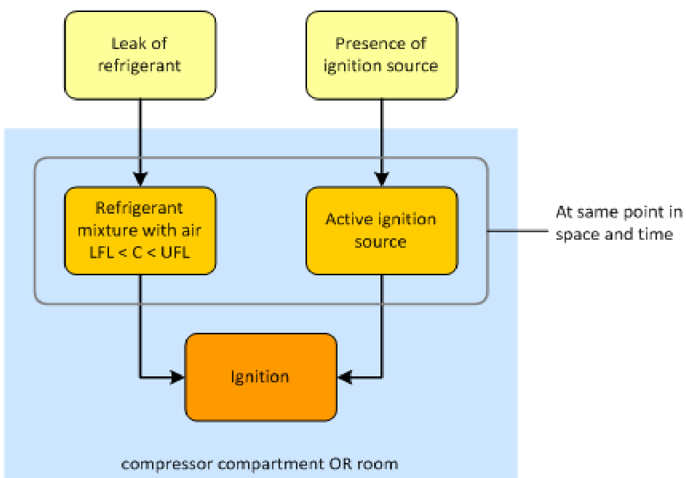
4.1.2 Quantitative risk assessment of new DACS designs

It is necessary describe the generic operating and environmental conditions that could affect the likelihood of ignition in order to quantify the normal operation risk. Consequently, it is also necessary to characterise the three co-incident events that are necessary to cause ignition:

- A leak of refrigerant that enters a given control volume (enclosure, room, etc.).
- Formation of a flammable mixture.
- At the same time, presence of an active SOI within the condensing unit compartment or room.

This general sequence of events is shown in Figure 4.17

Figure 4.17: General sequence of events for normal operation



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

The variables will be described in more detail to identify effectively the condition that could lead to ignition of a release within each stage. Various leak sizes are considered (ranging from "pin hole" to "catastrophic"), the compressor operating mode (in these smaller systems with no mechanical joints, the leak characteristics are considered to be largely unaffected by compressor operation. Therefore, this parameter is neglected), an evaporator blower or condenser fan may or may not be operating on the DACS, creating an internal airflow within enclosure, ducting and the local area.

Ambient air movement: Various forms of airflow can affect the dispersion of the refrigerant and therefore the size and duration of a flammable volume. Indoors, this can arise from infiltration, thermal convection currents and movement of personnel; outside, it can be caused by the wind.

The frequency of fatalities can indicate the severity of the secondary consequence. However, this study found that the consequence of ignition is very unlikely to cause overpressure or a thermal dose that could result in a fatality; therefore, the number of occupants is not applied, except in terms of their distribution, implying an average distance from the ignition event.

The size of the room can affect the build-up of gas concentrations and thus the occurrence of a flammable mixture within the room. Only one room size is opted for, a particularly small space where these types of appliances are normally located.

The Results for the relevant risk measures associated with the various control volumes are:

– Ducted split:

  The main observations concerning ignition frequency are:

  - Both AHU and condensing unit have extremely low ignition frequencies, corresponding to less than one ignition event per million-million units per year; such a frequency is so low it may be considered negligible.
  - Ignition within the supply duct is also negligible (on account that the only ignition source is another ignition event within an adjacent space).
  - Ignition within the room floor region is very small, less than one ignition event per 1,000 million units per year and as such also has no significance.
  - Ignition frequency within the space through which the interconnecting piping runs is fairly small (about two ignition events per 10 million units per year).
  - The control volume which experiences the highest ignition frequency is the area surrounding the condensing unit, with about three ignition events per millions units per year.

– Rooftop

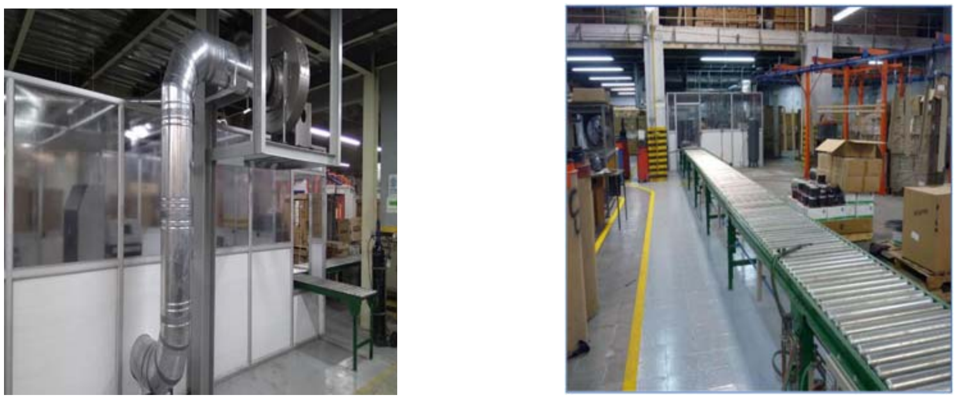
  The main observations concerning ignition frequency are:

  - Both AHU and condensing unit section have extremely low ignition frequencies, corresponding to less than one ignition event per million-million units per year; such a frequency is so low it may be considered negligible.
  - Ignition within both with the supply and return duct is also negligible (on account that the only ignition source is another ignition event within an adjacent space).
  - Ignition within the room floor region is very small indeed, about one ignition event per million-million units per year and as such is negligible.
  - The control volume which experiences the highest ignition frequency is the area surrounding the condensing unit, with about three ignition events per millions units per year.

4.2 Conversion and installation of equipment in the manufacturing line

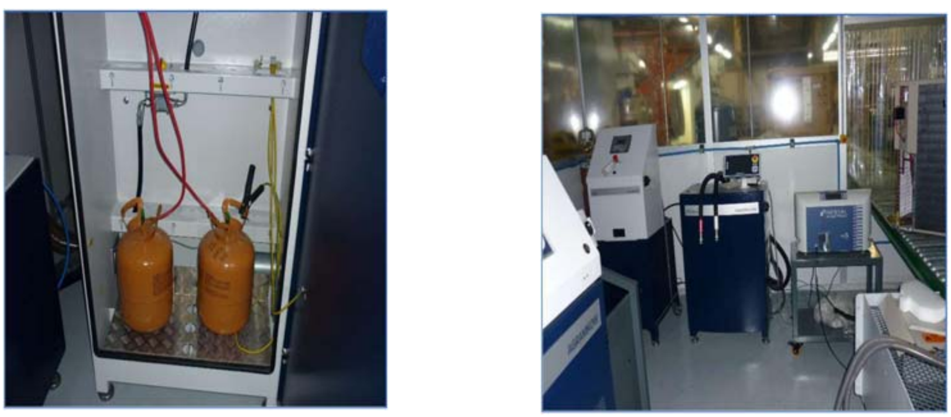
During project execution, the modifications and civil works required for the new infrastructure were made, and the new manufacture line of HC-290 air-conditioning equipment was installed. As a relevant fact, the new production line has an insulated chamber, which is five (5) meters apart from any other type of equipment that is part of the manufacturing plant. In addition to containing all the equipment that is part of the manufacturing process, this insulated chamber has a hopper located in the lower part of the conveyor belt, which has a hydrocarbon extraction and permanent air-renewal system (explosion-proof extractor). This system is energized at its maximum power by more than one hydrocarbon sensor (HC-290) located inside the hopper and insulated chamber. Additionally, the new line is powered by four (4) non-rechargeable 5.5 kg HC-290 cylinders (charger cylinder unit) located in the charging compartment within the insulated chamber.

Figure 4.18: Insulated chamber; parts assembly and welding line.



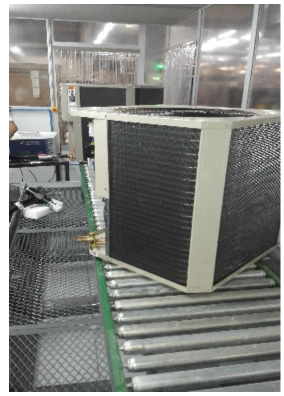
Source: Ozono Technical Unit, Colombia

Figure 4.19: Storage compartment of R290 refrigerant gas (capacity: 4 cylinders, 5.5 kg each); charge and leak test equipment.



Source: Ozono Technical Unit, Colombia

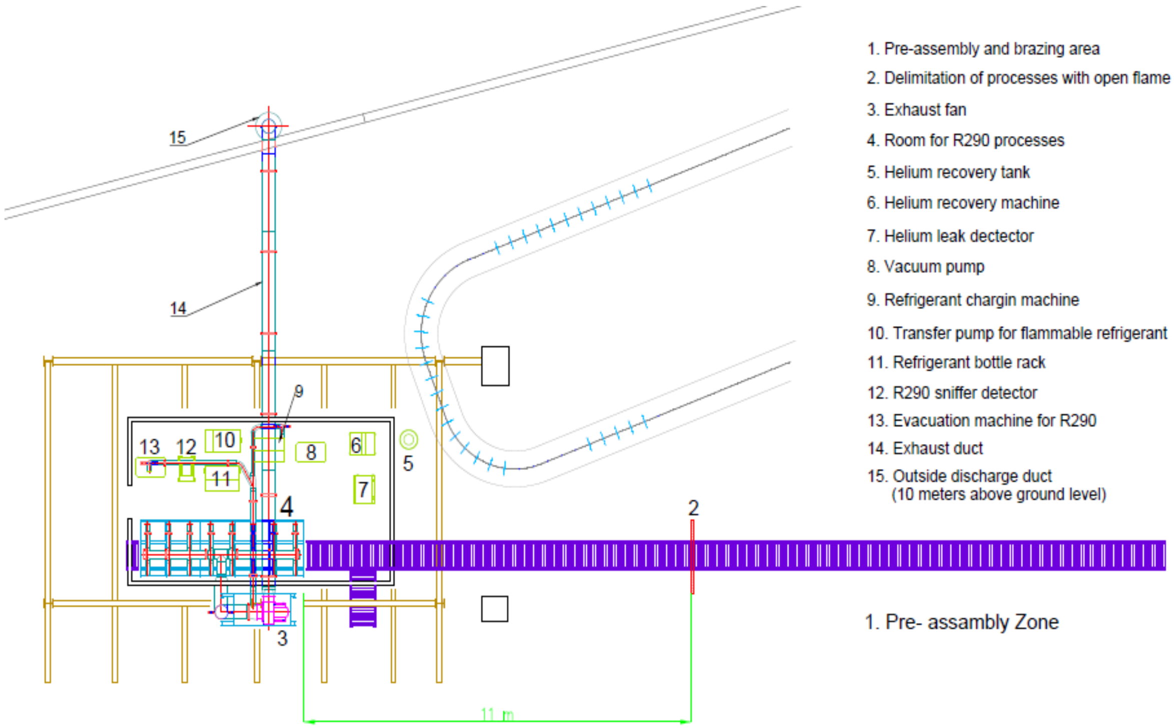
Figure 4.20: Hopper with sensors located inside the isolated chamber and below the HC-290 charging line.



Source: Ozono Technical Unit, Colombia

The several production stages were defined as follows: manufacture of the furniture or metal structure and heat exchangers according to the new designs (processes carried out in the metalwork area), assembly of components and welding (processes carried out in the new line at eleven (11) meters from the hydrocarbon charging area), and the helium-leak test, prevacuum, vacuum, HC-290 charging, and final leak test on the manufactured air-conditioning equipment (procedures performed in the insulated chamber), equipment quality control and packaging (packaging and storage area). It should be noted that any reprocessing due to a non-compliance will be carried out inside the isolated chamber with an independent equipment that performs the hydrocarbon discharge.

Figure 4.21: Drawing of the HC-290 AC manufacturing line



Source: Industrias Thermotar Ltda.

The maximum amount of units produced is twenty (20) units per day, which will depend on the market demand for new equipment.

4.3 Risk assessment of the manufacture line at Industries Thermotar Ltda

The risk assessment of the HC-290 line production process was developed through the provision of information by Industrias Thermotar, a stage carried out through meetings with key staff with extensive knowledge on the HC-290 project, followed by a field inspection to identify the risk conditions this new implementation will entail. This analysis was developed by sectioning the production process, where occurs the HC-290 charging operation, from the receipt of HC-290 cylinders as raw material. Next, we show the partitions of the process for our analysis. Additionally, the study was conducted based on the NFPA 54 National Fuel Gas Code.

- HC-290 receipt and storage operation.
- HC-290 recharge process and transfer systems.
- Risks posed by environmental conditions or neighbouring risks.

The result obtained from the risk assessment study showed that special attention should be paid to the risks surrounding the HC-290 recharging chamber, since the event or risk of fire adjacent to that chamber could have adverse consequences according to the matrices.

Followed by this risk, even though the risks of fire, gas leak and explosion are located in matrix number 2 of the study document or risk assessment (see Annex B), we consider the most critical event for the HC-290 recharge booth would be an explosion event with subsequent fire. It is estimated that the consequences of this event are not as serious as those of a fire inside the warehouse because it is assumed that the fuel load inside the HC-290 recharging cabin is much lower than the fuel load in the storage warehouse. However, we want to consider that, if the following events are combined, namely, explosion with subsequent fire and damage to the walls of the enclosure, and if the minimum distances of the finished product are not maintained, the fire may spread rapidly to other areas of the plant causing a major scale fire difficult to control with the current resources available for fire control and the current configuration of the plant, which has a single fire area. The technical adjustments made to the manufacture line for the elimination of possible risks identified in the evaluation are presented in section 5.3 (results analysis).

4.4 Training for servicing in installation during guarantee, post-sales services

The training courses included theory and practice and were developed based on the contents proposed by the international expert consultant. The topics of this content are:

– Theoretical module (based on the NTC 6828)
- introduction to refrigerants focused on the handling of hydrocarbon-type refrigerant (HC),
- safety aspects of hydrocarbon refrigerants (HC),
- characteristics of air conditioners, ducted vertical split condensing units with ducts and ducted package-type units that operate with HC-290,
- and safe handling of HC hydrocarbon refrigerants. .

– Practical module
- calculations referring to the verification of the minimum area and maximum charge that should be used for the installation of ducted vertical split condensing units with ducts and ducted package-type units that operate with HC-290,
- performance of leak test or leakage simulation in the equipment through sensors that verified whether the concentration exceeded the lower limit of flammability,
- and an activity on applying good refrigeration practices in the installation, maintenance and removal of these types of equipment devices.

The workshops held during the development of the demonstrative project were:

– Training, education and qualification workshop for technicians or companies of the sector responsible for the installation and maintenance of air-conditioning (AC) equipment with hydrocarbons. (Colombia, October 2017)
– Training and qualification workshop for the instructors or professors of SENA (National Learning Service of Colombia) in charge of the training of the refrigeration and air-conditioning technicians. (Colombia, April 2018)
– Scheduling of training and qualification workshops through the thirty-two (32) SENA centres in the country (Colombia, 2018).

4.5 Workshops for dissemination

The international expert consultant supported the dissemination workshops held during the development of the demonstrative project. The workshops focused mainly on disseminating the results obtained in each phase, which clearly explained issues related to the safe handling and proper management of the risks associated with the introduction of flammable refrigerants in the commercial air-conditioning sector. The following workshops stand out:

- Presentation on the progress of the demonstrative project in the I International Congress for the Management of Substances that Deplete the Ozone Layer and its Contribution to Climate Stability. (Colombia, Bogotá, September 2017)
- Virtual presentation at Atmosphere Business Case of Natural Shecco – Shecco. (Spain, October 2017)
- Dissemination workshop on the presentation of results from the demonstrative project for the use of HC-290 as an alternative refrigerant in the manufacture of commercial air-conditioning equipment - Industrias Thermotar Ltda. (Colombia, Barranquilla, February 2018)
- Full Paper "SAFE DESIGN OF R290 DUCTED AIR-CONDITIONING EQUIPMENT" submitted for publication at "13th IIR Gustav Lorentzen Conference on Natural Refrigerants"
- Presentation on the results obtained in the 13th IIR-GUSTAV LORENTZEN CONFERENCE ON NATURAL REFRIGERANTS. (Spain, Valencia, June 18, 2018).

5. ANALYSIS OF RESULTS

5.1 Designs and safety assessment of HC-290 based DACS

The analysis of results obtained in the development of the prototypes with designs for explosion protection yielded the following aspects and additional safety measures:

- Both DACS have been designed to minimise the likelihood of a flammable mixture forming around an area beyond the unit housing.
- The evaporator can also be approached, although significant effort is often needed to obtain marginally more than a negligible gain.
- The released masses and mass flow rates have been used within the main study to identify the most appropriate control strategies and estimate leak rates.
- A recommended mitigation measure to reduce the refrigerant charge released was to include a pump-down cycle in the designs, which will reduce the refrigerant charge that can be released into the conditioned enclosure. The above can be seen in the following table:

Table 5.1: Averaged release masses for different leak conditions*

Condition	Released mass (g)	Charge percentage
Shut-down (compr NRV only) → low side leak	420	40%
Shut-down (additional tight NRV)→ low side leak (ducted)	350	35%
Shut-down (additional tight NRV)→ low side leak (rooftop)	300	30%
Low side leak, LP switch → compressor terminates	540	65%
Low side leak, LP switch → shut-down	540	50%
Pump-down → low side leak	90	10%
Compressor off → high side leak	990	90%
Compressor oil de-gassing	20	2%

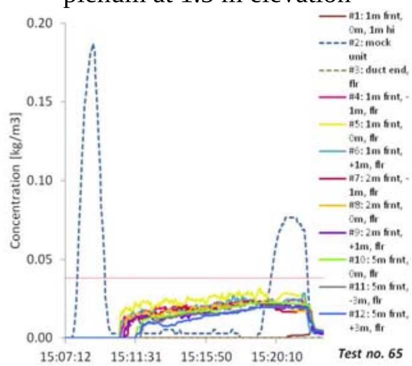
* Differences in the proportion of charge and actual mass are due to variations in charged amounts

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- The supplementary test with 1,000 g of HC-290 and a high leak rate of 100 g/min was again carried out and results are shown in Figure 5.2. A significant difference is seen here compared to the ducted split AHU case (Figure 5.1), where all sampling positions are well below LFL; still supporting the assumption that increased falling velocity from the higher level ultimately helps to disperse the release before falling to the room floor.

Figure 5.1: Mock elevated AHU and associated single ducting

Figure 5.2: 1000 g release at 100 g/min from ceiling level mock rooftop with plenum at 1.5 m elevation

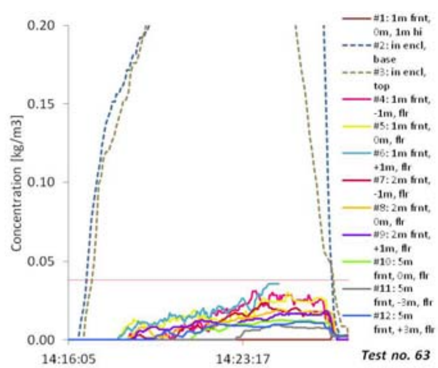


Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- Recommended mitigation measures for the AHU enclosure (low side): To this end, a plenum chamber was constructed around the outlet of the AHU so that any released refrigerant must flow over the upper lip before it flows across the room floor; this additional height is intended to help accentuate the dispersion of refrigerant as it enters the room. Four elevations of plenum chamber – 0.25 m, 0.50 m, 1.0 m and 1.5 m – were tested, as indicated in Figure 27.

Figure 5.3: Elevations of outlet plenum; 1.5 m

Figure 5.4: 350 g release at 50 g/min from ducted split AHU with plenum at 1.5 m elevation



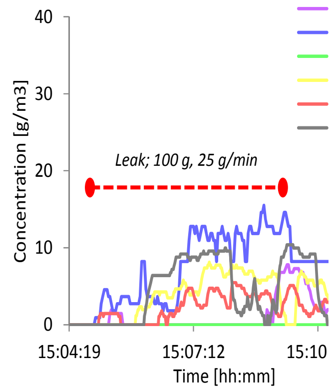
Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- As a result of the above, the company designed a new AHU, on which the previous tests were carried out in the same way. The results obtained were positive.

Figure 5.5: Typical contents of electrical panel

Figure 5.6: Example of evaporator fan motor

Figure 5.7: Example of fan blades



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

– The modifications defined for the removal of the SOI, namely, separating the electrical panel, will ensure that if a technician inadvertently fits an unsuitable component after the units has been installed, there remains no residual risk that it could act as a SOI to a refrigerant leak.

  The leak simulation test performed (pursuant to NTC 6228-2), showed that the revised construction prevents contact with a concentration exceeding 50% LFL.

Figure 5.8: Insulated electrical box

Source: Industrias Thermotar Ltda.

– Performance tests on a ducted split condenser unit prototype: Industrias Thermotar performed these tests pursuant to the ISO 5151: 2017 standard, which specifies the standard conditions and the test methods for determining the capacity and efficiency of air-cooled air conditioners and air-to-air heat pumps. Additionally, these tests are being corroborated by a certified laboratory in Colombia.

Table 5.2: Results of comparative testing of HCFC-22, R-410A and HC-290 5-TR AC equipment.

Parametros	Split central HCFC-22	Split central R-410A	Split central HC-290
Rated capacity (BTU / h)	60000	60000	60000

Supply (V)	440	440	440
Phases	3	3	3
Frequency (Hz)	60	60	60
Operating time (Hr)	4	3,5	3,5
Refrigerant charge (g)	2265	2404	1000
Temp. Dry Bulb Supply (ºF)	54,2	54,0	53,9
Relative Humidity (%)	78,7	79,2	80,1
Temp. Dry Bulb Return (ºF)	72,8	73,5	74,0
Relative Humidity Return (%)	51,8	51,9	50,1
Low pressure (PSIG)	65,0	135,0	65,0
Ambient Temp. (ºF)	94,0	95,0	96,0
High pressure (PSIG)	245,0	370,0	215,0
The input electrical power of compressor (W)	4475,0	4350,0	3780,0
Difference in the electrical power consumption between an conventional equipment HCFC-22 to a conventional equipment R-410A and a new equipment HC-290 (%)	0,0	-3,0	-15,6
Difference in the eletrical power consumption between an conventional equipment R-410A to conventional equipment HCFC-22 and a new equipment HC-290 (%)	2,9	0,0	-13,1

Source: Industrias Thermotar Ltda.

Lessons learned: Human Intervention in DACS is the most likely cause of accidents. Therefore, it was essential to ensure that the DACS design was such that technicians and other staff were given limited scope to interfere with the safety features associated with the HC-290 DACS. For this reason, designs have three identification measures and leak Reponses: Cabin or metal structure to isolate the electrical box and increase ventilation around the unit, pumping cycle (Pump Down) and ultrasound sensor. Moreover, it is critical for the national infrastructure to be prepared to minimise the possibility of untrained or non-competent technicians involved in the installation, servicing and decommissioning of HC-290 DACS.

5.2 Manufacture line for production of air-conditioning (AC) equipment with HC-290

The new installed production line has the safety measures required for the safe handling of the hydrocarbon refrigerant. These measures were supported by both the company in charge of supplying the equipment for the manufacture of the ACs and the risk assessment carried out on the new line. Moreover, the training provided to the operators in charge of the equipment is an important step to apply good manufacturing practices in the company Industrias Thermotar Ltda.

Learned lessons: There are already suppliers of equipment to manufacture refrigerators and air conditioners with flammable refrigerants in the international market. But the most important feature that should be considered for the assembly of this line are the space and civil works required within the facilities; therefore, using an insulated chamber contributes to the safe handling of this flammable refrigerant gas within the company.

Once the suggested recommendations have been presented through the risk assessment study, Industrias Thermotar Ltda. made the necessary technical modifications to correct the deficiencies identified. Consequently, a follow-up exercise of recommendations is carried out once more to check compliance with the standards; this activity is a duty of the specialist firm dedicated to implement these types of projects.

The most important corrections are, among others:

Figure 5.9: Civil and technical adaptations to the exterior and interior of the storage room (ventilation system)

Source: Engrin de Colombia SAS (SURA)

Source: Engrin de Colombia SAS (SURA)

Figure 5.10: Introduction of restrictions to the storage of finished product inside the plant in general

Source: Engrin de Colombia SAS (SURA)

Figure 5.11: Installation of a pedestal with a safety chain to prevent the fall of the Helium cylinder.

Source: Engrin de Colombia SAS (SURA)

Figure 5.12: Additional sensor installations in the HC-290 recharging chamber.

Source: Engrin de Colombia SAS (SURA)

Source: Engrin de Colombia SAS (SURA)

Learned lessons: The risk assessment study must consider other stages not in the manufacturing line such as: storage of non-returnable cylinders with hydrocarbon as raw material, and storage of the final product. On the other hand, to increase the safety level of the manufacturing line, it is feasible to consider installing other sensors in addition to the current equipment sensors of the manufacturing line, as well as, consider the explosion-proof lamps within.

5.4 Training for servicing in installation during guarantee, post-sales services

This phase is the most important challenge posed by the demonstrative project, and should be considered as a permanent phase in the country; to this end, it must be included in the different programs related to the training and qualification of the refrigeration and air-conditioning service sector.

The follow-up plan prepared by Industrias Thermotar Ltda. partially supports the challenge faced by the country in relation to the training and education of technicians in the service sector. This plan is part of the post-sales strategy that should be implemented by the technical services of HC-290 AC systems installation, maintenance and repair.

Having a public learning system in the country, such as the SENA centres, makes it possible to train the sector not only in the management of hydrocarbon refrigerant gases, but also in the handling of HFOs or other refrigerant with some hazardous attributes.

Learned lessons: To face the training and education of the service sector in the best way possible, it is necessary to have a network of training or education centres that can certify the sector's technicians in the safe handling of hydrocarbons and other refrigerant gases with medium flammability. Additionally, it is necessary to update or adopt international standards regarding the safety and environmental requirements necessary in refrigeration systems and heat pumps.
The follow-up plan is binding not only on Industrias Thermotar Ltda., but also on the users or customers who acquire this equipment as they must guarantee the safe handling and proper management of risks associated with the introduction of these flammable refrigerants in the commercial air-conditioning sector. The strategy or plan includes the monitoring and follow-up of the first units installed in the commercial sector.

5.5 Workshops for dissemination of results

The dissemination workshops communicated and fully presented the main results obtained through the demonstrative project. Likewise, the paper or study prepared in conjunction with the international expert consultant represents the positive and significant results that influence technical aspects in the technological development related to the use of refrigerant gases with insignificant GWP and zero ODP.

6. INDUSTRIAL HYGIENE & SAFETY

The risk assessment study carried out on the manufacture line of HC-290 AC, not only included the manufacture line but also the plant in general, which is why the emergency plan of the security management system of Industrias Thermotar Ltda. was complemented by including the control measures for responding to emergencies caused by the handling of HC-290, as well as the safety measures for prevention of combustion and explosions.

7. INCREMENTAL COSTS

The incremental costs of the demonstrative project are divided into incremental capital costs and incremental operating costs. Within the incremental capital costs, the costs associated with the activities carried out were discriminated taking into account the economic contributions made by Industrias Thermotar Ltda, as well as those defined in the UNDP Project COL101294.

For the incremental operating costs, the 5 TR DACS models that work with HCFC-22 and R-410A were compared to the new HC-290 designs.

7.1 Incremental capital cost

Table 7.1 Incremental capital cost.

ITEM	DESCRIPTION	FINANCED BY	UNIT	QUANTITY	UNIT VALUE (USD$)[13]	SUB - TOTAL (USD$)
1.0	**PRELIMINARY**					
1.01	Preliminary documentation - presentation of the demonstrative project, analysis of risk vulnerability in the production plant, description and assessment of the project impacts.	THERMOTAR	-	1	$1,620.59	$1,620.59
1.02	Project Engineer - 30 months (7200 Hr)	THERMOTAR	HOUR	7200	$12.73	$91,669.70
					SUBTOTAL	**$93,290.29**
2.0	**INTERNATIONAL CONSULTANT**					
2.01	Hiring of international expert (Travel and commissions)	PROJECT[14]	DAYS	83	$870.00	$73,080.00
					SUBTOTAL	**$73,080.00**
3.0	**DESIGN, CONSTRUCTION AND PROTOTYPE TESTING**					
3.01	Advisory by the design department, intervention by the production and quality department / SST	PROJECT	HOUR	3500	$10.91	$38,192.07
3.02	Constructions or manufacture of prototypes and final designs of DACS for HC-290	PROJECT	UNIT	18	$1,849.16	$33,284.83
3.03	HC-290 Refrigerant Cylinder X 5.5 KG / 12.1 LB	THERMOTAR	UNIT	42	$67.53	$2,836.26
3.04	Instrumentation equipment for prototype testing, supplies for conducting safety tests, drills and performance testing in prototypes	THERMOTAR	-	1	$18,486.49	$18,486.49
3.05	New line of compressors for tests with HC-290 Models ZH13KCU imported by air	THERMOTAR	UNIT	10	$891.23	$8,912.33
3.06	Testing of prototypes in a national certified laboratory (transport, accessories and test costs)	THERMOTAR	UNIT	2	$2,309.93	$4,619.86
3.07	Testing of electric motors in laboratories (Shipping costs, nationalization, test)	THERMOTAR	UNIT	2	$2,673.70	$5,347.40
					SUBTOTAL	**$111,679.24**
4.0	**PRODUCTION PLANT ADAPTATIONS**					
4.01	Adaptations to conveyor rack with rollers	PROJECT	MTS	30	$127.32	$3,819.57

[13] Exchange rate used for calculations: 2,749 $US / $COP

[14] PNUD Colombia. 2016. PRODOC, Output ID 000101294 Project ID 000101294. Demonstration project for the use of HC-290 (propane), as an alternative refrigerant in the manufacture of commercial air conditioning equipment at Industrias Thermotar Ltda.

4.02	Electrical restructuring of the transport rail, grounding, connection accessories and labour, paint work of production plant, redistribution of oxyacetylene, nitrogen and compressed air sources, and additional adjustments recommended in the risk assessment	PROJECT	-	4	$2,273.55	$6,857.04
4.03	87 m^2 cabin construction for the HC-290 charging area	PROJECT	-	1	$6,129.50	$6,129.50
4.04	Ductwork and exhaust channels for flammable gases. Exhaust pipe for flammable gases that go from the extraction channel to the Explosion Proof extractor motor.	PROJECT	-	1	$8,695.16	$8,695.16
4.05	HC-290 cylinder storehouse adaptations: Extraction system (fan, ducts and support), propane gas sensors, and integrated security alarm system	PROJECT	-	1	$5,951.26	$5,951.26
					SUBTOTAL	**$31,452.53**
5.0	**ACQUISITION OF MACHINERY AND EQUIPMENT FOR THE HC-290 PRODUCTION LINE, INSTALLATION AND MAINTENANCE**					
5.01	Helium leak test system with Sniffer detector and Helium recuperator	PROJECT	-	1	$63,320.93	$63,320.93
5.02	Vacuum pump with process controller	PROJECT	-	1	$6,085.39	$6,085.39
5.03	Evacuation and charging equipment for flammable refrigerant (HC-290)	PROJECT	-	1	$40,614.60	$40,614.60
5.04	Equipment for safe discharge and disposal of flammable refrigerant (HC-290)	PROJECT	-	1	$11,218.88	$11,218.88
5.05	HC-290 detector equipment for leakage test in repair and rework area	PROJECT	-	1	$18,188.18	$18,188.18
5.06	Integrated safety monitoring and control system for flammable gases	PROJECT	-	1	$6,980.64	$6,980.64
5.07	Ventilation system for flammable gases (Without ductwork)	PROJECT	-	1	$10,000.00	$10,000.00
5.08	Supplies for spares, assembly and equipment operation	PROJECT	-	1	$4,284.70	$4,284.70
5.09	Pre-engineering design for civil works in plant	PROJECT	-	1	$5,610.00	$5,610.00
5.10	Installation, start-up and training in handling of equipment.	PROJECT	-	1	$4,950.00	$4,950.00
5.11	Flammable refrigerant pneumatic transfer pump	PROJECT	-	1	$10,565.00	$10,565.00
5.12	Accessories for equipment handling in production process	PROJECT	-	1	$2,132.85	$2,132.85
5.13	Tools and accessories for copper tubing coupling by pressure	PROJECT	-	1	$8,065.67	$8,065.67
5.14	Other expenses (taxes, expenses at destination, freight certificate, customs agent fees)	PROJECT	-	1	$31,807.16	$33,869.71
					SUBTOTAL	**$225,886.55**
6.0	**TRAINING AND QUALIFICATION OF ENGINEERS, TECHNICIANS AND OPERATORS**					
6.01	Training materials for training courses and prototype equipment for manipulation during training, training material	PROJECT	-	1	$1,911.60	$1,911.60
6.02	Transport and missions of participants	PROJECT	-	6	$974.33	$5,846.00
6.03	International Consultant (Training)	PROJECT	DAYS	6	$330.00	$1,980.00
6.04	National consultant monitoring and development of BPR workshops	PROJECT	YEAR	1	$16,342.86	$16,342.86
6.05	National training strategy for technical training	PROJECT	WORKSHOP	7	$2,000.00	$14,000.00
6.06	Preparation of the follow-up plan	PROJECT	STUDY	1	$4,300.00	$4,300.00
6.07	Follow-up plan implementation. 6 months, first 30 units manufactured.	THERMOTAR / PROJECT	UNIT	30	$187.00	$33,660.00
					SUBTOTAL	**$78,040.46**
7.0	**RISK ASSESSMENT OF HC-290 AC MANUFACTURE LINE**					

7.01	Document containing the safety procedures related to the handling of the R290	PROJECT	STUDY	1	$1,820.00	$1,820.00
7.02	Certificate or document evidencing the risk assessment study carried out on the manufacture line	PROJECT	STUDY	1	$2,450.00	$2,450.00
					SUBTOTAL	**$4,270.00**
8.0	**DISSEMINATION WORKSHOPS**					
8.01	Dissemination workshops (International tickets, travel expenses, related documentation)	PROJECT	-	3	$32,568.00	$32,568.00
					SUBTOTAL	**$32,568.00**
9.0	**ADDITIONAL GENERAL COSTS**					
9.01	Other expenses, general documentation (Stationery)	THERMOTAR	-	2	$591.12	$591.12
9.02	Transport and travel expenses of project engineer (Training and project presentations)	THERMOTAR	-	1	$1,218.62	$1,218.62
9.03	Signs, warnings and banners for presentations and training	THERMOTAR	-	1	$1,136.78	$1,136.78
					SUBTOTAL	**$2,946.52**
					TOTAL (USD)	**$653,213.60**

Source: Industrias Thermotar Ltda. and Ozono Technical Unit, Colombia

7.2 Incremental operating cost

– Ducted split condensing units:

Table 7.2 Incremental operating cost. Split unit 5 TR

Incremental Operating Cost DACS: Split unit 5 TR (8 mm-diameter copper exchanger within the condenser)						
	Incremental cost[15] by platform (USD $ per unit)	**Cost with R-410A**	**Cost with HCFC-22**	**Cost with HC-290**	**Difference**	
					R-410A vs R290	**HCFC-22 vs HC-290**
Air-Handler unit	Cabinet (Structure)	$165.51	$165.51	$190.98	**$25.46**	**$25.46**
	Refrigerant charge	$0.00	$0.00	$0.00	**$0.00**	**$0.00**
	Main operation components (Compressor, condenser motor, blower motor, blower, blade, copper pipe, filter drier, pressure switches, solenoid valves)	$412.15	$412.15	$424.15	**$12.00**	**$12.00**
	Electric components and accessories for safety, control and power	$15.46	$15.46	$27.28	**$11.82**	**$11.82**
	Refrigerant cost (Cost per Pound)	$0.00	$0.00	$0.00	**$0.00**	**$0.00**
Condenser unit	Cabinet (Structure)	$110.95	$110.95	$110.95	**$0.00**	**$0.00**
	Refrigerant charge	$38.20	$20.01	$11.46	**- $26.74**	**- $8.55**
	Main operating components (Compressor, condenser motor, blower motor, blower, blade, copper tubing, filter drier, pressure switches, solenoid valves)	$771.19	$740.27	$879.23	**$108.04**	**$138.96**
	Electrical components and accessories for safety, control and power	$15.30	$15.30	$42.13	**$26.83**	**$26.83**
	Refrigerant cost (Cost per Pound)	$2.91	$1.15	$1.89	**-$1.02**	**$0.75**
TOTAL		**$1,531.67**	**$1,480.80**	**$1,688.07**	**$156.40**	**$207.28**

Source: Industrias Thermotar Ltda.

Manufacturing a 5-TR split unit equipment with HC-290 costs 10% more than manufacturing a 5-TR split unit with R-410A. This increase is mainly due to the cost associated with the compressor, and other such as the electric components and accessories for safety, pressure switches and solenoid valves.

[15] Exchange rate used for calculations: 2,749 $ US/$ COP

– Rooftop unit with duct:

Table 7.3 Incremental operating cost. Rooftop unit 5 TR

Incremental Operating cost DACS: 5 TR Rooftop unit (8 mm-diameter copper exchanger within the condenser)					
Incremental cost by platform (US $ per unit)[16]	**Cost with R-410A**	**Cost with HCFC-22**	**Cost with HC-290**	**Difference**	
				R-410A vs R290	**HCFC-22 vs HC-290**
Cabinet (Structure)	$245.54	$245.54	$265.55	**$20.01**	**$20.01**
Refrigerant charge	$38.20	$20.01	$11.46	**- $26.74**	**- $8.55**
Main operation components (Compressor, condenser motor, blower motor, blower, blade, copper pipe, filter drier, pressure switches, solenoid valves)	$1,089.49	$1,094.94	$1,218.62	**$129.14**	**$123.68**
Electric components and accessories for safety, control and power	$63.66	$63.66	$116.41	**$52.75**	**$52.75**
Refrigerant cost (Cost per Pound)	$2.91	$1.15	$1.89	**-$1.02**	**$0.75**
TOTAL	**$1,436.89**	**$1,424.15**	**$1,612.04**	**$175.15**	**$187.89**

Source: Industrias Thermotar Ltda.

Manufacturing a 5-TR split unit equipment with HC-290 costs 12% more than manufacturing a 5 TR split unit with R-410A. This increase is mainly due to the cost associated with the compressor, and other such as: The electric components and accessories for safety, pressure switches and solenoid valves.

8. CONCLUSIONS

[16] Exchange rate used for calculations: 2,749 $ US/$ COP

The demonstrative project complied with the objectives that were proposed by its execution. The following conclusions no only show the general inferences but also include specific conclusions

General conclusions:

- HC-290 based DACS have been developed within the project to demonstrate the safe use of HC-290 (propane) as a low GWP refrigerant in the commercial production of air-conditioning. Commercial production has not yet begun, however, there are a few prototype DACS already installed and are being monitored. Through QRA and using – typically pessimistic – assumptions about the installation and operational conditions, the developed products can be considered as **"safe".**
- The only DACS developed on HC-290 are the 17.5 kW ducted split and rooftop models, with the QRA carried out on both of these. The same concepts and technical feature will be applied equally to these smaller units as for the 17.5 kW unit, thus all designs are feasibility.
- Throughout the development process prototypes were regularly checked for performance. The most recent findings indicated the same cooling capacity as the baseline DACS and a lower electrical power consumption, thus giving a higher COP[17].
- Selections of specific design features have been developed to help mitigate flammability risk. Several of these incur incremental operating costs. This increase is low (10% more than R-410A based DACS) and by the future its reduction depends on the supply in the market of the differents parts, mainly the compressor (HC-290).
- Necessary security features and conditions have been integrated into the new DACS designs. However, addressing safe handling and good flammability risk management is predominantly achieved through company-wide and national technician training, assessment, certification and registration schemes and associated changes to company conditions of sale and warrantee agreements; this is beyond the remit of product design and development.
- According to current design, each kg of HCFC-22 can be replaced with approximately 0.4 kg of HC-290 in any DACS of broadly the same design and construction. For this reason, Industrias Thermotar Ltda. with the closure of its production line of AC equipment with HCFC-22 is removing 13.75 metric tons of HCFC-22 from national consumption rates.

Specific conclusions:

- The HC-290 AC models (DACS) developed meet the technical requirements related to the tightness of the system and the removal of ignition sources. This is based on the testing carried out on mass of refrigerant released, leakage rates and concentrations of HC-290 inside and around the units, and along the pipelines.
- The technical modifications implemented in the HC-290 AC models are based on the integration of a leak-identification and response system, which consisted of: redesign of the furniture or metal structure to insulate the electrical box, increase of the ventilation around the unit, and installation of a pump cycle (Pump Down) and an ultrasonic sensor in the condenser unit and evaporator respectively.
- The most representative change in relation to the design, in the HC based model, was in the handling unit (AHU). The air intake opening was located laterally, one meter (1 m) above the floor level.
- The reduction of the refrigerant charge in the HC-290 AC model was significant. The charge of HC-290 for the largest unit (5 TR split condensing unit, with 8 mm tube diamenter for the condenser and 3 meters of pipe) was 1000 grams.

[17] COP: Coefficient of performance

- When leaks occur in the AC designs, the pump down cycle reduces the load within the handling unit (within the conditioned enclosure) to approximately 10% (100 grams) of the total equipment load.
- In relation to energy consumption, an HC-290 5TR split unit equipment (HC-290 scroll compressor) consumes 13.1% less energy (kWh) than a similar R-410A unit.
- Manufacturing a split 5-TR unit with HC-290 costs 10% more than manufacturing a split 5-TR unit with R-410A; likewise, manufacturing a 5-TR rooftop unit HC-290 costs 12% more than manufacturing a 5-TR rooftop unit with R-410A. This increase is mainly due to the cost associated with the compressor and other such as the electric components and accessories for safety, pressure switches and solenoid valves.
- The AC equipment manufacture line with HC-290 has a production capacity equivalent to twenty (20) units per day.
- The helium tightness test that is performed inside the production chamber will largely reduce the non-conformities of the finished product.
- The risk assessment carried out on the HC-290 equipment manufacture line considered the analysis of the most representative impacts including storage, internal transport and HC handling in the refrigerant charging or precharging area. In essence, the new line has the protection measures that the foresaid line must have in order to guarantee its correct operation before, during and after each activity to recharge DACS with HC-290.
- The HC-290 storage area and insulated chamber have the necessary safety measures to identify and eliminate any leaks arising within these spaces. These measures are linked to the electrical lines of the manufacturing plant, so that the manufacturing plant is de-energized once the explosion-proof extractors are activated.
- The demonstrative project had a training and education strategy focused on the service sector. Initially it was intended for the companies and technicians that are part of Industrias Thermotar Ltda. staff, responsible for the installation and maintenance of company equipment, but the strategy is now permanent with a national scope.
- NTC 6828 defines the steps that must be considered for the installation and maintenance of RAC equipment with refrigerants that have some hazardous attributes, such as A3 (HC-290). The service sector must calculate a minimum area or maximum charge required before installing these new designs or equipment with flammable or toxic refrigerants.
- The follow-up plan developed by Industrias Thermotar Ltda. will support the monitoring and control strategy for the first units manufactured and reduce the risks associated with the use of hydrocarbon refrigerant.

9. RECOMMENDATIONS

9.1 Execution recommendations

It is necessary to consider a longer time for the development of this kind of demostrative project that include the re-design of equipment for the use of flammable refrigerants in the RAC sector. Design of protypes requires an iterative risk assessment and risk analysis, for this reason it is suggested to take in account at least two years for this activity.

9.2 Technicals recommendations

According to the report that was developed by International Expert it is necessary to carry out the following technical aspects:

- Re-calculation of electric equipment fault probability based on service database (DC).
- Estimate the probability that technicians may not replace one or more base panels on the new. AHU following a service or would not follow instructions that air return ducts should be installed at least 1 m above the floor.
- Explore redesign alternatives for finned-tube evaporator for further charge reduction (DC).
- Perform additional measurements to demonstrate effectiveness of ultrasonic leak detection.
- Confirmation on the type of internal overload protectors used on the blower fan motors, and compliance certificate for fan motors to IEC 60079.
- Compliance certificate for low and high pressure switches to IEC 60079.
- More comprehensive assessment of the latest factory performance testing.

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ANNEX A. Designs and safety assessment of Thermotar AC units for HC-290 application – Interim Report.

ANNEX B. Risk assessment studies

For	**Leydy Maria Suarez Orozco, Unidad Técnica Ozono, Ministerio de Ambiente y Desarrollo Sostenible.**
Project	**UNDP Project COL101294: Demonstration of HC-290 (propane) as an alternative refrigerant in commercial air-conditioning manufacturing at Industrias Thermotar ltda.**
On	**Designs and safety assessment of Thermotar AC units for application of R290 – Part 1 and Part 2 (integrated) – interim report.**
Date	15th April 2018; DRAFT v2

Daniel Colbourne, tel: +44 (0)1789 268285, email: d.colbourne@re-phridge.co.uk

Contents

Summary

Thermotar produce a wide range of air conditioning equipment. Amongst these are two product groups: rooftop “packaged “ducted units and centralised ducted split (comprising and condensing unit and air handling unit). These units currently use R22. The intention of the current project is to switch them to use R290. Since this represents a move from a non-flammable to a flammable refrigerant, it is necessary to carry out a product assessment accounting for the flammability characteristics of R290 to determine the necessary changes to the design, construction and operation or the units and associated changes to the manuals to help minimise the risk. Whilst there are several models, the work is focussed on the largest (i.e., “5 TR”) of each centralised split system (condensing unit plus air handling unit) and rooftop unit and the findings then extrapolated to the smaller models (i.e., “2 TR” and “3 TR”) in the range.

The main task is to consider the unit in terms of design and construction for explosion protection. Additional measures are proposed for leak tightness, such as those within NTC 6552 and EN 1127-1, in order to ensure the system is technically durably tight. Further, tests were carried out so as to determine the releasable mass of refrigerant under various operating conditions. Based on these releasable masses and the possible operating conditions, the likely concentrations arising from a leak were evaluated, first by testing and then numerically to extrapolate to non-tested conditions. Avoidance of flammable concentrations both within the occupied space and surrounding the external part of the unit is then achieved by adopting the necessary flammability mitigation measures and installation constraints. Assessment of potential sources of ignition (SOIs) is also carried out for the unit and leak simulation testing as part of an area classification is used to support this. Using quantitative risk assessment (QRA) the likelihood and severity of possible consequences – overpressure, thermal radiation, secondary fire and fatality – is also evaluated under the main operating conditions in order to ensure they are not unacceptably high and also to determine the effectiveness of the mitigation measures.

In addition to the general approach of safe design and construction, the unit is also assessed for conformity against NTC 6228, specifically for the requirements that are directly related to refrigerant flammability.

Disclaimer

1. Introduction

1.1 Overview

Thermotar produces a range of packaged and centralised ducted air conditioning systems (DACS). These currently use R22, but the intention is to switch them to use R290. R22 and other alternatives such as R410A and R32 have high GWPs (Table 1). Whilst R290 has a negligible GWP, it is a flammable refrigerant, which introduces new considerations into the design, construction and handling of refrigeration systems.

Table 1: Basic information on R22, R290 and other alternatives[1]

R-number	R22	R410A	R32	R290
Type	Hydrochlorofluorocarbon (HCFC)	Hydrofluorocarbon (HFC)	Hydrofluorocarbon (HFC)	Hydrocarbon (HC)
Global warming potential (GWP)	1800	2100	700	5
Lower Flammability Limit (LFL)	(non-flammable)	(non-flammable)	13% vol.	2.1% vol.

In order to place a product on the market – such as a DACS – it is necessary to ensure that it is safe to do so and complies with applicable safety rules. Whilst it is assumed that the baseline DACS designs (i.e., that currently use R22) already comply with the relevant requirements related to electrical, pressure and mechanical safety, additional safety assessment is required for flammability. As such it is necessary to re-evaluate the DACS with regards to any requirements that deviate from the R22 model due to different properties and characteristics of the new refrigerant (R290) and associated parts and components.

1.2 General approach

The work described in this report follows the sequence summarised within Figure 1. Essentially this is based on an iterative risk assessment/risk analysis approach, where each stage ultimately leads to a revaluation and refinement in the design of the DACS under development. Accordingly, it should be recognised that the process is one of continuous development and it is (should be) expected that further improvements are always underway.

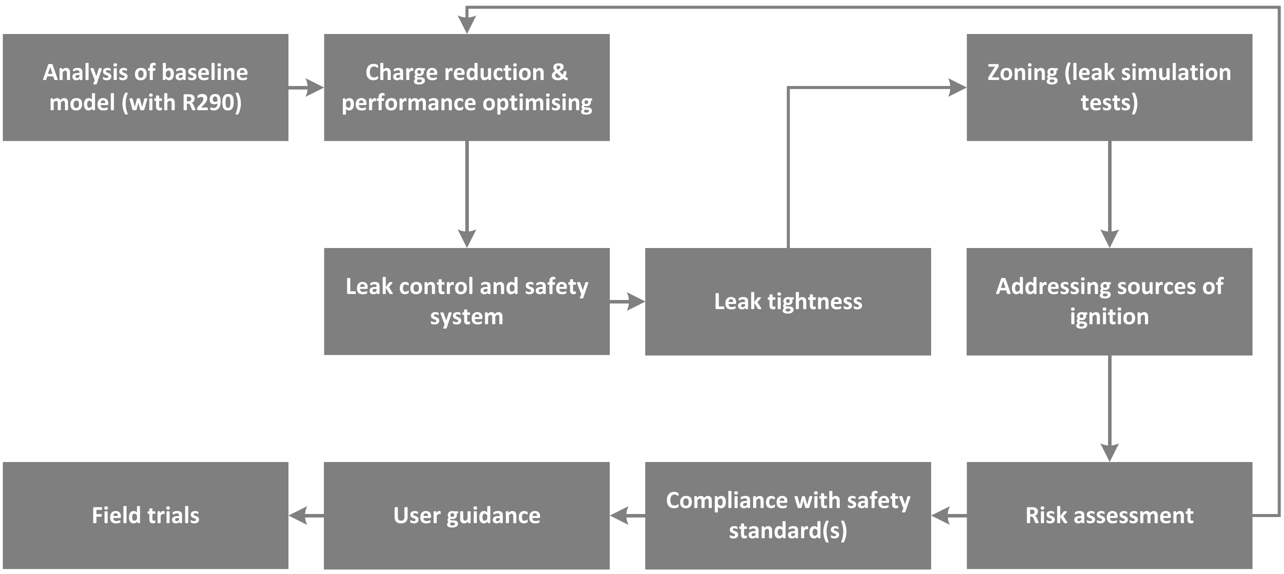


Figure 1: Systematic approach for safe design of DACS

[1] Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 2014 Assessment. UN Environment Programme (UNEP), Ozone Secretariat, Nairobi, http://ozone.unep.org/Assessment_Panels/TEAP/Reports/RTOC/RTOC-Assessment-Report-2014.pdf

Throughout this process several stages of prototype for both ducted split and rooftop units have evolved, as summarised below:

Stage 1	R22 system charged with R290
Stage 2	Modifications to electrical components and enclosures/panels
Stage 3	Optimised condenser and inclusion of liquid line solenoid valve (LLSV) and additional non-return valve (NRV)
Stage 4	Revised electrical components and enclosures/panels and AHU return inlet construction
Stage 5	R290 compressor
Stage 6:	Inclusion of leak detection system

The final design and quantitative risk assessment is based on the stage 6 prototype.

1.3 Product description

The DACs under consideration are packaged or centralised/split units that are used primarily for residential and commercial applications, where the conditioned air is supplied via ducting. The packaged unit is a single factory-sealed, pre-charged system. The centralised system comprises a separate indoor air handling unit and an outdoor condensing unit. Pictures of the DACs under consideration in this study are shown in Figure 2.

Figure 2: Picture of the 5TR packaged ducted unit (left), and the centralised split unit; air handling unit (centre) and condensing unit (right) under consideration

The DACS specifically addressed under this project are identified in Table 2, although the primary focus has been in the 17.5 kW units; if the safety issues associated with the largest units can be satisfied then applying R290 to the smaller units should be less of a challenge.

Table 2: Models to be addressed for application of R290

Capacity	Centralised ducted split	Packaged rooftop
7 kW (2TR)	CV024 + FCD024	EPAC-024
10.5 kW (3TR)	CV036 + FCD036	EPAC-036
17.5 kW (5TR)	CV060 + FCD060	EPAC-060

1.4 Installation characteristics

The two DACS are subject to notably different installation characteristics.

The ducted split condensing unit will be placed outside, either on a room or on the ground. Its AHU will be positioned inside the building, typically within a dedicated closet. Figure 3 shows typical examples. Refrigerant piping (suction and liquid lines) will be connected between the two. The standard piping length is 5 m and the maximum length of interconnecting piping does not normally exceed 20 m.

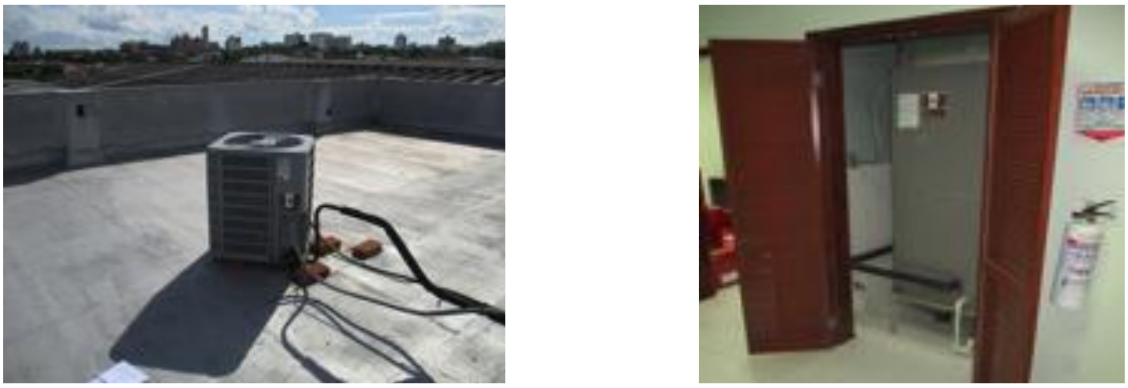


Figure 3: Typical installation example of ducted split DACS; condensing unit (left) and AHU (right)

Supply ducting is taken from the AHU and fed into the room(s) to be supplied. Sometimes there are return ducts; otherwise the AHU return inlet is open to the room(s) via gaps in the closet envelope. Figure 4 illustrates the various installation combinations for ducted split systems.

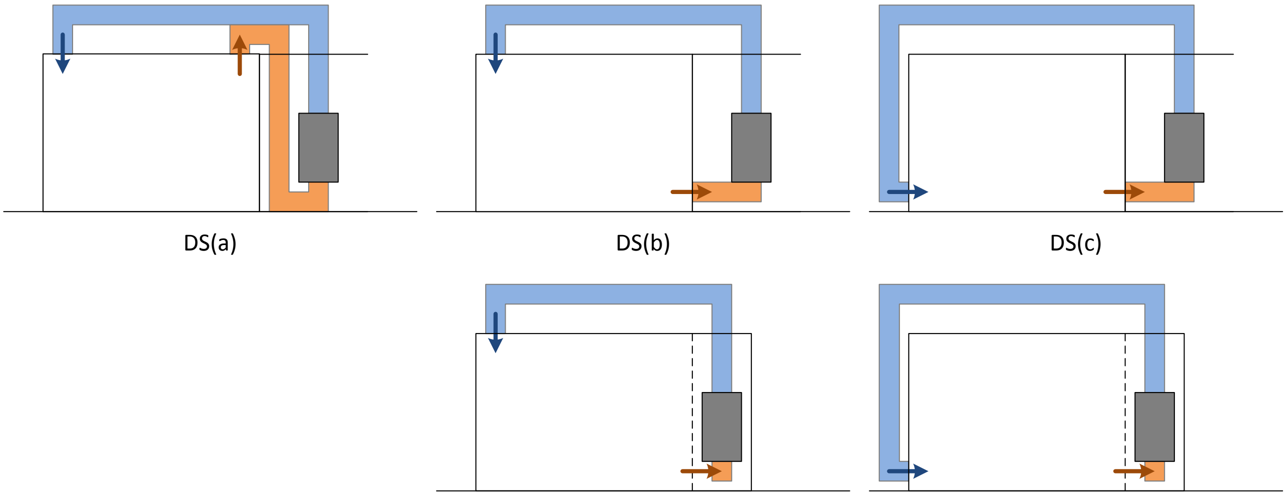


Figure 4: Typical example of duct paths for the ducted split DACS

Rootop DACS are installed outside, against either at ground level or on a roof. Flow and return ducting is installed from the unit to the room(s) to be served. Ducting may be singular or split off to multiple duct outlets feeding one or more rooms. A return duct from the room(s) supplies air back into the DACS. Figure 5 gives a typical example for the installation of the DACS.

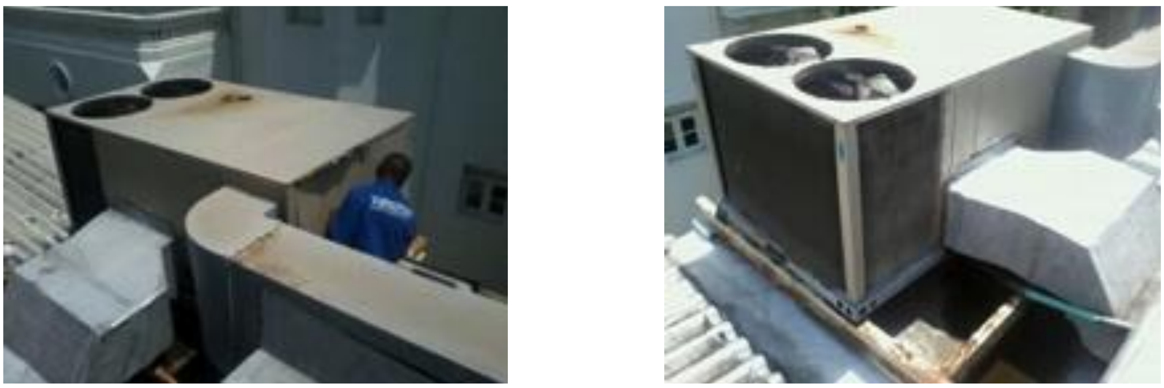


Figure 5: Typical installation example of rooftop units

Examples of the ducting configurations for rooftop DACS are indicated in Figure 6.

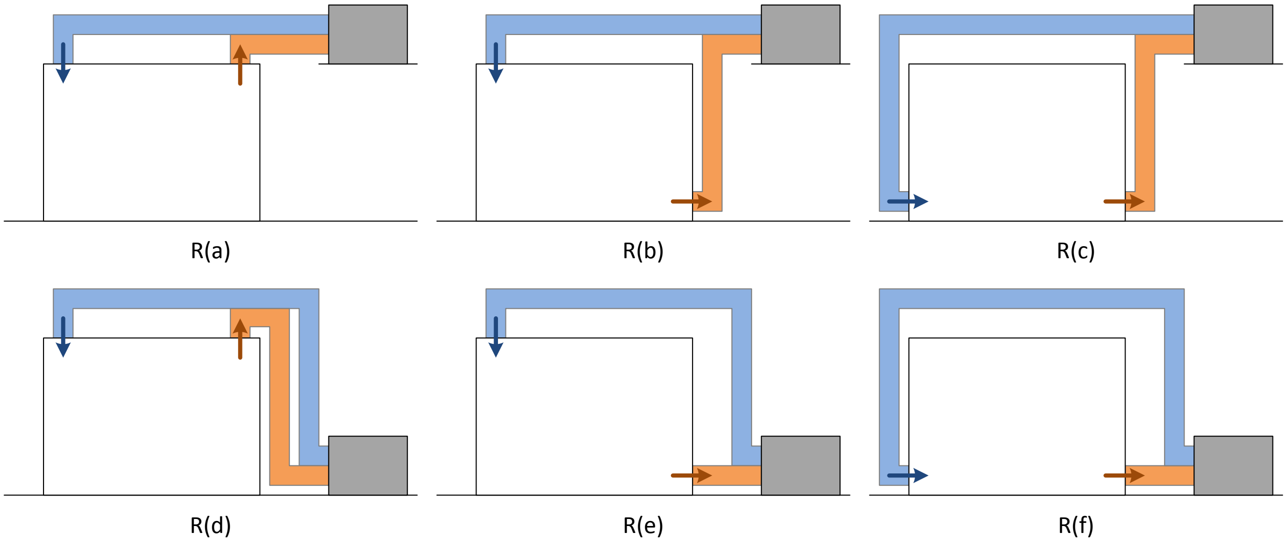


Figure 6: Typical example of duct paths for the rooftop DACS

It is essential that all possible configurations are evaluated from a flammability safety perspective, such that even the most vulnerable arrangements will not pose an adverse risk.

1.5 Technician and refrigerant handling practices

Human intervention in DACS is the most likely cause of accidents. Therefore it is essential to ensure that the design of the DACS is such that technicians and others are given limited scope to interfere with the safety features associated with the R2900 DACS. Moreover, it is critical that the national infrastructure is prepared to minimise the possibility of untrained or non-competent technicians being involved with the installation, servicing and decommissioning of R290 DACS.

2. Design and construction for explosion protection

2.1 Introduction

The design and construction of the DACS must be handled with due considerations to the general approaches for explosion protection and thus minimisation of risk. There are several basic principles, as identified in EN 1127-1, where the focus is on prevention of explosion (as opposed to reduction of consequences). In principle, this requires:

- Minimise the amount of flammable material
- Avoid or reduce explosive atmospheres
- Avoid all effective ignition sources

In practical terms, the following general approaches can be applied:

- Substitution or reduction of amount of flammable refrigerant
- Limitation of concentration of flammable refrigerant
- Inerting the flammable refrigerant
- Avoidance or reduction of releases of flammable refrigerant

- Dilution of a release of flammable refrigerant by ventilation

Specific for the DACS, a combination of the appropriate approaches has been applied:

- Ensuring leak tightness against leakage
- Minimisation of refrigerant charge
- Reduction of releasable mass of flammable refrigerant
- Construction to limit the formation of flammable mixtures beyond the DACS
- Housing construction to prevent persistent accumulation of release refrigerant
- Use of airflow to disperse releases
- Application of a control system to minimise the possibility of releases
- Avoidance of potential sources of ignition
- Designs to limit the severity of possible consequences
- Specification of minimum room sizes
- Provision of necessary marking, installation information and instructions

These items are described in the following sections and recommendations given for the appropriate application of the measures to the DACS.

2.2 Leak tightness

2.2.1 General

Leak tightness is essential for risk reduction. A high level of leak tightness can be achieved through compliance to the following:

- Requirements for leak tightness testing in ISO 5149-2 clause 5.3.3 (plus 5.3.2 for strength test)
- Ensuring the system is technically durably tight
- Adopting additional design measures

Additional guidance is provided in Appendix B.

Throughout the development of the prototypes circuits and piping were examined and checked to ensure so as to minimise their vulnerability to leakage. Final design models must be re-checked against the items above to ensure that they still comply.

2.3 Refrigerant charge minimisation

Ordinarily AHU systems are not designed with much consideration to reduction of refrigerant charge. Since under a fixed set of conditions a release of a smaller refrigerant charge presents a slower risk than the release of a higher charge, there is significant appeal to minims charge size where possible.

Typical refrigerant charge distribution for an ACU is shown in Figure 7. This implies that most benefit for change reduction can be gained from addressing the condenser. Although compressor can yield potential charge reduction, it is reliant upon efforts of the compressor manufacturer. Evaporator can also be approached, although significant effort is often needed to obtain marginally more than a negligible gain.

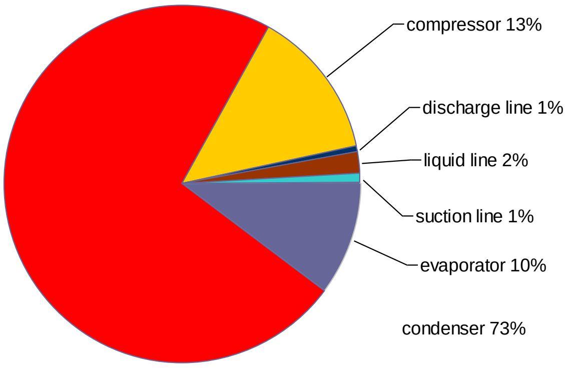


Figure 7: Typical refrigerant charge distribution in an air conditioning system

2.3.1 Condenser

Analysis of exiting condenser design was carried out. The primary modification is to reduce the tube size; ideally from 9.5 mm diameter to about 5 mm, however, since this option is not available then a 7.9 mm option has to be resorted to. Often changes to the condenser circuitry can offer additional opportunities for charge reduction, although according to the current (single row) design, the options are limited. Appendix C contains the condenser analysis and some proposals that may yield moderate benefits for charge reduction (whilst improving or maintain system performance). In addition to the finned tube condenser, a parallel prototype has been developed with a micro-channel condenser which also provides charge reduction.

2.3.2 Evaporator

To date, analysis and redesign of the evaporator coil has not taken place.

2.3.3 Compressor

Dedicated R290 compressors should be used within the DACS and appropriate models have been sourced and integrated into the systems. R290 compressors have more appropriate electrical components, the necessary marking and the requisite reliability/compatibility with R290.

2.3.4 Overall system

According to the trials to date, the refrigerant has been reduced from approximately 1300 – 1400 g R290 to about 1000 g with the finned tube condenser in the ducted split and with the standard 5 m interconnecting piping and 950 g with the microchannel condenser in the rooftop unit. Table 3 provides the current and estimated charge sizes for the six models under consideration. Overall these correspond to a specific charge of approximately 55 g/kW, which is relatively low compared to other direct AC products on the market.

Table 3: Models with R22 and anticipated R290 charge sizes

	Rooftop			Ducted split		
Model number	EPAC-036-	EPAC-048-	EPAC-060-	CV036-	CV048-	CV060-
Nominal capacity	10.5 kW	14 kW	17.5 kW	10.5 kW	14 kW	17.5 kW
R22 charge	1300 g	1775 g	2210 g	1360 g	1815 g	2265 g
R290 charge	*560 g	*760 g	950 g	*600 g	*800 g	1000 g

* *Expected*

2.4 Releasable mass of refrigerant

2.4.1 General

For the 5TR DACS, the refrigerant charge is about 2500 g of R22, based on the unmodified R22 system design. By employing R290 the refrigerant charge reduces to approximately 1000 g, based on initial measurements, on account of the lower liquid and vapour densities and to some extent the higher latent heat.[2]

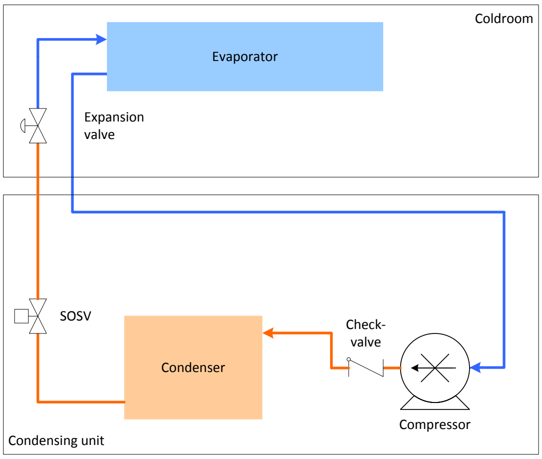


Figure 8: Typical circuit arrangement

Ordinarily these systems do not use valves within the refrigerant circuit. However, it is proposed to use shut off solenoid valve in the liquid line (LLSV) located in the outdoor part of the assembly. In addition, the compressor used is a scroll type, which employs a non-return valve (NRV) in the discharge port. This has the effect of preventing any refrigerant transferring back through the compressor to the low side of the system. However, initial measurements found that this NRV was not actually tight and could thus allow migration of the total charge into the evaporator side of the system. As a result a second dedicated and tight NRV has to be fitted in the discharge line. The general circuit arrangement is shown in Figure 8. As discussed later (section 2.4**¡Error! No se encuentra el origen de la referencia.**) the inclusion of a SOSV helps minimise the amount of refrigerant than can potentially be released from the evaporator; for instance, during off-mode only 10 – 40% of the charge may be released.

It is important to establish how much refrigerant will be released from the system in the event of a leak and under different operating modes. An extensive series of tests was carried out and the findings are discussed below.

2.4.2 Test objective

Of the various uncertainties associated with the flammability assessment of products, two of the more critical issues are the quantities of refrigerant that could potentially be leaked under a given set of conditions and the mass flow rate of that leak. Both of these parameters directly affect the refrigerant concentrations in the event of a leak. Quantifying the amount of leaked refrigerant is particularly important if the system may operate or shut-down according to different valve arrangements. The output from these measurements helps choose refrigerant quantities and mass flow rates to be used for the leak simulation concentration measurements. Additionally, they provide empirical data for inputs to the QRA.

[2] As part of the development process, measures to further reduce the refrigerant charge should be applied, such as reducing the condenser tube diameter, for example, to 5 mm.

2.4.3 Test conditions and variables

The two types systems – ducted split and rooftop – have similar operating functions; however, their geometries – such as heat exchanger dimensions, piping lengths and positioning of components around the circuit – may differ. As such, there is a need to carry out tests on both types of equipment to ensure that such variations are captured.

It is also important to identify the various operating modes under which a leak could ordinarily occur. This requires consideration of the transient operation of the system, i.e., including how the controls respond to a leak. Results of the tests also then help identify the most preferable controller settings to minimise releasable mass and leak rates to minimise risk.

Figure 9 shows the various operating steps for three possible system configurations and the states under which a leak may be considered to occur. The control steps (such as "thermostat cold", "solenoid valve closes", "low pressure switches", etc.) are usually part of a transient sequences that occurs over a few seconds and is therefore neglected when evaluating leaks since they represent a miniscule fraction of the likely leak duration. In the event that a compressor re-starts (state on(ii)), a secondary leak scenario should be considered as a leak may continue for certain configurations, such as where refrigerant had previously been trapped elsewhere in the system.

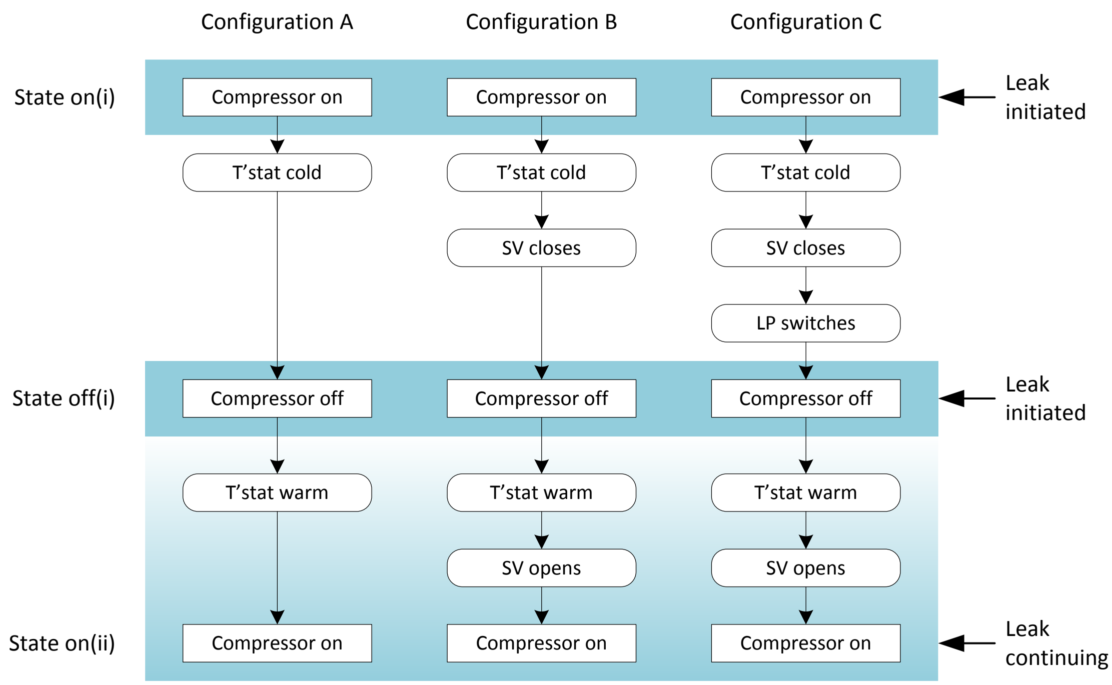


Figure 9: Operating states for different system configurations

According to Figure 9, Table 4 qualifies the likely proportion of the total system charge that is expected to leak from the high or low sides of the system under a given operating state for each configuration.

Table 4: Proportion of system charge likely to be released

Op. state	Leak position	Configuration A	Configuration B	Configuration C(a)	Configuration C(b)
On(i)	Low side	Majority	Majority	Majority	Majority
	High side	Majority	Majority	Majority	Majority
Off(i)	Low side	Majority	Less than half	Residual	Residual
	High side	Majority	More than half	Near-majority	Near-majority
On(ii)	Low side	Residual	More than half	Near-majority	Near-majority
	High side	Residual	Less than half	Residual	Residual

* Note: Configuration C(a) is with a the use of an effective non-return (check) valve within the compressor or discharge line.

Based on the different scenarios in Table 4, several specific test conditions were identified and used for the measurements. It is noted that certain conditions were not tested, since others will adequately mimic them, or that the test would not yield useful data (such as where residual amount are assumed). Also for the high side release when the compressor is on, since the result in known from consistent experience and is nevertheless of minor importance since the condenser fan will be operating anyway.

2.4.4 Methodology and arrangement

The following apparatus was used for the measurements:

- Ducted air conditioners (a ducted split and rooftop type)
- 2.5 mm diameter (4.9 mm^2) leak orifice
- Electronic pressure transducers
- Electronic balance
- Sealed collection bags

An example arrangement is shown in Figure 10.

Figure 10: Photograph of test arrangement, where refrigerant hose is connected from leak position and fed into collection bag for measuring once test is finished

Tests were carried out following the procedure:

- Attaching short, wide-bore hoses to chosen leak positions with the leak hole orifice at the end
- Feeding the outlet of the release orifice to inside a sealed collection bag
- Operate the system for at least 30 minutes so that reasonably steady conditions are achieved
- Adjust system operation to achieve the desired operating state and/or function
- Open valve to initiate simulated leak

It is noted that there are some inherent uncertainties associated with this set-up, specifically when determining mass flow of the release:

- Pressure losses through the refrigerant hose reduces mass flow more than what would be experienced with the stated orifice only, so a correction is integrated (to the determination of mass flux).
- Positioning of the low side leak source was different from those preferred, i.e., the suction tube rather than the preferred evaporator inlet.

High side leak was from the liquid tube, which represents the most severe case.

All test conditions and results are listed in Table 7.

2.4.5 Preliminary results

Overall, 23 preliminary measurements were carried out over 18 tests. Tests #1 and #2 are not included in the analysis due to errors at set-up. Preliminary tests were with the prototype that used the original R22 compressor, albeit with the remaining part of the refrigerant circuit designed for R290.

The two main reasons for carrying out these tests is to determine the releasable charge under a given set of conditions and subsequently to obtain a mass flow rate for leaks of a certain size.

From the system pressure data generated during the measurements, two distinctive slopes can be seen. The first is somewhat flatter than the second, which indicates the presence of liquid refrigerant boiling off; thereafter the relatively rapid decline in pressure is due to the remaining vapour exiting the system. The division between the two stages is inferred by the inflexion point. Figure 11 identifies these leak durations and the transition between boiling (two-phase) and vapour only. Since the leak rate during the "boiling" stage will be higher due to the higher pressure and usually the presence of liquid droplets, it may be considered to represent the more relevant leak rate. The vapour only stage occurs at lower pressures and lower vapour densities and is thus considered less critical. Accordingly, two leak rates and mass fluxes will be identified based on the available data.

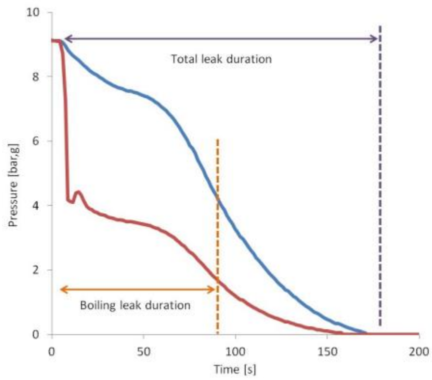


Figure 11: Identification of total leak duration and leak duration whilst "boiling" occurs

Low side leak, compressor off only

Description: System is operated, the compressor terminated and then leak initiated from the low side. (Measurements: none.)

Low side leak, shut-down (internal NRV only)

Description: System is operated, the compressor terminated and LLSV closed (simultaneously) and then leak initiated from the low side. Only the compressor internal non-return valve is used. Examples are shown in Figure 12 and Figure 13. (Measurements: test #3, test #5.)

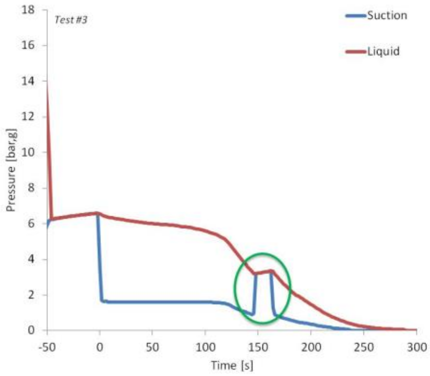


Figure 12: Pressure variation during test no. 3; compressor off, leak from low side (note: the "blip" indicated by green circle was use to accidental closing of leak valve)

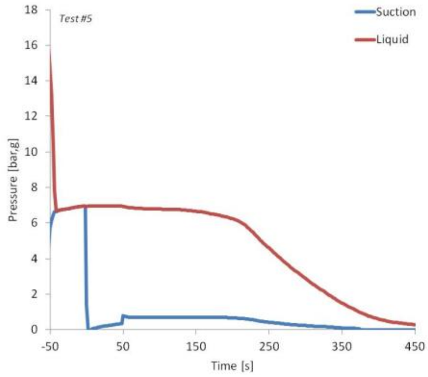


Figure 13: Pressure variation during test no. 5; compressor switched off, leak from low side

Low side leak, shut-down (additional tight NRV)

Description: System is operated, the compressor terminated and LLSV closed (simultaneously) and then leak initiated from the low side. An additional discharge line non-return valve is used. An example is shown in Figure 14. (Measurements: test #7.)

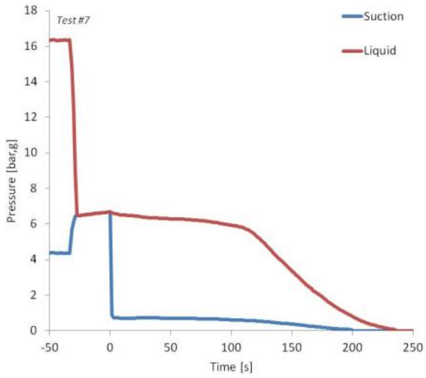


Figure 14: Pressure variation during test no. 7; compressor switched off, leak from low side

Low side leak, compressor on, LP switch terminates compressor

Description: System is operated and leak is initiated from the low side, the LP switch terminates compressor and leak is continued. Example results are shown in Figure 15, Figure 16, Figure 17 and Figure 18. (Measurements: test #13+14, test #15a+15b.)

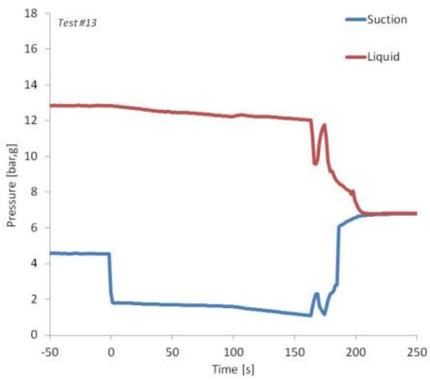


Figure 15: Pressure variation during test no. 13; leak from low side, LP switch terminates compressor

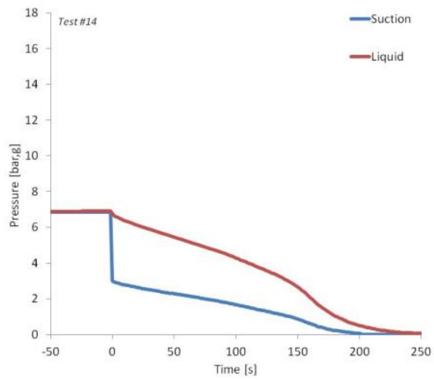


Figure 16: Pressure variation during test no. 14; (following test no. 13, where LP switch terminated compressor) leak continues from low side

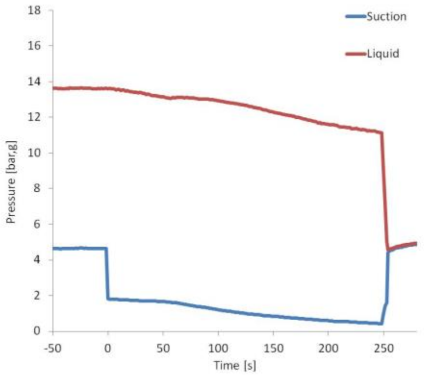


Figure 17: Pressure variation during test no. 15a; compressor on, leak from low side, LP switch terminates compressor

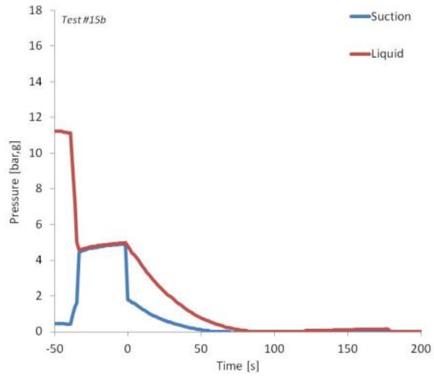


Figure 18: Pressure variation during test no. 15b; (following test no. 15a, where LP switch terminated compressor) leak continues from low side

Low side leak, compressor on, LP switch terminates, closes LLSV

Description: System is operated and leak is initiated from the low side, the LP switch terminates compressor and closes the LLSV. An example is shown in Figure 19. (Measurements: test #11.)

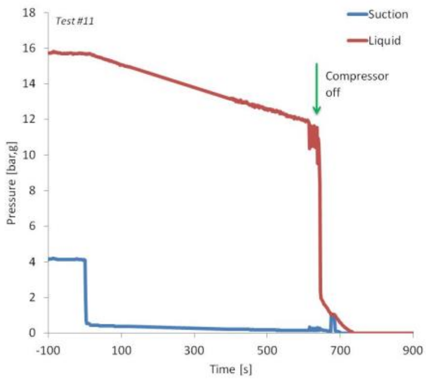


Figure 19: Pressure variation during test no. 11; leak from low side, LP switch terminates compressor and LLSV closes

Low side leak, pump-down

Description: System is operated and then LLSV is closed, the LP switch terminates compressor and then a leak is initiated from the low side. Example results are shown in Figure 20, Figure 21, Figure 22 and Figure 23. (Measurements: test #9a, test #9b, test #9c, test #17a, test #17b, test #17c.)

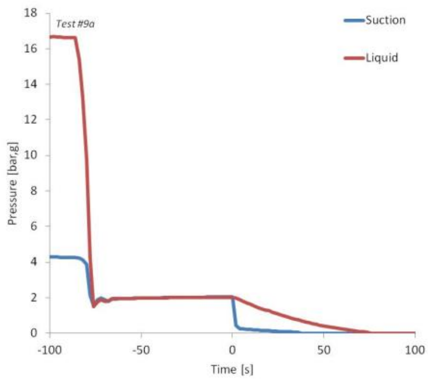


Figure 20: Pressure variation during test no. 9a; LLSV closes, pump-down, LP switch terminates compressor, leak from low side (ducted split)

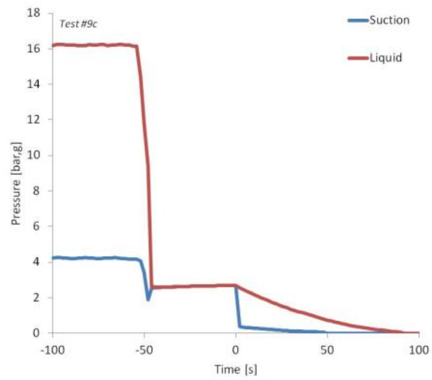


Figure 21: Pressure variation during test no. 9c; LLSV closes, pump-down, LP switch terminates compressor, leak from low side (ducted split)

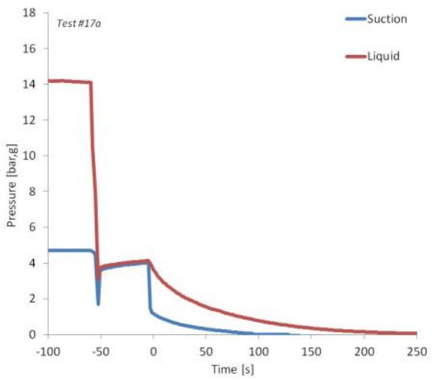


Figure 22: Pressure variation during test no. 17a; LLSV closes, pump-down, LP switch terminates compressor, leak from low side (rooftop unit)

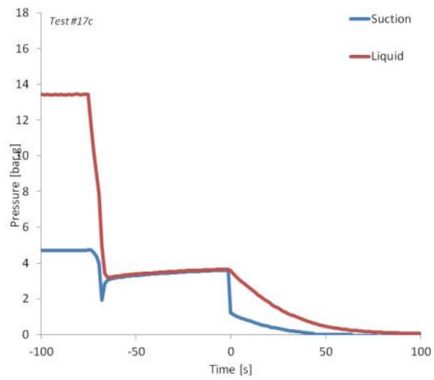


Figure 23: Pressure variation during test no. 17c; LLSV closes, pump-down, LP switch terminates compressor, leak from low side (rooftop unit)

High side leak, compressor off

Description: System is operated and then LLSV is closed for one of several reasons and then a leak is initiated from the high side. Example results are shown in Figure 24, Figure 25 and Figure 26. (Measurements: test #9a, test #9b, test #9c, test #17a, test #17b, test #17c.)

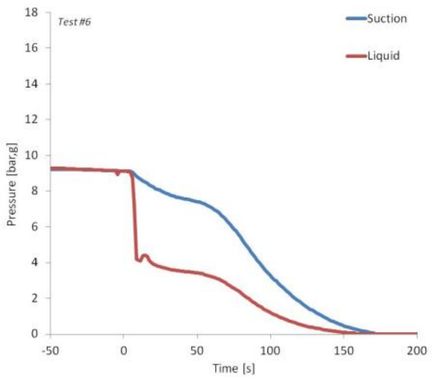


Figure 24: Pressure variation during test no. 6; compressor off, leak from high side (with partial charge)

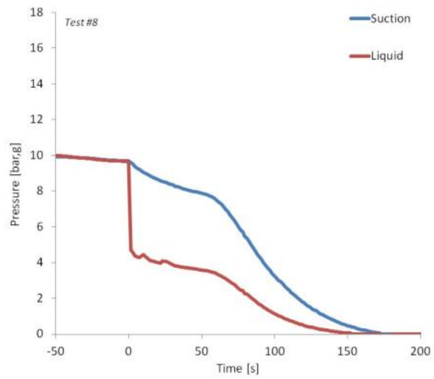


Figure 25: Pressure variation during test no. 8; compressor off, leak from high side (with partial charge)

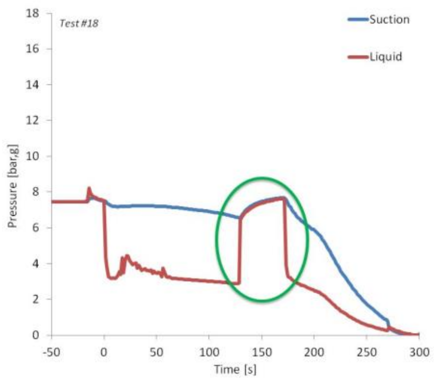


Figure 26: Pressure variation during test no. 18; compressor off, leak from high side (note: the "blip" indicated by green circle was use to accidental closing of leak valve)

Compressor oil de-gassing

Following several tests, it was observed that after the internal pressures reached atmospheric and the leak orifice was closed, there proceeded to be a gradual increase in system pressure; see Figure 27 and Figure 28. This was determined to be due to dissolved oil degassing out of the compressor oil. This is usually apparent with oils intended for use with R22 due to their much higher solubility with R290. Across the various tests, the rate of de-gassing was found to be about 2 g/min over the first five minutes and about 1 g/min over 20 minutes.

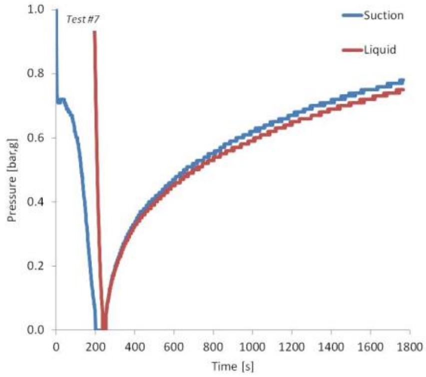


Figure 27: Pressure variation following during test no. 7 due to compressor oil de-gassing

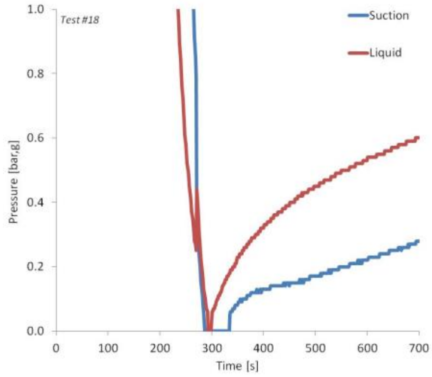


Figure 28: Pressure variation following during test no. 18 due to compressor oil de-gassing

2.4.6 Secondary results

General

Additional 15 measurements were carried out with the prototypes including R290 compressors. These tests were primarily focussed on "pump-down" and "shut-down" conditions and should provide the actual releasable refrigerant amounts for the developed ("5TR") models. Three measurements were carried out for both ducted split and rooftop models, each for the pump-down and shut-down cases.

Low side leak, shut-down

Description: System is operated, the compressor terminated and LLSV closed (simultaneously) and then leak initiated from the low side. An additional (tight) discharge line non-return valve is used. Example results are shown in Figure 29 and Figure 30. (Measurements with ducted split: test #22, test #23, test #24, measurements with rooftop: test #27, test #29, test #31.)

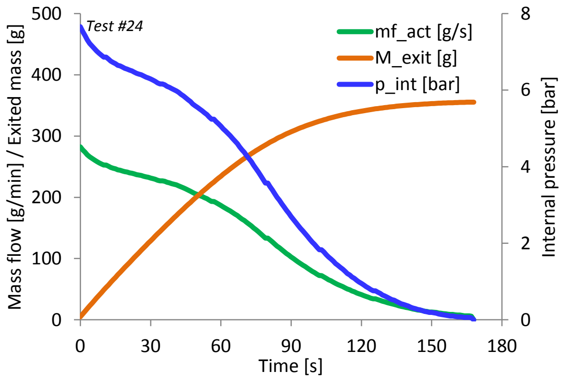


Figure 29: Example pressure variation, calculated mass flow and cumulative released mass for ducted split model with pump-down (test no. 24)

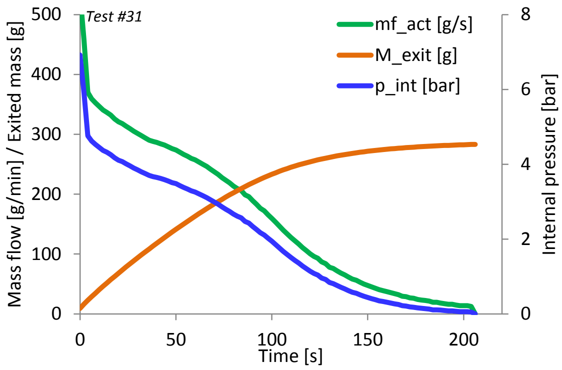


Figure 30: Example pressure variation, calculated mass flow and cumulative released mass for rooftop model with pump-down (test no. 31)

Low side leak, pump-down

Description: System is operated, the LLSV is closed and the low pressure switch terminates the compressor and then a leak is initiated from the low side. An additional discharge line non-return valve is used. Example results are shown in Figure 31 and Figure 32. (Measurements with ducted split: test #19, test #20, test #21, measurements with rooftop: test #26, test #28, test #30.)

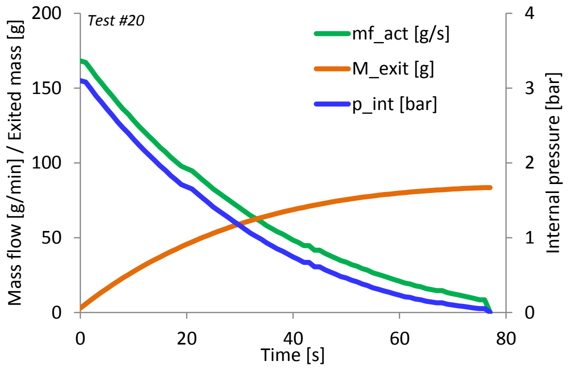


Figure 31: Example pressure variation, calculated mass flow and cumulative released mass for ducted split model with pump-down (test no. 20)

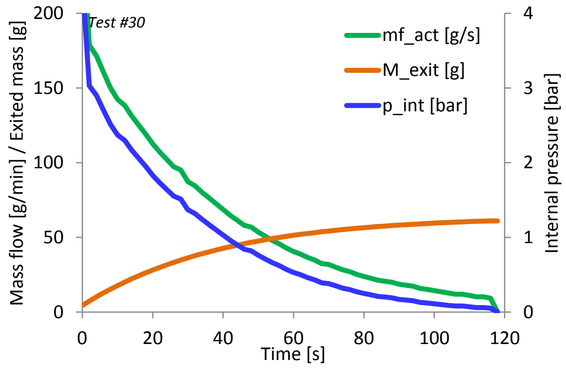


Figure 32: Example pressure variation, calculated mass flow and cumulative released mass for rooftop model with pump-down (test no. 30)

2.4.7 Final remarks

Based on the compilation of results given in Table 7, the average values for released masses (and as a proportion of the charged amount) are provided in Table 5. In general, the following observations can be made:

- The use of pump-down cycle is most effective in retaining refrigerant in the system in the event of a leak from the low side;
- Relying on a LLSV only but without pump-down when compressor terminates in 3 – 4 times as much charge being released (than with pump-down);
- Relying on LP switch to close down system and prevent more refrigerant from leaking is not particularly effective, since more than half the charge will be released;
- Leak from the high side will result in almost all charge being released (outside).

In addition, consideration should be given to residual release of refrigerant from compressor oil, although the amount that may be released is minimal.

*Table 5: Averaged release masses for different leak conditions**

Condition	Released mass (g)	As proportion of charge
Shut-down (compr NRV only) → low side leak	420	40%
Shut-down (additional tight NRV)→ low side leak (ducted)	350	35%
Shut-down (additional tight NRV)→ low side leak (rooftop)	300	30%
Low side leak, LP switch → compressor terminates	540	65%
Low side leak, LP switch → shut-down	540	50%
Pump-down → low side leak	90	10%
Compressor off → high side leak	990	90%
Compressor oil de-gassing	20	2%

* Differences in the proportion of charge and actual mass are due to variations in charged amounts

Similarly, the results from Table 7 were also averaged for mass flow rates and detailed in Table 6. In general, the following observations can be made:

- Wherever a LLSV is used to limit the amount of refrigerant that may be released, average leak rates tend to be lower, with mass fluxes in the order of 15 – 25 g/min per mm^2;

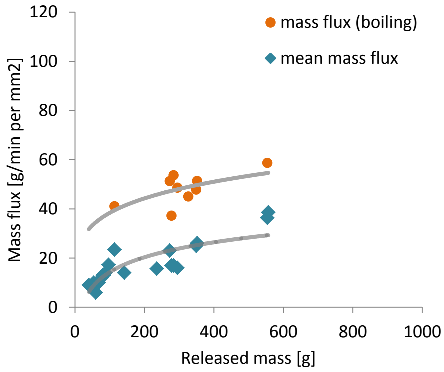
- Leak rates from the low side are approximately double when there is no closed LLSV, which is due to the driving force of the refrigerant migrating from the high pressure side of the system;
- Releases from the high pressure side result in average leak rates two to five times higher than those from the low side, largely due to the higher pressure and the greater quantity of refrigerant held locally;
- Mass flow rates for the boiling stage when the compressor is off are generally one and a half to two times the average mass flow, which is expected due to the higher pressure during that stage and occasional liquid droplets;
- When a leak occurs whilst the compressor is on, the boiling stage mass flow is almost the same as the average mass flow since the low pressure side is continually replenished with liquid for the majority of the leak period;
- For leaks from the low side following pump-down, there is a negligible boiling stage due to the prior removal of most of the refrigerant;

In addition, release rate of refrigerant from compressor oil is minuscule by comparison to the other conditions.

Table 6: Averaged mass flow rates and mass fluxes for different leak conditions

Condition	average mass flow (g/min)	av mass flux (g/min/mm^2)	mass flow (boiling) (g/min)	mass flux (boiling) (g/min/mm^2)
Shut-down (compr NRV only) → low side leak	65	20	140	40
Shut-down (add. tight NRV)→ low side leak (ducted)	120	25	230	45
Shut-down (add. tight NRV)→ low side leak (rooftop)	80	15	140	30
Low side leak, LP switch → compressor terminates	130	40	165	50
Low side leak, LP switch → shut-down	45	15	50	15
Pump-down → low side leak	60	15	n/a	n/a
Compressor off → high side leak	240	70	340	100
Compressor oil de-gassing	1.5	0.5	n/a	n/a

Averaged release mass fluxes from the various tests have been plotted against the released mass in Figure 33 and Figure 34 for low pressure and high pressure releases, respectively; results from compressor on conditions have not been included. The approximate correlation between the two parameters is due to a larger available mass of refrigerant within the leaking part of the system provides greater sustained back pressure for maintaining a higher release rate. Mass flux during the boiling phase, however, seems to remain fairly constant which is likely due to the contribution of residual heat from the compressor and condenser materials.



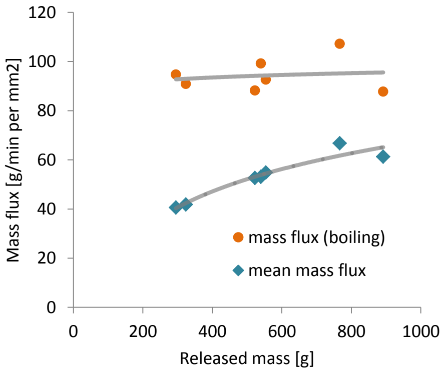


Figure 33: Variation in average mass flux according to mass of refrigerant released from the low side of the system

Figure 34: Variation in average mass flux according to mass of refrigerant released from the high side of the system

These released masses and mass flow rates may be used within the main study to identify the most appropriate control strategies and to estimate leak rates and release masses for leak simulation tests and quantification of flammable volumes for risk assessment.

Table 7: Summary of leak amount tests conditions and results

Test no	Unit	Location	Mode	Charged (g)	Leaked mass (g)	Total leak mass (g)	Leaked fraction of charge (%)	Average leak rate (g/min)	Av leak mass flux (g/m/mm^2)	Leak rate (boiling) (g/min)	Leak mass flux (boiling) (g/m/mm^2)
3	Duct split	low side	On --> off; LLSV closed	1009	395	934	93%	86	25	186	54
4	Duct split	high side	Off; remaining	1009	540			184	53	344	99
5	Duct split	low side	On --> off; LLSV closed	1050	434	957	91%	43	12	87	25
6	Duct split	high side	Off; remaining	1050	522			182	53	305	88
7	Duct split	low side	On --> off; LLSV closed + DNRV	1043	327	880	84%	82	24	156	45
8	Duct split	high side	Off; remaining	1043	554			190	55	321	93
9a	Duct split	low side	On; pump-down	1035	40	912	88%	31	9	n/a	n/a
9b	Duct split	low side	On; pump-down	1035	54			34	10	n/a	n/a
9c	Duct split	low side	On; pump-down	1035	51			33	9	n/a	n/a
10	Duct split	high side	Off; remaining	1035	767			231	67	371	107
11	Duct split	low side	Compr on; LPS --> off	1035	537	832	80%	44	13	47	14
12	Duct split	high side	Off; remaining	1035	295			141	41	328	95
13	Duct split	low side	Compr on; LPS --> off	1120	522	1076	96%	189	55	184	53
14	Duct split	high side	Off; remaining	1120	554			126	36	203	59
15a	Duct split	low side	Compr on; LPS --> off	1120	557	994	89%	134	39	130	38
15b	Duct split	low side	Off	1120	114			81	23	142	41
16	Duct split	high side	Off; remaining	1120	324			145	42	315	91
17a	Duct split	low side	On; pump-down	1400*	236	1366	98%	54	16	n/a	n/a
17b	Duct split	low side	On; pump-down	1400*	142			49	14	n/a	n/a
17c	Duct split	low side	On; pump-down	1400*	97			60	17	n/a	n/a
18	Duct split	high side	Off; remaining	1400*	892			212	61	304	88
19	Duct split	low side	On; pump-down	880	80	80	9%	63	13	n/a	n/a

Test no	Unit	Location	Mode	Charged (g)	Leaked mass (g)	Total leak mass (g)	Leaked fraction of charge (%)	Average leak rate (g/min)	Av leak mass flux (g/m/mm^2)	Leak rate (boiling) (g/min)	Leak mass flux (boiling) (g/m/mm^2)
20	Duct split	low side	On; pump-down	880	83	83	9%	66	13	n/a	n/a
21	Duct split	low side	On; pump-down	880	77	77	9%	61	12	n/a	n/a
22	Duct split	low side	On; shut-down	880	273	273	31%	115	23	237	48
23	Duct split	low side	On; shut-down	880	349	349	40%	125	25	218	45
24	Duct split	low side	On; shut-down	1010	352	352	35%	126	26	236	48
25	Duct split	low side	On; pump-down	1010	68	68	7%	51	10	n/a	n/a
26	Rooftop	low side	On; pump-down	1100	88	88	8%	69	14	n/a	n/a
27	Rooftop	low side	On; shut-down	1100	278	278	25%	83	17	122	25
28	Rooftop	low side	On; pump-down	1100	51	51	5%	40	8	n/a	n/a
29	Rooftop	low side	On; shut-down	1100	295	295	27%	80	16	145	30
30	Rooftop	low side	On; pump-down	1100	60	60	5%	31	6	n/a	n/a
31	Rooftop	high side	On; shut-down	1100	284	284	26%	83	17	157	32

* System overcharged; released quantities deemed to be higher than if the system was correctly charged.

2.5 Characterisation and avoidance of flammable concentrations

2.5.1 General

A release of refrigerant from either the internal or external parts of the DACS can form flammable mixtures. Ventilation, particularly mechanical ventilation is known to provide risk reduction by assisting in the dispersion of a leak of flammable refrigerant by increasing the rate of entrainment and thus diluting the mixture to below the flammable limit moiré rapidly. DACS ordinarily uses mechanical ventilation both for the evaporator and condenser. The characteristics of the airflow are given in Table 8. The airflow provided by the system can be used to provide additional protection against ignition risk by means of dispersing leaked refrigerant to below the LFL.

Table 8: ACU airflow characteristics

Type	Condition	Evaporator fan			Condenser fan		
	Availability	Only during compressor operation			Only during compressor operation		
	Unit capacity	2TR	3TR	5TR	2TR	3TR	5TR
Centralised	Volume flow rate (m^3/h)	1360	2040	3400	1738	2439	2836
	Discharge area (m^2)	0.0369	0.0636	0.0732	0.1885	0.2206	0.2642
	Discharge velocity (m/s)	10.24	8.91	12.90	2.56	3.07	2.98
Packaged	Volume flow rate (m^3/h)	1360	2040	3400	1738	2439	2836
	Discharge area (m^2)	0.0369	0.0636	0.0732	0.1885	0.2206	0.2642
	Discharge velocity (m/s)	10.24	8.91	12.90	2.56	3.07	2.98

In general, it is essential to know the circumstances under which flammable concentrations could arise in the event of a refrigerant leak. To this end, a series of tests were carried out in order to measure R290 concentrations at various positions within the AC equipment, ducting and the rooms served by the AC equipment. Based on the results and analysis of these tests, potentially unsafe situations can be identified and the effectiveness of risk-reducing measures. Furthermore, such measures can also be tested.

2.5.2 Test conditions and variables

Possible formation of flammable mixtures across various elements of the DACS installation requires examination of the locations identified in Table 9.

Table 9: Locations for examination of concentration development

Concentration development	Ducted split	Rooftop
Within AHU enclosure		×
Within indoor AHU	×	
Within outdoor unit	×	×
Surrounding outdoor unit	×	×
Surrounding indoor unit	×	
Within ducting system	×	×
At duct outlets	×	×
At return duct inlet	×	×
Within conditioned space	×	×

In addition, it is necessary to consider the applicable operating modes, as identified in Table 10.

Table 10: Overview of possible operating modes

Compressor mode	Airflow outside	Airflow inside	Static condition	Response to leak
On	Condenser fan on	Blower on	n/a	LP switch terminate compr
				LP switch terminate compr, close LLSV
				Pump-down cycle
Off	Condenser fan off	Blower off	Basic circuit	None
			LLSV closed	
			Pumped-down	

Considering the type of AC equipment under evaluation, the variety of different ducting arrangements must be accounted for when carrying out measurements. A summary of the various possible generic arrangements are shown in Figure 35 for rooftop units and Figure 36 for ducted split units.

Overall, more than 70 tests were carried out.

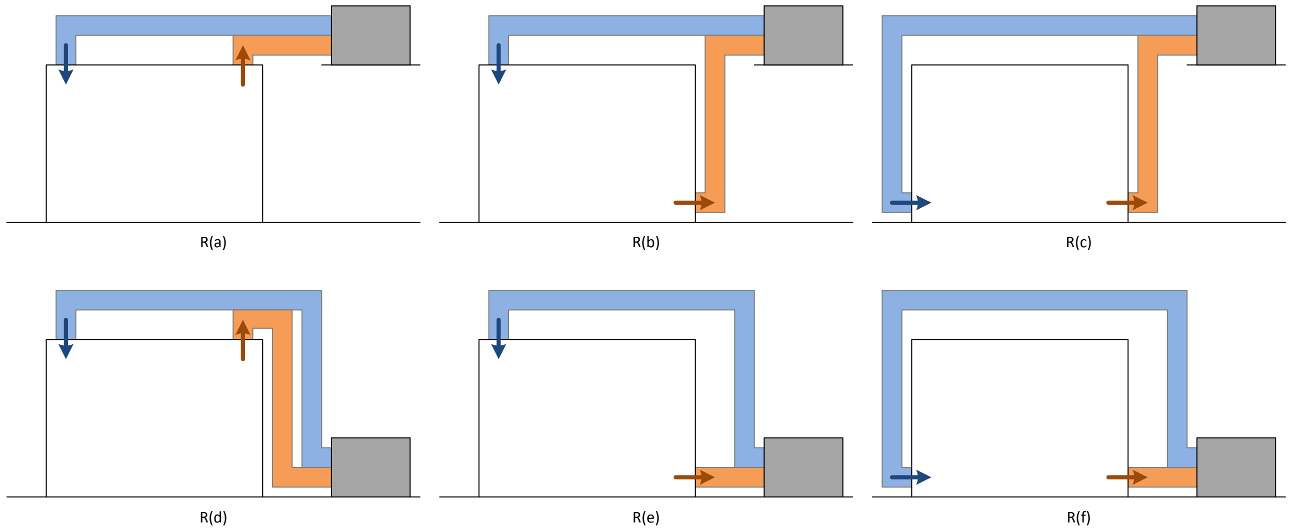


Figure 35: Combinations of flow and return ducting for rooftop (R) units, which are at elevated (top row) or at ground level (bottom row) positions

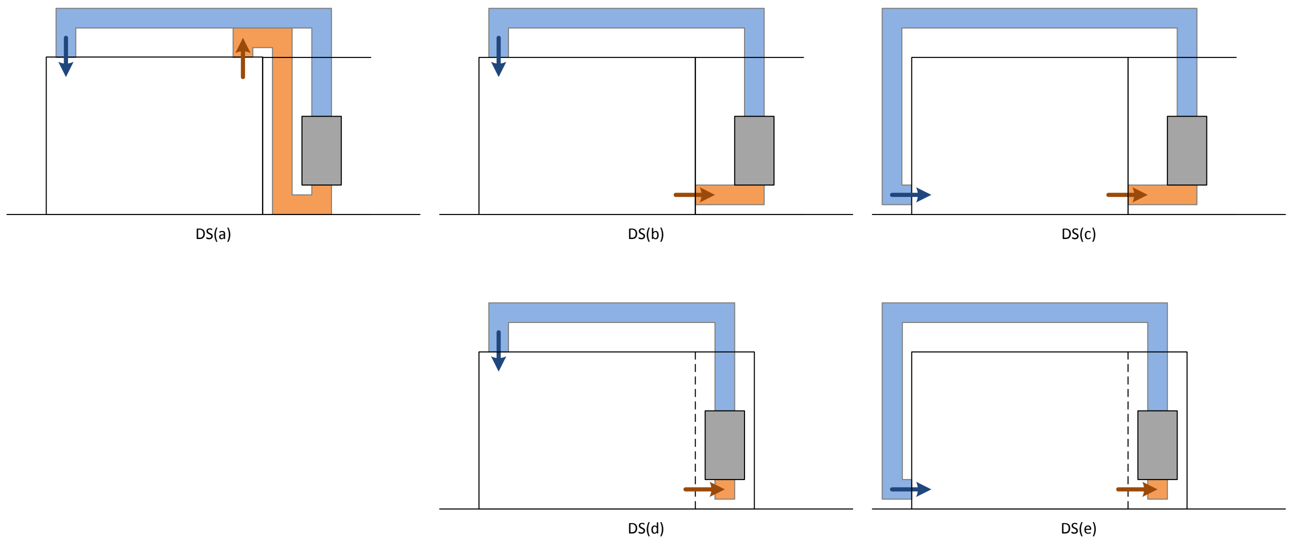


Figure 36: Combinations of flow and return ducting for ducted split (DS) units, which have air handling unit in separate space (top row) or in adjoining closet space (bottom row)

2.5.3 Methodology and arrangement

The following apparatus was used for the measurements:

- Ducted air conditioners (a ducted split and rooftop type) with ducting fitted, where required
- Various sized leak hole (to suit specific leak conditions)
- R290 cylinder and hoses
- Electronic balance
- Electronic flow meter
- Gas analysers with data logging

Example arrangements are shown in Figure 10

Figure 37: Photographs of example test arrangements

Photographs of the ducted split unit and rooftop units are shown in Figure 38.

Figure 38: Photographs of models used for testing; ducted split (left and centre) and rooftop unit (right)

Tests were carried out following the procedure:

- Set up room and equipment in desired manner, including placement of gas sensors at appropriate locations
- Ensure all unintended sources of ventilation are eliminated
- Initiate release of refrigerant from cylinder at desired flow rate
- Terminate flow once released mass has been achieved
- Wait for necessary duration until end of test period

2.5.4 Results

General

As mentioned above, the two main reasons for carrying out these tests is to determine the releasable charge under a given set of conditions and subsequently to obtain a mass flow rate for leaks of a certain size.

AHU enclosure

Leaks were simulated within the AHU enclosure of both the rooftop and ducted split units. Figure 39 and Figure 40 show the release points within the ducted split AHU enclosure and the positioning of the two sampling points in Figure 41 and Figure 42.

Figure 39: Leak position 1 within ducted split AHU

Figure 40: Leak position 2 within ducted split AHU

Figure 41: Sampling location #3 within ducted split AHU

Figure 42: Sampling location #2 within ducted split AHU

Concentrations within the ducted split AHU enclosure are shown in Figure 43 and Figure 44 for the two leak positions. In both cases the results are similar, where there is a rapid increase in local concentration and this soon transitions to a gradual rise as some of the mixtures falls out of the base of the AHU. Within seconds of the leak stopping both sampling points fall towards zero. As would be expected, concentrations at the base are higher than at the top of the enclosure. Importantly, with this leak size, the concentration easily exceeds the LFL, demonstrating that the entire internal space is potentially flammable. Even with a fraction of the charge, the concentration would still exceed LFL.

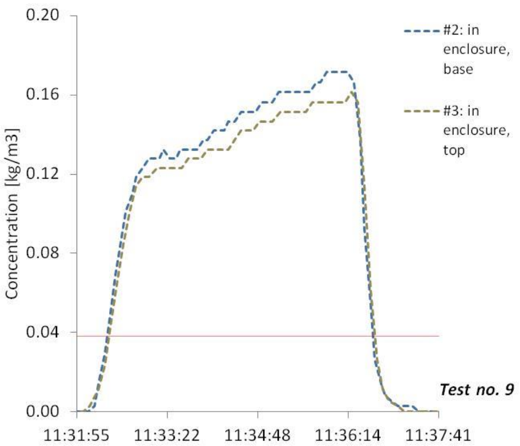


Figure 43: Leak position 1, 220 g, 50 g/min

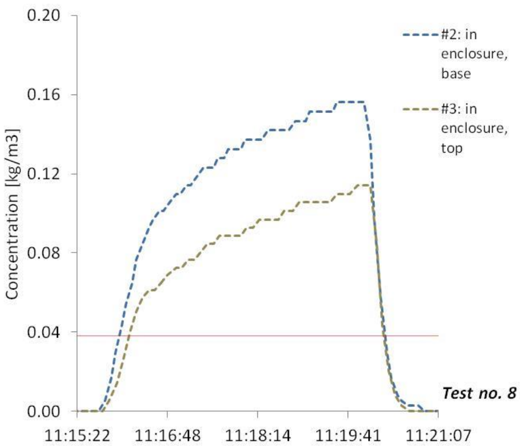


Figure 44: Leak position 2, 220 g, 50 g/min

With the blower on, the measured concentrations were negligible. Even with a release of 530 g at 135 g/min and the blower on "low" setting, the concentrations were below 0.005 g/m^3 (on account that the sensors did not return a value). Dividing release mass flow rate by the blower volume flow infers an average concentration of 0.003 kg/m^3 – about 7% of the LFL of R290.

Figure 45 and Figure 46 show the release points within the rooftop AHU enclosure and the positioning of the two sampling points in Figure 47.

Figure 45: Leak position 1 within rooftop AHU

Figure 46: Leak position 2 within rooftop AHU

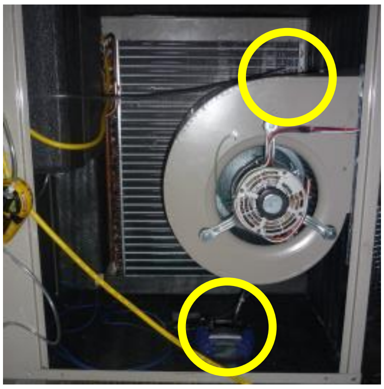


Figure 47: Sampling location #2 (base) and #3 (top) within rooftop AHU

Concentrations within the rooftop AHU enclosure are shown in Figure 48 and Figure 49 for the two leak positions. In both cases the results are similar, where there is an initial rapid increase in local concentration and these then transition to a fairly steady value with further addition of refrigerant as the mixture migrates from the openings within the AHU envelope. Within seconds of the leak stopping both sampling points fall towards zero. As would be expected, concentrations at the base are higher than at the top of the enclosure. Importantly, with this leak size, the concentration easily exceeds the LFL, demonstrating that the entire internal space is potentially flammable. Even with a fraction of the charge, the concentration would still exceed LFL.

Compared to the case of the ducted split AHU enclosure in Figure 43 and Figure 44, the behaviour is slightly different. Firstly the initial jump in concentration is substantially higher with the rooftop AHU, which is likely due to a smaller internal volume. (The fact that a larger mass is used in the rooftop tests is not important since it does not affect in initial values.) Secondly, whereas with the ducted split AHU concentration preceded to increase gradually over time, those within the AHU reach an equilibrium within a couple minutes into the release. This is due to differences in the size of openings through which the mixture can flow out; whilst the rooftop AHU has a smaller internal volume, the gaps are larger (relative to, for example, the internal volume) thus enabling a higher rate of outflow.

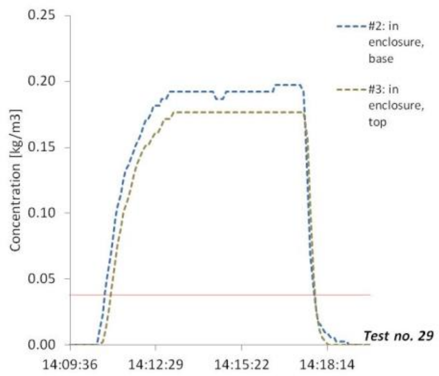


Figure 48: Leak position 1, 380 g, 50 g/min

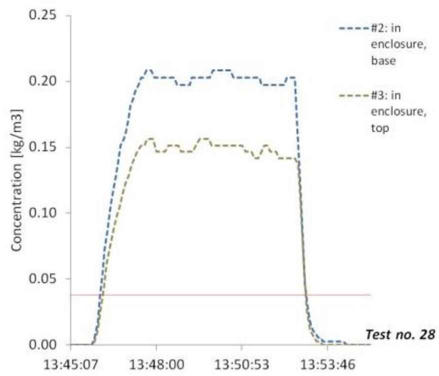


Figure 49: Leak position 2, 380 g, 50 g/min

As with the ducted split AHU, with the blower on the measured concentrations were negligible. Using a release of 350 g at 230 g/min and the blower on "low" setting, the concentrations were below 0.005 g/m^3 (on account that the sensors did not return a value). Dividing release mass flow rate by the blower volume flow infers an average concentration of just under 0.005 kg/m^3 – about 12% of the LFL of R290.

Condensing unit enclosure

Leaks were simulated within the condensing unit enclosure of the rooftop unit. Since the dimensions and geometry of the rooftop and ducted split condensing units were almost identical, it was deemed sufficient to carry out tests on the rooftop condensing unit compartment only.

Figure 50 and Figure 51 show the release points within the condensing unit enclosure (red circles) and the positioning of two of the three sampling locations (yellow circles). A third location was on top of the condenser fan motor.


Figure 50: Selected release and sampling points


Figure 51: Selected release and sampling points

Concentrations within the rooftop condensing unit enclosure are shown in Figure 52 and Figure 53 for the two leak positions. As with the releases inside the rooftop AHU enclosure, there is an initial rapid increase in local concentration and these then transition to a relatively steady value as further refrigerant is released, although only at the lower sampling location. Despite the mass flow being 2.5 times greater than the AHU tests, this concentration equilibrium occurs, which is on account of the considerably larger free area in the housing, i.e., between condenser fins and the fan housing. The sampling locations towards the top of the enclosure are rather erratic and relatively low, due to rapid ingress of fresh air. Whilst at the base the concentrations exceed LFL, those at the top are comfortably lower than LFL.

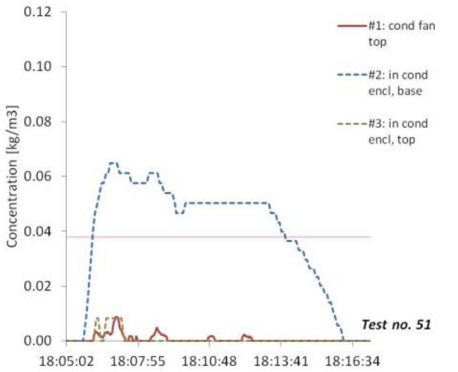


Figure 52: Leak position [discharge pipe], 1000 g, 150 g/min

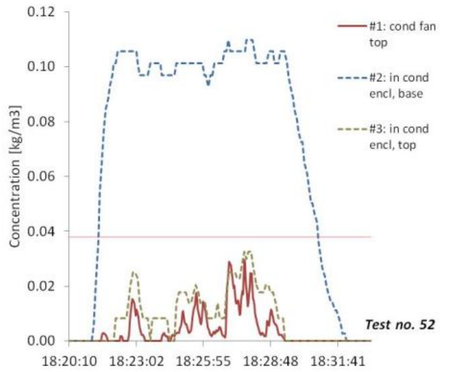


Figure 53: Leak position [liquid line], 1000 g, 150 g/min

Ducting

Concentrations within supply ducting is a precursor to the concentrations developing within the room9s) being supplied.

Several cases were evaluated, as shown in Table 11.

Table 11: Overview of different ducting arrangements tested

Duct type	Flow	Direction	Airflow	Reference
Main	Supply	Rising	On	D1
		Horizontal	On	D2
			Off	D3
			Off → On	D4
	Return	Rising	On	D5
			Off	
Branch (outlets)	Supply	Rising	On	D6
		Horizontal	On	D7
			Off	D8
			Off → On	D9

D1: Main supply duct rising with airflow

Sensors were arranged in a 3 × 3 matrix across the duct cross-section, as shown in Figure 54. Sampling location is 1.0 m along the duct and 1.5 m after the leak point.

Several tests were carried out, where different release rates were used with a low and high airflow setting. Since the duct is rising, testing without airflow is irrelevant since the release will not flow upwards.

Figure 55 illustrates how the concentration at the various sampling points varies over time as the release proceeds.[3]

[3] When carrying out these tests it was not expected that good mixing would occur, as is seen in these results. As such all measurements are rather close to the lower end of the gas analysers' range; this is indicated by the poor resolution of the values seen in Figure 55. For this reason the data described for these measurements should be regarded as having a relatively wide uncertainty.

Figure 54: Sampling matric for main duct

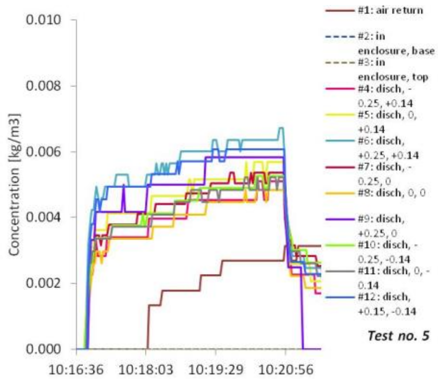


Figure 55: Example time-concentration data

The following graphs show the plane distribution at a time moments before cessation of the leak, minus the concentration entering the AHU (to help normalise the results for different release amounts). Figure 61 and Figure 62 are for "low" and "high" airflow settings, respectively with medium leak rate. Figure 63 and Figure 64 are for "low" and "high" airflow settings, respectively with high leak rate.

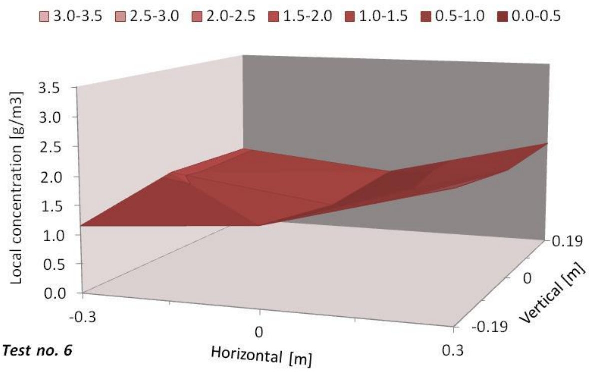


Figure 56: Low airflow (0.8 m3/s), medium leak rate (90 g/min)

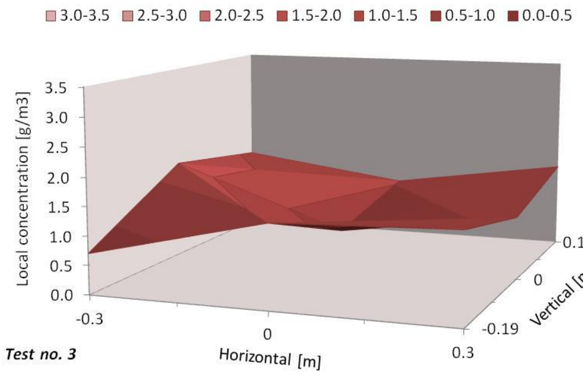


Figure 57: High airflow (0.95 m3/s), medium leak rate (80 g/min)

Across all tests, the distribution of leaked refrigerant may be considered as fairly even (compared to cases without airflow, for example). There is no obvious pattern seen in these figures, except a possible tendency for higher concentrations on the right side (horizontal +0.3 m) which corresponds to the release location. Nonetheless, this relatively even distribution of refrigerant in the airflow is a helpful observation since it infers that maldistribution of leaked refrigerants through branch ducts is highly unlikely and thus negates the need for potentially complicated treatment of evaluating charge size limits for individually served rooms.

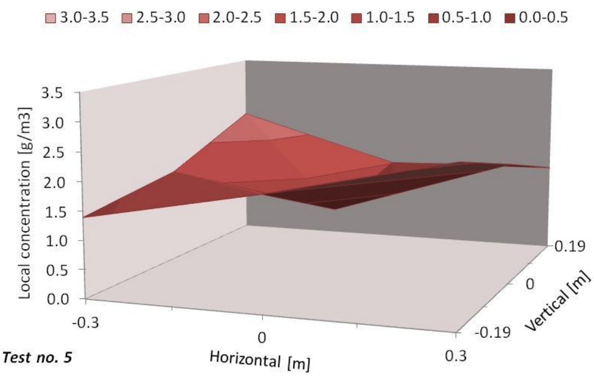


Figure 58: Low airflow (0.8 m/3s), high leak rate (135 g/min)

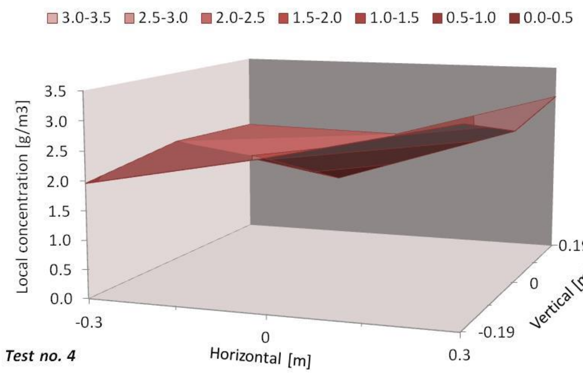


Figure 59: High airflow (0.95 m3/s), high leak rate (155 g/min)

Maximum variation of local concentrations across all sampling points (at a given time) – referred to as "concentration span" – has been plotted against the theoretical average concertation within the airflow (release mass flow divided by airflow volume flow rate). Figure 60 shows a tendency for a wider span with increasing theoretical average concertation, irrespective of airflow rate. This trend can be used to approximate potential maldistribution occurrences with greater leak rates or lower airflows. Extrapolating to a theoretical average concertation of 50% LFL suggests a possible span of between 3 g/m^3 and 12 g/m^3 (depending upon the function). Even in the most pessimistic case, this would suggest that with a theoretical average concentration of 50% LFL, localised maximum values would unlikely exceed 25 g/m^3 or 66% LFL. A longer duct length (as would be expected in real installations) would assist with developing a more homogenous mixture; this is indicated by the additional data point "horiz" which was taken from the test with a 5 m horizontal duct).

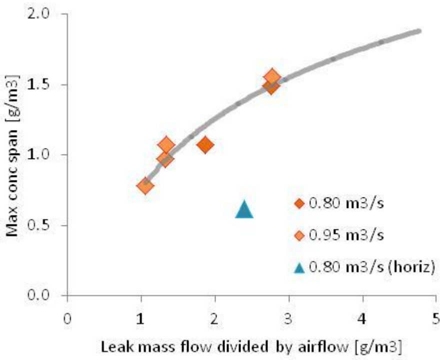


Figure 60: Relationship between theoretical average concentration within the duct and maximum concentration span across the sampling matrix

D2: Main supply duct horizontal with airflow

A single duct was run horizontally from the rooftop unit, ordinarily with four branches. Three of the branches were closed off so as to mimic a single main duct. Sampling points were positioned across the end in a 2 × 4 matrix, as shown in Figure 61.

Concentration distribution prior to the cessation of the release is given in Figure 62. As with the rising duct, refrigerant is distributed fairly evenly across the horizontal duct. Plotting resulting span onto the graph in Figure 60 shows that the heterogeneity is much less that for the other cases; this is likely due to the longer distance (and higher mean flow velocity) between the release and the measurement, allowing better mixing to occur.

Figure 61: Sampling matric for horizontal main duct

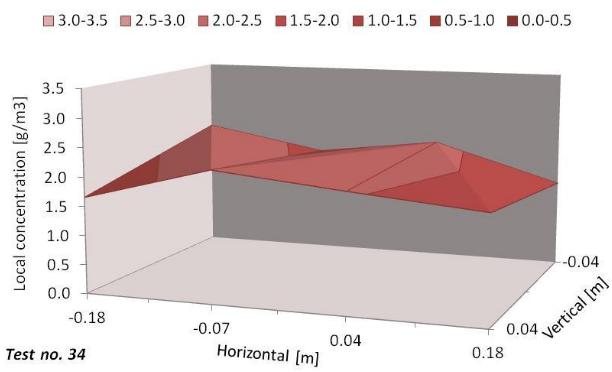


Figure 62: Low airflow (0.80 m3/s), high leak rate (120 g/min)

D3: Main supply duct horizontal without airflow

The same arrangement as with the horizontal main duct in D2 (see Figure 61) was used to examine concentrations arising from a release without the blower operating.

Figure 63 and Figure 64 show local concentrations across the matrix with a 50 g/min and 120 g/min release, respectively, four minutes into the release (averaged over 30 seconds). Measured values are vastly different from the case with airflow (Figure 62) where concentrations at the lower half of the duct are around 10 to 20 times higher than in the upper half. This suggests that the refrigerant is flowing along the duct as a stratified layer (for example, how one may expect a liquid to flow along a conduit), as opposed to filling the entire cross-section. Another observation is that the local concentrations are similar for both (unventilated) cases, despite one arising from three times the release rate as the other; whilst sampling matrix is too course to draw any definite conclusions, this observation suggests that the higher leak rate only causes primarily a higher flow velocity rather than larger flammable volume within the duct.

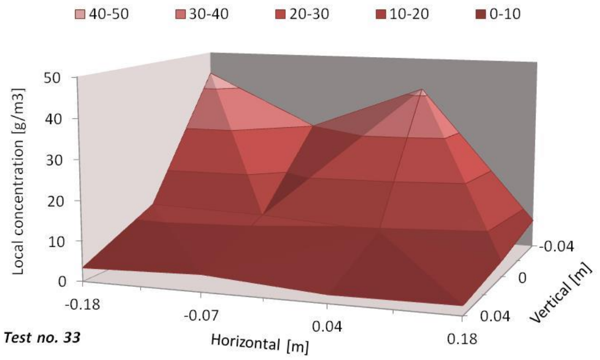


Figure 63: No airflow, medium leak rate (50 g/min), 4 minutes (200 g) into the leak

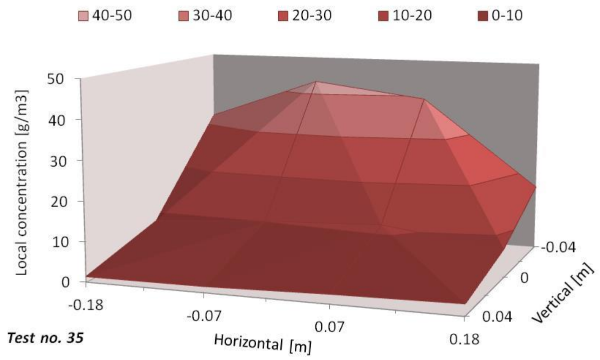


Figure 64: No airflow, high leak rate (120 g/min), 4 minutes (500 g) into the leak

At the same time, the concentrations close to the duct connection of the AHU enclosure were about 300 g/m3 (for both cases), suggesting a dilution ratio in the order of 1.5 per metre of horizontal ducting. This this is a simple approximation derived from a single configuration, it helps provide an indication as to the minimum duct lengths necessary if a flammable concentration at the duct outlet is to be avoided.

Further to this, since these a flammable concentration has been found to occur within an unventilated duct, it is useful to identify the potential extent of that flammable region following its decent from an outlet. To this end, sensors were also placed on a surface 0.45 m below the base of the duct outlet; resulting data for the two cases above are shown in Figure 65 and Figure 66. Blue lines are two local concentrations at the lower part of the duct outlet and red lines are at 0.45 m directly below the outlet. Whist for the 120 g/min release the concentrations below the duct outlet are marginally higher than those for the 50 g/min release, all concentrations are well below the LFL.

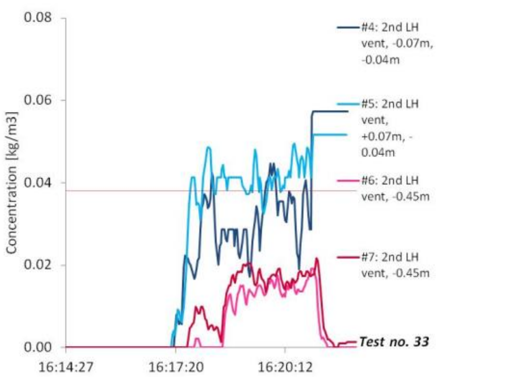


Figure 65: Concentrations at half metre below duct outlet for 350 g released at 50 g/min release within rooftop unit

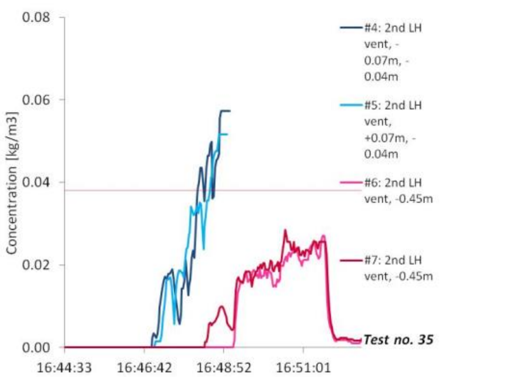


Figure 66: Concentrations at half metre below duct outlet for 350 g released at 120 g/min release within rooftop unit

Further insight into the extent of the potentially flammable mixture arising from it pouring from a duct outlet was gained by calibrating a simple plume dilution model against these results. Figure 67 shows the expected trend in centreline concentration with respect to distance below the duct outlet (assuming an infinitely sized room within which preceding gas release is evenly mixed). The mixture dilutes to below LFL at about 0.2 m below the outlet and at 1 m below is well below 20% of LFL. Usually, ceiling ducts are no less than 0.5 m above "head height" so it is highly unlikely that a flammable concentration from a duct outlet would reach an occupant.

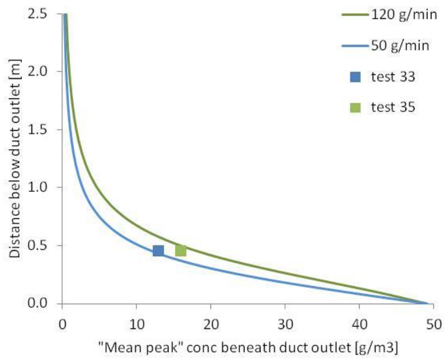


Figure 67: Result of plume model showing diminishing centreline concentration below duct outlet

D4: Main supply duct horizontal with airflow initiated after leak

Consideration of the prior cases of distribution of R290 through a main duct was based on a steady flow release source (be the blower on or off). However, a third scenario may occur, where a leak develops whilst the blower is off and at some point the blower is switched on; the consequence is that the entire accumulated refrigerant will then be blown through the entire ducting system almost instantaneously. (This situation may be analogous to a leak involving the majority of the system charge within a few seconds.) To mimic this scenario a fixed quantity of R290 was released into the AHU, but to minimise migration of refrigerant the return air duct was closed, until the instant that the blower was started.

An illustration of the effect is seen in Figure 65. Concentrations at the lower part of the duct outlet are blue lines, upper part are green lines and red lines are sampling points 0.5 m below the duct outlet. With seconds of switching on the blower, all concentrations at the duct outlet (except one at the near top side of the matrix) jump immediately to above LFL (and beyond the operating range of the sensor – indicated by the flat lines). At the same time, the concentration at the position 0.5 m below the duct decline to near zero and the concentration within the AHU also drops rapidly as all the release refrigerant is exhausted from the enclosure. Implication is a transient guff of flammable mixture being discharged laterally from the duct outlet. It is important to characterise this volume of potentially flammable mixture, in terms of its size and its throw.

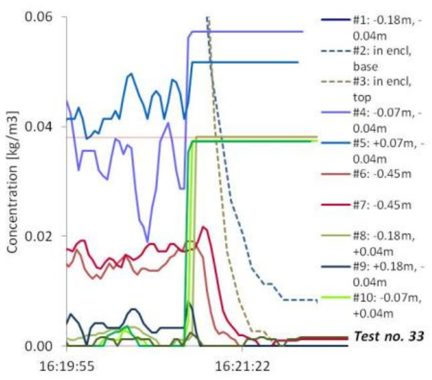


Figure 68: Concentrations at various sampling points upon initiation of blower after a release of 350 g at 50 g/min (Flat lines indicate concentration exceeded limit of sensor)

A matrix of sampling points was arranged for successive tests about the main duct outlet, to a distance extending to around 1.5 m in the direction of airflow and about 0.5 m perpendicular to the discharge centreline. Examples of the arrangement are shown in Figure 69. Successive tests were repeated where 1000 g of R290 was released at about 130 g/min into the rooftop unit AHU (with return duct blocked) and the blower then started.

Figure 69: Arrangement of sampling points to determine extent of flammable mixture exhausted from the single duct outlet

Values of the maximum concentration at any one sampling point during a test were isolated and plotted against the linear distance from the duct outlet.

Figure 70 provides the values for sampling points positioned at lateral widths from the normal discharged airflow centreline. These results suggest that a flammable mixture exists only somewhere within about a 0.4 m band about some (revised) centreline, i.e., ±0.2 m. Furthermore, the throw of the flammable mixture does not seem to extend any further than about 1 m beyond the outlet. Figure 71 presents' further data but with the furthest sampling points at 0.35 m above and below the normal discharged airflow centreline (i.e., at 0.7 m the sampling points are about 0.2 m above and below). As would be expected, higher concentrations can be seen below the centreline than above, due to the negative buoyancy of the mixture. Although above the normal centreline a flammable mixture appears not to be present beyond about 0.5 m in the discharge direction and 0.15 m above the centreline, concentration at about LFL are still present 1.2 m in the discharge direction at a distance of about 0.3 m below the normal centreline.

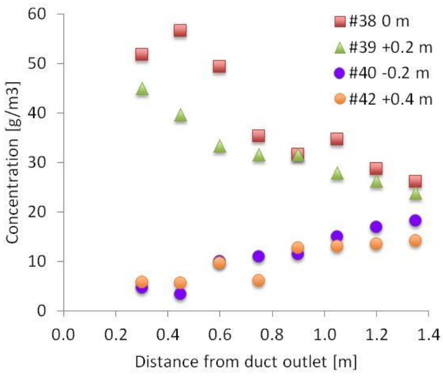


Figure 70: Maximum concentrations of R290 following a 130 g/min release of 1000g at sampling points positioned at various lateral distances from discharge centreline*

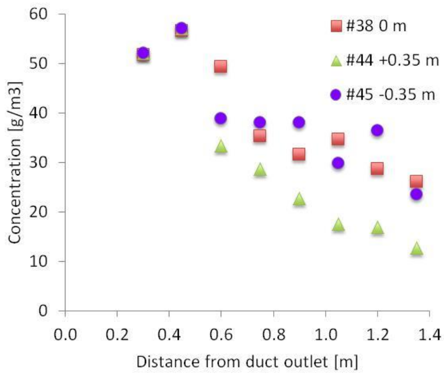


Figure 71: Maximum concentrations of R290 following a 130 g/min release of 1000g at sampling points positioned at various vertical distances from discharge centreline*

*Actual values likely to be up to 1½ times higher because of response time of sensors

Data clearly indicates a "slumping horizontal plume", with a potentially flammable mixture filling a space of about 0.4 m wide × 0.2 – 0.4 m high × 1.2 m long. From the first "peak" concentration value (at 0.3 m along the normal centreline) to the last "peak" (at 1.35 m) approximately 15 s elapses across all tests, indicating the flammable mixture is travelling at about 0.1 m/s and overall is present for no more than 15 s; see Figure 70. Furthermore, the "peaks" exist only for a few seconds each; inferring that at any one point in time the "length" of the projected flammable mixture is about 0.3 m. Volume of the flammable mixture projected in to the conditioned space under this blower off-on scenario is approximated to be no more than about 50 litres.

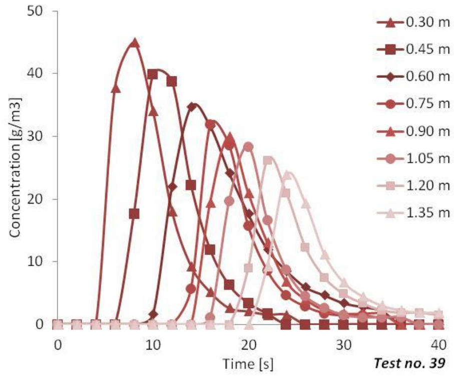


Figure 72: R290 concentration changes over time for sequentially spaced sensors along normal airflow discharge centreline

D5: Main return duct rising with and without airflow

Often, return air duct inlet is close to the floor of the served space and then rises upwards towards the rooftop unit air inlet opening.

If the blower is on, the local concentration entering this inlet duct will always be lower than that of the air supply outlet duct (within the same room). An example can be seen in Figure 55.

An example employs the set-up shown in Figure 73 and measurements are shown in Figure 74, where the concentration at the base of the return duct is plotted over time. For the first period the blower is off and then it is switched on; within 30 s the concentration has dropped from above LFL to below the sensor sensitivity range (i.e., < 2.5 g/m^3). Thus whenever the blower is on, concentration at return air duct inlets is always negligible.

Figure 73: Test arrangement with return duct inlet indicated with red arrow

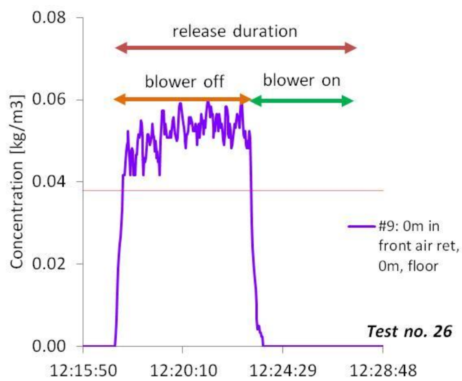


Figure 74: Concentration at base of return air inlet duct without airflow and then with blower on

Critically, as seen in Figure 74, absence of airflow can lead to potentially high concentrations due to refrigerant migrating back out of return air ducts, when close to floor level. (Note that for this scenario but with return air ducts at high level, the same process as described for "D3" can be assumed to apply.)

For return duct inlets at floor level, it is useful to identify any design characteristics that can help mitigate the development of such potentially flammable concentrations.

For the investigation a rooftop unit is positioned approximately 1 m above floor level (as for Figure 73). When a leak occurs it flows back through the return air inlet connection, into the duct and then downwards and into the room. As with the supply duct when the blower is off, this poses concern with a potential build-up of a flammable mixture on the room floor. The effects of incrementally closing off the return air inlet on the rooftop unit was assessed (as shown in Figure 75) in order to identify any benefits in terms of reducing local concentrations. This was done using release positions at lower and upper levels within the AHU enclosure (see Figure 45 and Figure 46).

Figure 75: Rooftop unit return air inlet fully open, half blocked and fully blocked

Resulting concentrations close to the return duct opening are provided in Figure 76 and Figure 77 for unblocked opening, Figure 78 and Figure 79 for partially blocked and Figure 80 and Figure 81 for fully blocked cases, each for the low (A) and high (B) leak position.

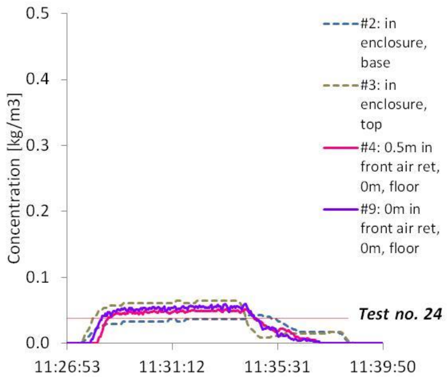


Figure 76: Fully open, leak position A

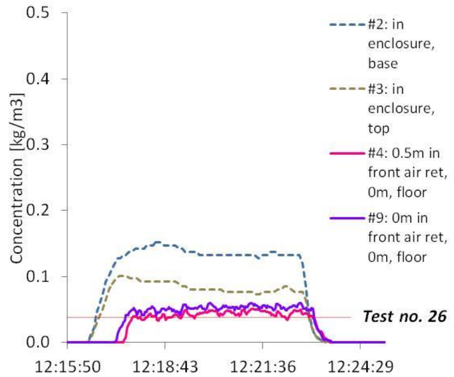


Figure 77: Fully open, leak position B

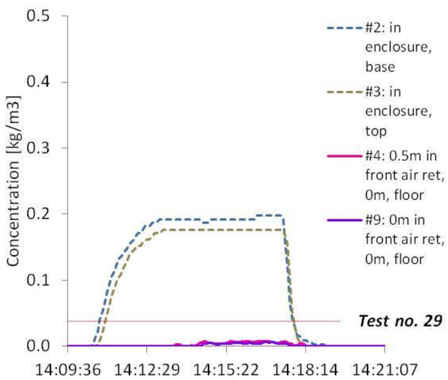


Figure 78: Half blocked, leak position A

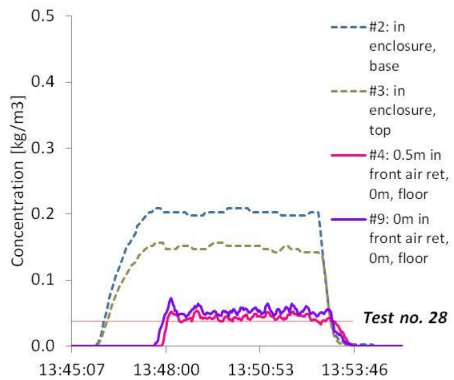


Figure 79: Half blocked, leak position B

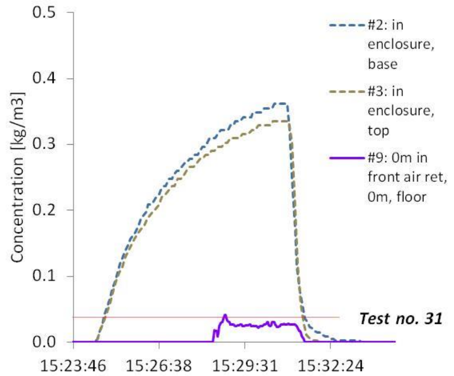


Figure 80: Fully blocked, leak position A

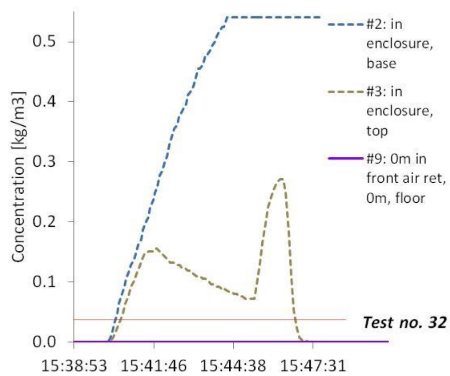


Figure 81: Fully blocked, leak position B

Another variable investigated is the effect of ducting length on the concentrations beyond the duct outlet.

Figure 82 and Figure 83 show concentrations at incremental distances from the duct outlet when the release originates from directly above the inlet opening and about 6 m before the inlet opening, respectfully. Any difference between the results of these two tests is relatively minor and is nevertheless difficult to identify clearly die to the local concentrations exceeding the upper range of several of the analysers. Average concentrations for the sampling points that remained active are 45 g/m^3 and 54 g/m^3 for the case with a release close to the inlet opening and 43 kg/m^3 and 48 g/m^3 for the release further from the inlet opening; a difference of around 5 to 10%. Some lowering of concentrations can occur from longer ducting, but it is relatively minor.

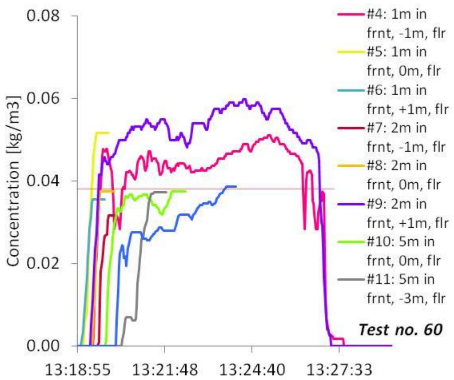


Figure 82: Release of 350 g at 50 g/min from 0.5 m above floor inlet duct opening

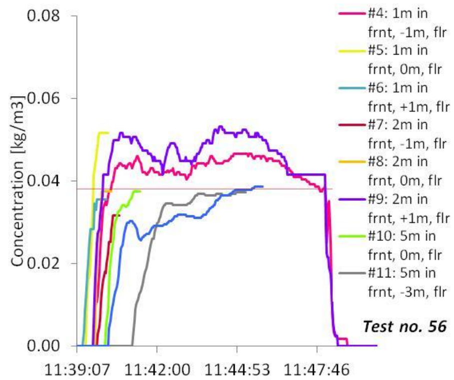


Figure 83: Release of 350 g at 50 g/min from 3.0 m above and 6.0 m along duct from floor inlet opening

D6: Branch outlet supply rising duct with airflow

Several tests were carried out to further check for maldistribution of refrigerant as it is blown from various branched outlets. Figure 84 provides an indication of the duct arrangement and the positioning of the sensors.

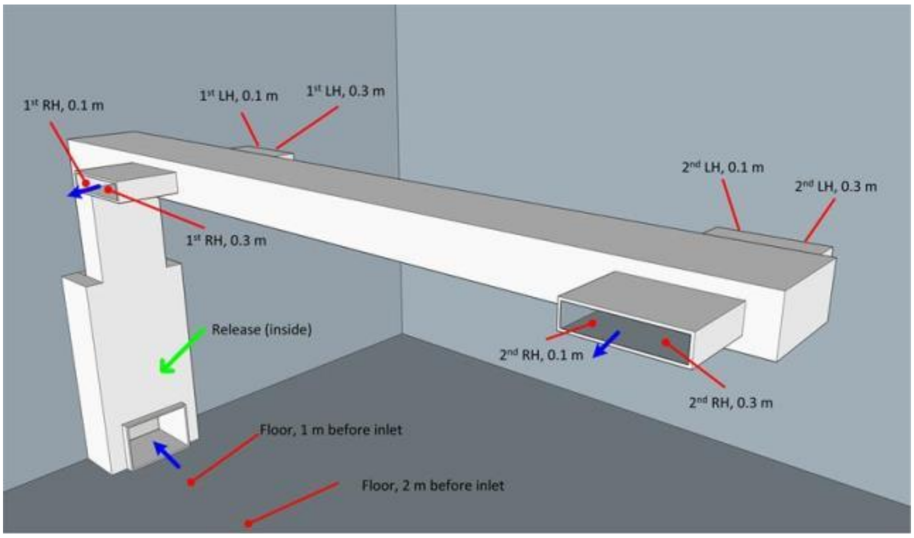


Figure 84: Illustration of ducting arrangement and positioning of sensors

Plots of the concentration over time for a 300 g release at 50 g/min and 1000 g at 150 g/min are shown in Figure 85 and Figure 86, respectively. Generally, a linear increase in concentration occurs until cessation of the release at which point steady concentrations form within the room (until venting of the room begins).

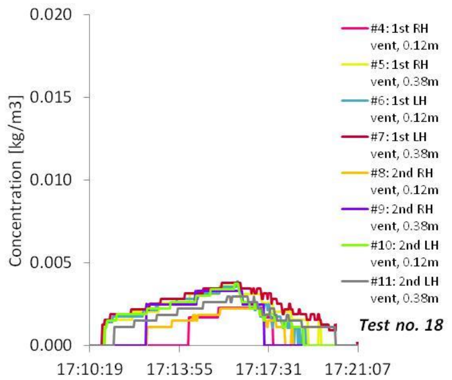


Figure 85: Release of 300 g at 50 g/min from 0.5 m above floor inlet duct opening

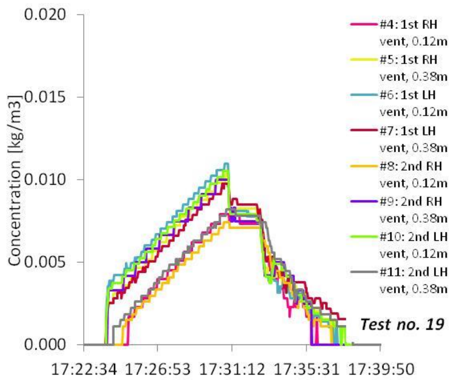


Figure 86: Release of 1000 g at 150 g/min from 0.5 m above floor inlet duct opening

Figure 87 and Figure 88 show concentrations at each outlet moments before cessation of the release for the 300 g and 1000 g release, respectively. Some differences between the outlet concentrations can be seen in Figure 87, however, due to the low values of concentration it may be due to the poor resolution of the gas analyser output. Figure 88 also indicates (similar) differences in local concentration, which is due to localised eddy currents being formed at the duct outlet, thereby drawing in room air to dilute the exiting mixture. Nevertheless, any maldistribution is minor and there is no indication that localised concentrations, close to or exceeding LFL, would arise.

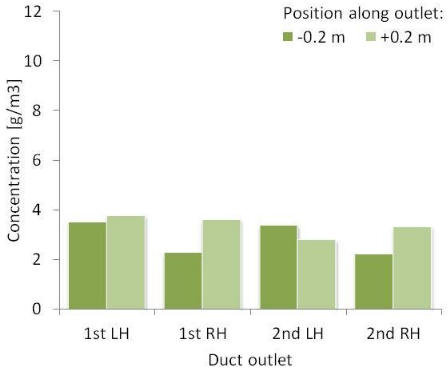


Figure 87: Concentration a few moments before termination of release of 300 g at 50 g/min from 0.5 m above floor inlet duct opening

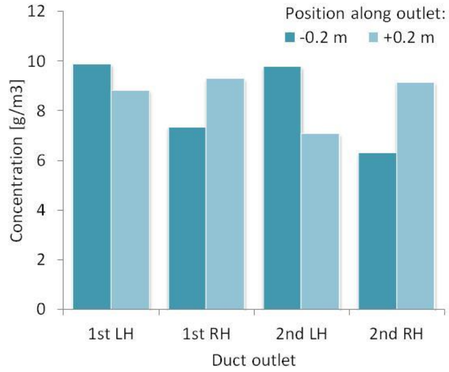


Figure 88: Concentration a few moments before termination of release of 1000 g at 150 g/min from 0.5 m above floor inlet duct opening

D7: Branch outlet supply horizontal duct without airflow

Branch outlet concentrations were also measured for a horizontal duct being fed by the rooftop unit. For these tests, a single sampling point was located at the centre of each outlet and another approximately 0.5 m directly beneath the outlet opening. Since the air return inlet opening was at a lower height than the air discharge opening of the rooftop unit, additional tests involving the partial or full blocking of the return air opening were carried out to mimic the case of an elevated return duct.

Some example results for concentration over time are given in Figure 89 for an unblocked return air opening and a fully blocked return air opening in Figure 90. It is evident that in blocking the return air opening, the majority of released refrigerant flowed through the supply duct, whereas the unblocked case resulted in a minimal flow through of refrigerant. In both examples, there is too great a fluctuation in local concentrations to be able to differentiate tendencies for maldistribution of the refrigerant-air mixture through one or more outlets.

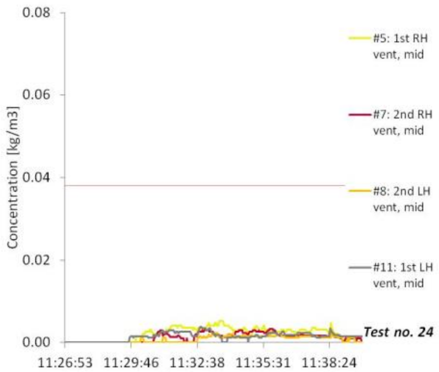


Figure 89: Concentrations at centre of each duct outlet from release of 350 g at 50 g/min from leak position A inside rooftop unit

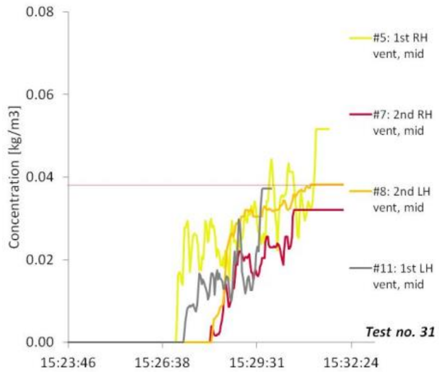


Figure 90: Concentrations at centre of each duct outlet from release of 350 g at 50 g/min from leak position A inside rooftop unit but with return air inlet fully blocked

Figure 91 and Figure 92 show the concentrations at about 0.5 m directly below each outlet. The observations in Figure 89Figure 90 are mirrored here, where almost nothing is measured beneath the ducts when the air return opening was not blocked but substantial concentrations found when the opening was blocked. The developed concentration is the blocked case do not exceed more than about 25% of LFL.

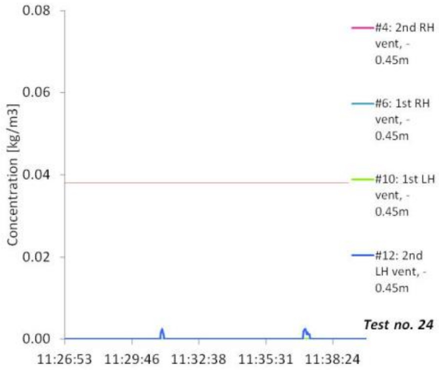


Figure 91: Concentrations directly below each duct outlet from release of 350 g at 50 g/min from leak position A inside rooftop unit

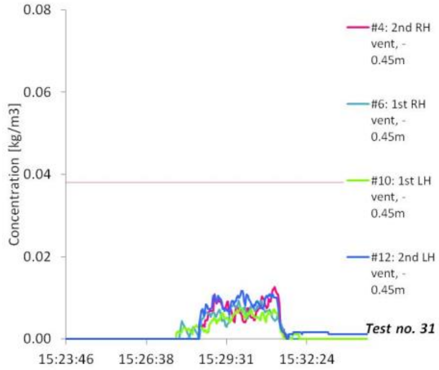


Figure 92: Concentrations directly below each duct outlet from release of 350 g at 50 g/min from leak position A inside rooftop unit but with return air inlet fully blocked

An overview of all six tests is provided in Figure 93 for duct outlet concentrations and 0.5 m below the outlet in Figure 94. These include the two different release positions within the rooftop unit and an intermediate case where the air return inlet was half blocked. Data is based on concentrations averaged of one minute preceding cessation of the release. Resulting data is somewhat inconsistent, largely due to the wide fluctuations in the data, which is believed to be a result of the central positioning of the sensors in the duct outlet. Nevertheless, results for the position 0.5 m below the outlets is more steady; more blocking of the return air opening forced more refrigerant through the supply duct leading to higher local concentrations within the room. However, the concentrations never exceed about 25% of LFL.

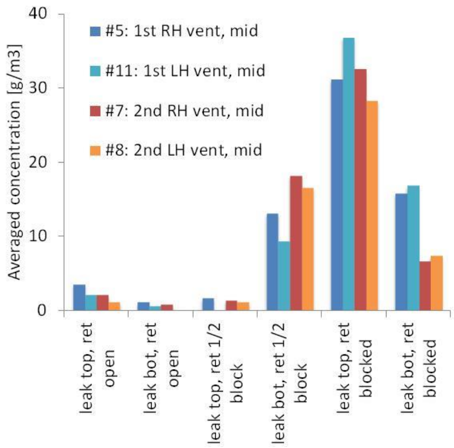


Figure 93: Release of 350 g at 50 g/min from 0.5 m above floor inlet duct opening

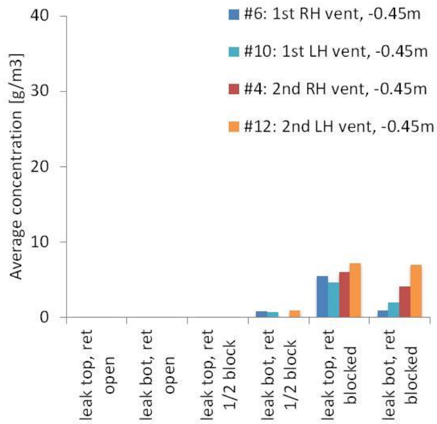


Figure 94: Release of 350 g at 50 g/min from 3.0 m above and 6.0 m along duct from floor inlet opening

Concluding remarks

Provided that the velocity is high enough to cause turbulent flow within the ducting – which is the case in most applications (i.e., Reynolds number is several orders of magnitude higher than that at transition between laminar and turbulent flow) it is likely that any refrigerant travelling along the duct with forced airflow will become very well mixed. When the blower is off, high concentrations can be found at duct outlets, but this depends upon how much of the refrigerant is allowed to flow back through the return ducting or through the supply ducting. If duct outlets are elevated then any refrigerant flowing from the outlet will dilute to low concentrations within a fraction of a metre along its decent. Where duct openings are positioned at floor level, significant concentrations can be found and mitigations measures are recommended.

Beyond condenser

Whilst releases from the condenser part of the rooftop unit, or the condensing unit of the ducted split unit are broadly of a lesser concern than leaks indoors, it is useful to understand how the refrigerant will distribute around the unit housing. In particular, this assists with determining “separation distances” from the unit to other electrical equipment or fresh air inlet ducts installed nearby.

Measurements were made using the rooftop unit, positioned on an elevated board (Figure 95). This is intended to more accurately represent an outdoor installation, where a release is not confined by room walls. Measurements were carried out indoors, where airflow is limited; usually outside airspeed is substantially higher and therefore these results represent a very pessimistic case. Whilst only the rooftop unit was used for these tests, the results are deemed to represent the condensing unit since the construction of the condenser parts is almost identical.

Six sampling points were used. Three sampling points are at the same level as the unit base corresponding to each condenser face and three others are then 0.5 m below those positions.

Figure 95: Arrangement of the rooftop unit for surrounding concentration measurements

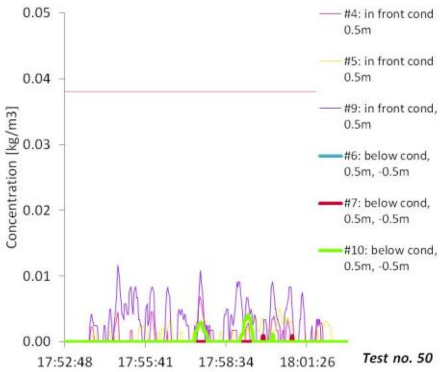


Figure 96: Concentrations surrounding rooftop unit at 0.5 m and 0.5 m below plinth with 1000 g at 150 g/min from discharge pipe, with access panel open

Figure 96 provides results for a large release, but with the housing access panel open. Concentrations both at condenser base level and at -0.5 m are low, due to the effective mixing with the surrounding by means of the open access panel; this may be related to a servicing scenario. Figure 97 and Figure 98 show concentrations arising from releases at the discharge line and liquid line, respectively (but with access panel closed). At the 0.5 m perimeter, concentrations are fairly high, occasionally exceeding LFL. At 0.5 m below, values never exceed 50% LFL. There is little difference between the discharge line and liquid line release points.

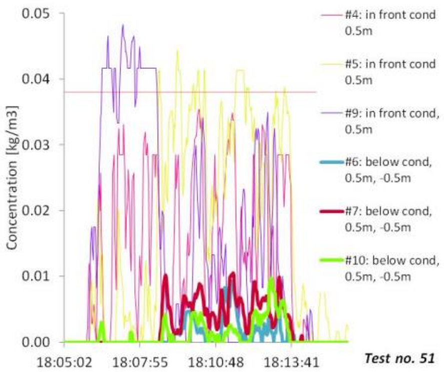


Figure 97: Concentrations surrounding rooftop unit at 0.5 m and 0.5 m below plinth, with release of 1000 g at 150 g/min from discharge pipe

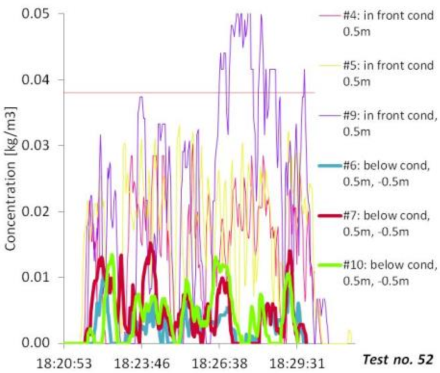


Figure 98: Concentrations surrounding rooftop unit at 0.5 m and 0.5 m below plinth, with release of 1000 g at 150 g/min from liquid pipe

Considering that the release rate used (150 g/min) is approximately three times greater than the 50 g/min expected based on measured values (Table 3) through a maximum expected leak hole size (0.5 mm^2) and that surrounding air speeds are substantially lower (0.1 – 0.2 m/s) than those of “still” conditions outside (0.5 m/s), setting a minimum separation distance of about 0.5 m to 1.0 m beyond the perimeter of the unit would be reasonable.

Conditioned space

Three cases were investigated, with refrigerant entering the space:

(i) Directly from the return air inlet of a ducted split AHU positioned in an empty room
(ii) A supply or return duct at floor level connected to an elevated mock AHU
(iii) Directly from a ducted split AHU positioned in a closet and associated room and corridor arrangement

i) Ducted split AHU in empty room

Leaks were simulated from the indoor ducted split AHU and refrigerant concentrations measured in a matrix across the room floor, as well as within the AHU housing. Assuming a limited releasable charge (due to use of a liquid line solenoid valve), 350 g was released at 50 g/min and for the case of pump-down, 180 g at 50 g/min; results are shown in Figure 99 and Figure 100, respectively. In both cases, it can be seen that concentrations within a 1 m (for 180 g) and 2 – 3 m (for 350 g) radius of the AHU exceed LFL, which is an undesirable outcome. Whilst the release rate may be deemed substantially higher than what may be expected with “real” leaks, it was considered appropriate to investigate application of mitigation measures to help minimise room floor concentrations.

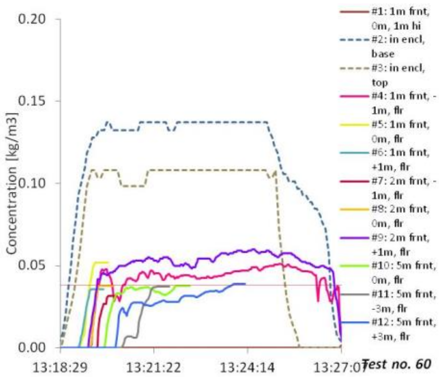


Figure 99: 350 g release at 50 g/min from ducted split AHU

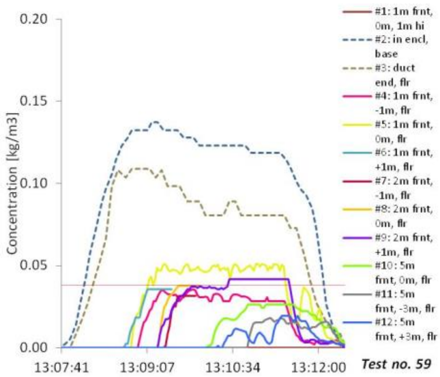


Figure 100: 180 g release at 50 g/min from ducted split AHU

To this end, a plenum chamber was constructed around the outlet of the AHU so that any released refrigerant must flow over the upper lip before it flows across the room floor; this additional height is intended to help accentuate the dispersion of refrigerant as it enters the room. Four elevations of plenum chamber – 0.25 m, 0.50 m, 1.0 m and 1.5 m – were tested, as indicated in Figure 101.

Figure 101: Different elevations of outlet plenum; from left to right – 0.0 m, 0.25 m, 0.50 m, 1.0 m and 1.5 m

Results for the 1.5 m elevation are given in Figure 102, which shows its effectiveness in avoiding the possibility of a flammable mixture developing on the room floor. A further test using 1000 g of R290 and a high leak rate of 100 g/min was also carried out; results are seen in Figure 103. In this latter case, positions close to the AHU begin to exceed LFL about two-thirds of the way through the release and eventually reaching about 1.5 × LFL.

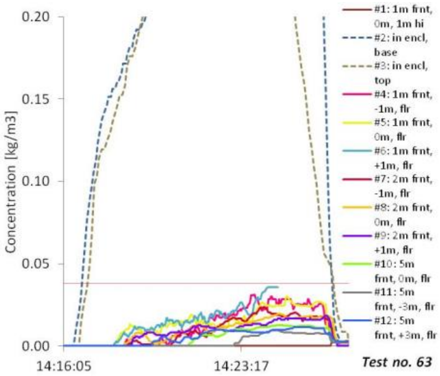


Figure 102: 350 g release at 50 g/min from ducted split AHU with plenum at 1.5 m elevation

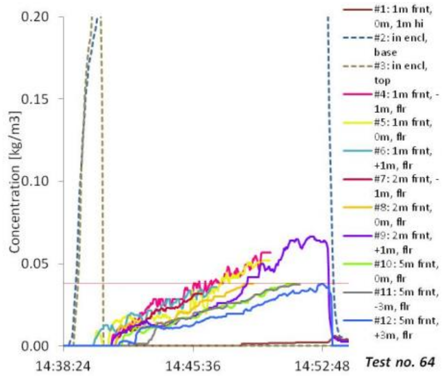


Figure 103: 1000 g release at 100 g/min from ducted split AHU with plenum at 1.5 m elevation

A plot of maximum mean floor concentration across the room floor for the various plenum elevations is shown in Figure 104. Here it can be seen that an elevation of at least 0.7 m or 0.8 m is required to avoid concentrations exceeding LFL for the conditions under evaluation. Given that the release rate of 50 g/min is rather high, compared to the maximum likely release rate of about 5 g/min, based on measured values (Table 3) through a maximum expected leak hole size (0.05 mm²), an elevation of at least 0.5 m may be considered reasonable.

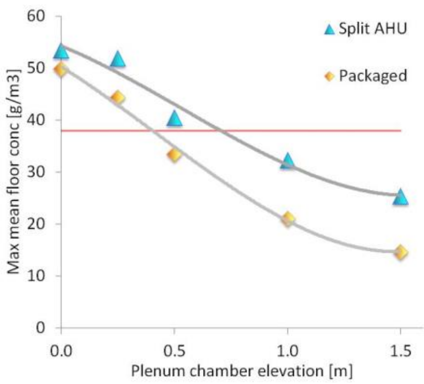


Figure 104: Variation in maximum mean floor concentration as a function of plenum elevation

A redesign of the AHU was developed, where an internal plenum chamber was integrated into the housing, as shown in Figure 105. This was then tested as described above to determine its effectiveness.

Figure 105: Redesign of AHU with internal plenum chamber

A release was made from the lowest position of the evaporator return bends, as indicated in Figure 106. The AHU was positioned within the room as in Figure 107.

Figure 106: Ducted split AHU release position

Figure 107: AHU position in test room

Results are shown in Figure 108, Figure 109, Figure 110 and Figure 111 for four tests, which use two different release rates and two released masses.

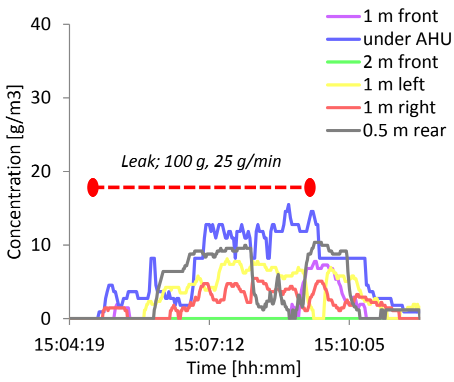


Figure 108: Results for test no. 70(1)

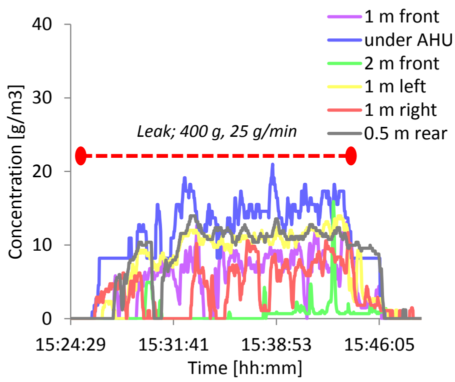


Figure 109: Results for test no. 71(2)

Under each test condition, maximum floor concentrations anywhere across the room do not reach the LFL. This shows a considerable improvement compared to the tests in Figure 99 and Figure 100 where releases under comparable conditions – but without modifications to the AHU – result in floor concentrations considerably above the LFL.

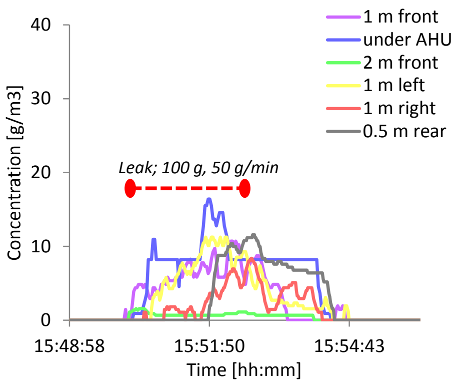


Figure 110: Results for test no. 72(3)

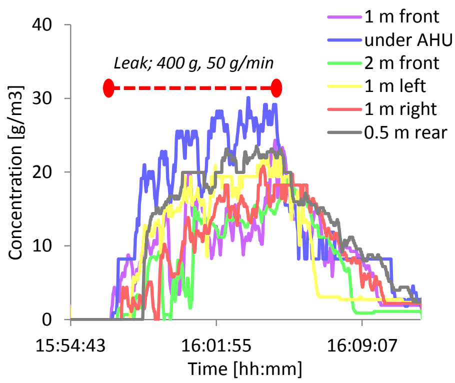


Figure 111: Results for test no. 73(4)

ii) Mock rooftop ducted to empty room

In the case of the AHU being positioned within the room itself, another scenario is where the return duct inlets are positioned at floor level and leaked refrigerant may flow from a roof-mounted units down to ground level. This scenario was simulated by means of a mock AHU formed at the room ceiling (about 3 m above the floor) and a closed duct fed to floor level; the arrangement can be seen in Figure 112 and Figure 113. Refrigerant was released from within the mock AHU and again measured across the room floor. The primary purpose was to identify whether additional mixing occurred (compared to the case of the ducted split AHU) due to the "run up" before exiting the outlet just above the floor.

Figure 112: Mock elevated AHU and associated single ducting

Figure 113: Mock elevated AHU and associated single ducting and surrounding test area

Measurements are given in Figure 114 and Figure 115 for the 0 m and 1.5 m elevation, again with 350 g released at 50 g/min. With no plenum chamber, room floor concentrations are slightly lower than those when the release was from the ducted split AHU, whilst with the 1.5 m elevation room floor concentrations are notably lower. Variation in maximum mean floor concentration against elevation height for the mock rooftop unit case is included in Figure 104. A distinct benefit is observed with the mock rooftop case over the ducted split, with higher plenum chamber elevations. This may be attributed to the release attaining a higher flow velocity as it falls through the ducted from greater height and thus the plume is "projected" to a higher level following discharge from the plenum.

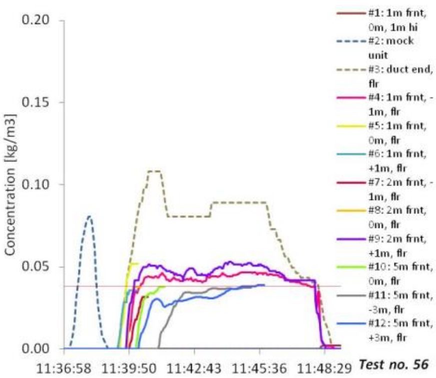


Figure 114: 350 g release at 50 g/min from ducted split AHU with plenum at 0.0 m elevation

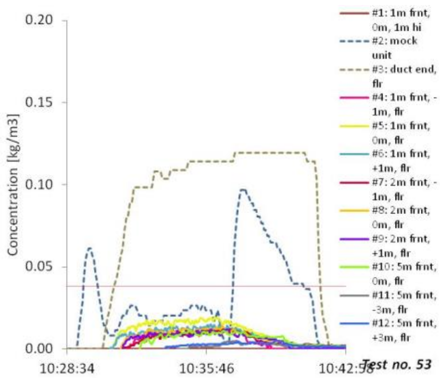


Figure 115: 350 g release at 50 g/min from ducted split AHU with plenum at 1.5 m elevation

The supplementary test with 1000 g of R290 and a high leak rate of 100 g/min was again carried out and results shown in Figure 116. Here, a significant difference is seen compared to the ducted split AHU case (Figure 103), where all sampling positions are well below LFL; again supporting the suggestion that the increased falling velocity from the higher level ultimately assists with dispersing the release before falling to the room floor.

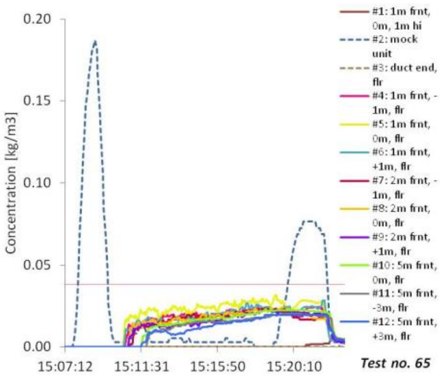


Figure 116: 1000 g release at 100 g/min from ceiling level mock rooftop with plenum at 1.5 m elevation

Results suggest that use of the plenum chamber is even more beneficial for return duct inlets when refrigerant-containing parts are positioned above the room.

iii) Ducted split AHU within closet

A real installation case was examined, where refrigerant was released from a ducted split AHU installed within a closet and concentrations measured within the surrounding area (kitchenette), corridors and main adjacent room. The AHU and closet are shown in Figure 117 and Figure 118, respectfully.

Figure 117: Ducted split AHU within closet

Figure 118: Closet containing ducted split AHU

A plan of the area is provided in Figure 119, indicating the positioning of each of the gas analysers.

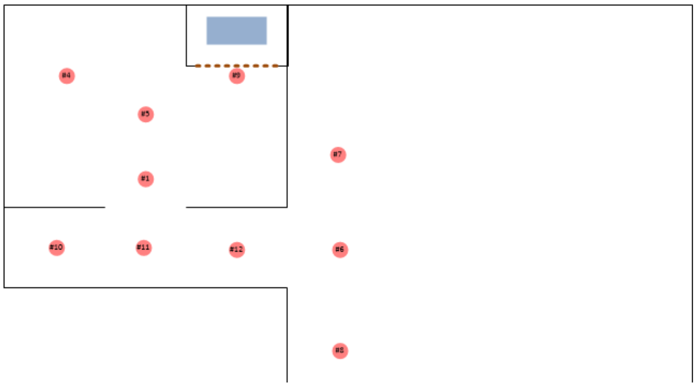


Figure 119: Plan of area nearby ducted split AHU closet

Figure 120 shows local concentrations arising from a 300 g release at 35 g/min and for a 400 g release at 50 g/min in Figure 121. Typically, concentrations closer to the AHU are higher and values diminish substantially further away sampling locations. For instance, concentrations within the hallway are approximately half of the values directly in front on the AHU and those within the big room (away from the hallway entrance) tend to be about half again. This is in contrast to the case of an empty room, where concentrations at a similar distance (e.g., 5 m) from the AHU are only marginally lower than those almost at the base of the AHU. Evidently, narrow openings between rooms impose significant resistance to outflow, causing a build-up of local concentrations and lower distant concentrations.

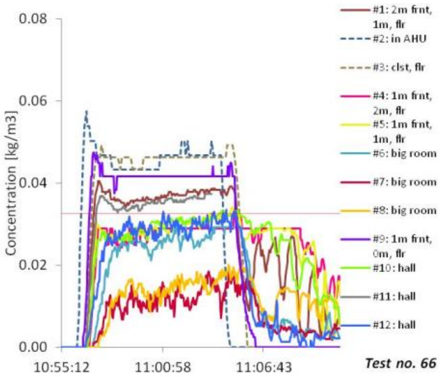


Figure 120: Release of 300 g at 35 g/min from AHU within closet

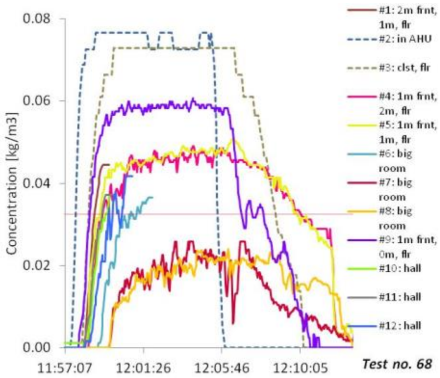


Figure 121: Release of 400 g at 50 g/min from AHU within closet

Figure 122 gives data for an “optimistic” release quantity where only 50 g is released (albeit at 50 g/min), mimicking the case of a leak from an evaporator where the system has pumped down. As with the larger release mass (Figure 121) local concentrations still exceed LFL, but persist at this level only for seconds.

Figure 123 repeats the test in Figure 121 but with a 1.0 m barrier across the closet door, to mimic the plenum chamber described previously. Whilst some positions close to the closet do exceed LFL for the second half of the release period, the overall effect is a considerable reduction in concentrations compared to the test without any intervention. Again, recognising that a 50 g/min release rate is considerably higher than what would ordinarily be expected with a large leak from an AHU, the 1.0 m plenum chamber elevation should be adequate for almost all anticipated leak scenarios.

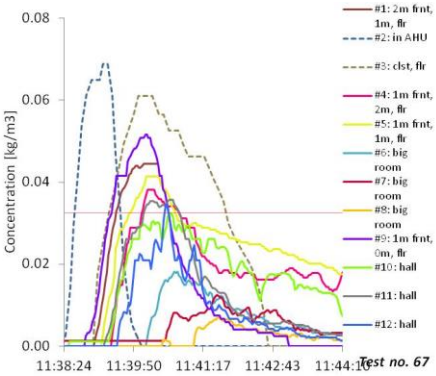


Figure 122: Release of 50 g at 50 g/min from AHU within closet

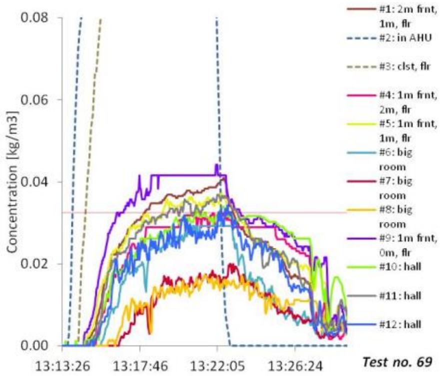


Figure 123: Release of 400 g at 50 g/min from AHU within closet with solid 1.0 m barrier at closet door

Table 12: Summary of leak simulation concentration test conditions

Test no.	Configuration	Equipment type	Room area (m2)	Leak mass (g)	Mass flow rate (g/min)	Airflow setting (m3/h)
1	main duct disch conc with airflow	ducted split AHU	33	375	75	3400
2	main duct disch conc with airflow	ducted split AHU	33	300	60	3400
3	main duct disch conc with airflow	ducted split AHU	33	380	76	3400
4	main duct disch conc with airflow	ducted split AHU	33	628	157	3400
5	main duct disch conc with airflow	ducted split AHU	33	532	133	2885
6	main duct disch conc with airflow	ducted split AHU	33	360	90	2885
7	main duct disch conc with airflow	ducted split AHU	33	171	60	0
8	main duct disch conc with airflow	ducted split AHU	33	221	56	0
9	main duct disch conc with airflow	ducted split AHU	33	218	50	0
10	main duct disch conc with airflow	ducted split AHU	33	50	50	0
11	main duct disch conc with airflow	ducted split AHU	33	300	50	2885
12	main duct disch conc with airflow	ducted split AHU	33	50	50	0
13	duct outlet conc distrib with airflow	ducted split AHU w/o return duct	33	200	50	0
14	duct outlet conc distrib with airflow	ducted split AHU w/o return duct	33	200	60	0
15	duct outlet conc distrib with airflow	ducted split AHU w/o return duct	33	100	60	0
16	duct outlet conc distrib with airflow	ducted split AHU w/o return duct	33	97	60	0
17	duct outlet conc distrib with airflow	ducted split AHU w/o return duct	33	320	60	0
18	duct outlet conc distrib with airflow	ducted split AHU w/o return duct	33	302	60	3400
19	duct outlet conc distrib with airflow	ducted split AHU w/o return duct	33	1013	145	2885
20	floor conc no airflow	ducted split AHU w/o return duct no airflow	33	73	25	0
21	floor conc no airflow	ducted split AHU w/o return duct no airflow	33	205	25	0
22	floor conc no airflow	ducted split AHU w/o return duct no airflow	33	410	50	0
23	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	304	70	0
24	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	351	50	0
25	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	359	50	0
26	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	350	50	0
27	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	355	50	0
28	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	375	50	0
29	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	380	50	0
30	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	340	50	0
31	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	350	50	0
32	duct outlet distrib pre/start airflow; floor conc	packaged/rooftop	115	350	50	0

Test no.	Configuration	Equipment type	Room area (m2)	Leak mass (g)	Mass flow rate (g/min)	Airflow setting (m3/h)
33	one duct outlet distrib pre/start airflow	packaged/rooftop	115	350	50	0
34	one duct outlet distrib continuous airflow	packaged/rooftop	115	350	230	2885
35	one duct outlet distrib continuous airflow	packaged/rooftop	115	350	230	0
36	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1000	130	0
37	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	600	130	0
38	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1045	125	0
39	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1018	125	0
40	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1013	125	0
41	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1025	125	0
42	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1021	130	0
43	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1022	130	0
44	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1042	130	0
45	beyond duct outlet pre/start airflow; elec box	packaged/rooftop	115	1022	130	0
46	beyond duct outlet pre/start airflow; floor conc with U-bend	packaged/rooftop	115	353	50	0
47	beyond duct outlet pre/start airflow; floor conc with U-bend	packaged/rooftop	115	350	50	0
48	beyond duct outlet pre/start airflow; floor conc with U-bend	packaged/rooftop	115	348	50	0
49	beyond duct outlet pre/start airflow; floor conc with U-bend	packaged/rooftop	115	347	50	0
50	surrounding outdoor unit	packaged/rooftop	115	1000	150	0
51	surrounding outdoor unit	packaged/rooftop	115	1000	150	0
52	surrounding outdoor unit	packaged/rooftop	115	1000	150	0
53	floor conc no airflow mock rooftop with U-bend	mock rooftop (duct) with down duct (split AHU)	33	362	50	0
54	floor conc no airflow mock rooftop with U-bend	mock rooftop (duct) with down duct (split AHU)	33	351	50	0
55	floor conc no airflow mock rooftop with U-bend	mock rooftop (duct) with down duct (split AHU)	33	352	50	0
56	floor conc no airflow mock rooftop with U-bend	mock rooftop (duct) with down duct (split AHU)	33	355	50	0
57	floor conc no airflow mock rooftop with U-bend	mock rooftop (duct) with down duct (split AHU)	33	351	50	0
58	floor conc no airflow split AHU with U-bend	ducted split AHU w/o return duct	33	53	50	0
59	floor conc no airflow split AHU with U-bend	ducted split AHU w/o return duct	33	187	50	0
60	floor conc no airflow split AHU with U-bend	ducted split AHU w/o return duct	33	346	50	0
61	floor conc no airflow split AHU with U-bend	ducted split AHU w/o return duct	33	349	50	0
62	floor conc no airflow split AHU with U-bend	ducted split AHU w/o return duct	33	351	50	0
63	floor conc no airflow split AHU with U-bend	ducted split AHU w/o return duct	33	355	50	0
64	floor conc no airflow split AHU with U-bend	ducted split AHU w/o return duct	33	1000	100	0
65	floor conc no airflow split AHU with U-bend	mock rooftop (duct) with down duct (split AHU)	33	1000	100	0
66	floor conc no airflow split AHU in closet	ducted split AHU w/o return duct	var	300	35	0

Test no.	Configuration	Equipment type	Room area (m2)	Leak mass (g)	Mass flow rate (g/min)	Airflow setting (m3/h)
67	floor conc no airflow split AHU in closet	ducted split AHU w/o return duct	var	52	50	0
68	floor conc no airflow split AHU in closet	ducted split AHU w/o return duct	var	399	50	0
69	floor conc no airflow split AHU in closet	ducted split AHU w/o return duct	var	408	50	0
70(1)	floor conc no airflow	ducted split AHU w/o return duct no airflow	33	100	25	0
71(2)	floor conc no airflow	ducted split AHU w/o return duct no airflow	33	400	25	0
72(3)	floor conc no airflow	ducted split AHU w/o return duct no airflow	33	100	50	0
73(4)	floor conc no airflow	ducted split AHU w/o return duct no airflow	33	400	50	0

2.6 Elimination of sources of ignition

2.6.1 Introduction

There are a variety of different types of sources of ignition (SOI) and their presence within or nearby the DACS must be established, as well as their particular characteristics. An initial filtering of potential SOIs is carried out (according to EN 1127-1) and a summary is given in Table 13.

Table 13: Filtering for potential sources of ignition

Type	Evaporator enclosure	Condensing unit enclosure
Hot surfaces	Friction on fan motor shaft	Compressor, friction on fan motor shaft
Flames and hot gases (including hot particles)	None	None
Mechanically generated sparks	Evaporator fan blade impacts	Condenser fan blade impacts
Electrical apparatus	Evaporator fan motor	Condenser fan motor, mains contactor, compressor relay, compressor start relay
Stray electric currents	None	None
Static electricity	Evaporator fan blades	Condenser fan blades
Lightning	None	Not applicable
Radio frequency (RF) electromagnetic waves from 10^4 Hz to 3×10^{11} Hz	None	None
Electromagnetic waves from 3×10^{11} Hz to 3×10^{15} Hz (microwave, infrared)	None	None
Ionising radiation	None	None
Ultrasonic	None	None
Adiabatic compression and shock waves	None	Compressor (internal)
Exothermic reactions	None	None

There are a number of items that could be possible SOIs. In order to comply with various standards, the equipment and location must be considered with respect to potential sources of ignition. An inspection of an installed system yielded the potential sources of ignition listed in Table 15.

EN 1127-1 describes the procedure for addressing potential SOIs and in summary is:

- Identify all possible points of leakage;
- Conduct hazardous area classification (zoning) exercise, as prescribed in IEC 60079-10-1;
- Ascertain electrical (or non-electrical) components within those zones that could be potential SOIs;
- Eliminate those potential SOIs from the zones, either by replacing with non-SOI equivalent components or relocating existing components outside the hazardous area.

This approach is included within the draft NTC 6228-2 and is indented for application to air conditioning and refrigeration equipment. Accordingly, the leak simulation test method within the annex has been used for the zoning exercise.

Note that this exercise is only applied to the DACS products (and associated equipment that the manufacturer has some degree of control over). Since the manufacturer has no control over potential SOIs beyond the boundaries of the products and associated equipment, it is intended to ensure that formation of flammable mixtures are reasonable prevented by design (see section 2.5).

2.6.2 Identification of leak points

All four unit housings are essentially single enclosures that encompass refrigerant-containing parts throughout, of which there are numerous potential leak points (such as joints, connection, line components, etc.) Of these numerous possible leak points at least two were selected that would lead to the highest concentration around the potential SOIs. Choice of these points is based on experience and trial-and-error.

2.6.3 Hazardous area classification

The zoning exercise can employ various means, including simple semi-empirical numerical or graphical methods (such as those offered in IEC 60079-10-1), computational method (such as CFD) or by test. Rigorous testing is perhaps the most reliable approach as it takes into account the nuances of particular equipment deigns that the numerical methods cannot. Therefore the method for leak simulation testing in the draft NTC 6228-2 was used. This prescribes that the total (releasable) charge is leaked through an orifice at 60 g/min in the least favourable direction and the refrigerant concentration measured at the relevant potential SOIs. Provided the concentration does not exceed 50% of the LFL then the component is not considered to be a SOI.

For purposes of completion the applicable conditions for zoning from IEC 60079-10-1 are addressed within Table 14. Note that the inputs are applicable to all DACS housings.

Table 14: Area classification

60079-10-1 clause		All housings
5.2	Sources of release †	Various bends, joints and line components, as applicable
5.2	Grade of release	Secondary
5.3	Type of zone	2
5.4.1	Release rate of gas or vapour	Vapour
5.4.1 a	Geometry of the source of release	Circular orifice
5.4.1 b	Release velocity	Supersonic (choked)
5.4.1 c	Concentration	> 50% of LFL
5.4.1 d	Volatility of a flammable liquid	Not applicable
5.4.1 e	Liquid temperature	Not applicable
5.4.2	Lower flammability limit	0.038 kg/m^3 (ref: ISO 817)
5.4.3	Ventilation	None
5.4.4	Relative density of the vapour	1.5 x air
5.4.5	Other parameters	Release from various directions/orientations
5.4.5 a	Climatic conditions	Not applicable (inside controlled room)
5.4.5 b	Topography	Internally congested
6	Ventilation	None
6.1	General	None
6.2	Main types of ventilation	None
6.3	Degree of ventilation	Not applicable
6.4	Availability of ventilation	Not applicable
	Zone	2
	Zone extent	Entire internal boundary of housing

† IEC 60079-10-1, clause 5.2 states: “for example, an all-welded pipeline is not considered to be a source of release”; the entire refrigerating circuit is entirely brazed (analogous to welded) and is therefore not necessarily considered to be a source of release.

Due to the relatively confined construction of the various DACS housings’ a release form any point rapidly ensures any position within the housing with exceed 50% of the LFL. Therefore it is necessary to position any potential SOIs into an externally located panel.

2.6.4 Consideration of potential SOIs

The majority of electrical components (many of which could be a potential SOI are located within inset electrical panels. Ordinarily this comprises (e.g., Figure 124):

- Mains relays
- Start capacitors
- Run capacitors
- Voltage transformers
- Timer/delay
- Terminal connections

Of these, only the relay and timer/delay could be considered as a potential SOI (see below).

Figure 124: Typical contents of electrical panel

Evaporator and condenser fans

Evaporator fans are located within the AHU housing and are thus likely to come into sustained contact with refrigerant in the event of a leak. Therefore significant attention should be paid to them for purpose of avoidance of ignition sources. Condenser fans are positioned at the top of the condensing unit and normally located in the open air. A leak of refrigerant is unlikely to accumulate around the condenser fan so limited attention may be paid to them.

Figure 125: Example of evaporator fan motor (left) and fan blades (right)

Both condenser fan and evaporator fan motors are AC induction type and since they are brushless do not present a SOI under normal operation. They do use internal overload protectors [types to be confirmed].

Figure 126: Example of condenser fan motor (left) and fan blades (right)

All fan blades are aluminium, whilst the cowling is galvanised steel. Provided that the fan and cowling materials are not stainless steel pairs or steel alloy and brass pairs, the possibility of sparking due to mechanical impact is negligible. In order to further ensure the fan assembly has negligible risk of producing arcs and sparks, the following must be complied with:

- Rotational speed should be less than 40 m/s.
- Powder coating must not contain aluminium or iron oxides.
- All metallic parts of the fan assembly are parts are earthed, which avoid the possibility of static build-up.
- Clearance distance between the fan blades and the casing shall be at least 1% of the diameter and no less than 2 mm.

It is recommended to consider that the evaporator fan motor be sent to a test house for evaluation of the evaporator fan motor against the relevant standard (e.g., IEC 60079-15 or EN 14986). As mentioned, the condenser fan motor does not raise a concern in this regard, since the concentration arising from a leak of refrigerant whilst the condenser fan is operating is a fraction of the LFL due to the fan's high volume flow rate.

High and low pressure switches

These are basic fixed-values encapsulated switches. They are likely to be suitable. However, several manufacturers are producing R290 approved components; these should be sought first before considering use of R22 components. If R22 items are applied then it is recommended they are checked for compliance against IEC 60079-15, e.g., for enclosed break type device. [Confirmation awaiting]

Figure 127: Example of pressure switch

Compressor

Currently compressors are Copeland R290 scrolls. Whilst they comprise internal windings and thermal overloads; the only external electrical parts are terminals and wires and have nevertheless been certified against the applicable Ex standard. As such they do not present as SOIs under normal operation.

Figure 128: Example of compressor (left) and electrical connection (right)

Liquid line solenoid valve

At present a LLSV is not used, however, it is strongly recommended that a normally-closed solenoid valve is installed within the liquid line for purposes of limiting releasable charge. Since solenoid valves do not arc or spark under normal operation they are not considered SOIs. However, it is recommended that R290 approved SVs are selected.

Mains relays

The electrical panel contains one 2/3 pole mains relay. Whilst it is intended to position the electrical panel external to the housing, it may be considered to check the construction of the used relays against the requirements for enclosed break device under IEC 60079-15 in order to provide additional confidence.

Figure 129: Example of mains relay employed

2.6.5 Modifications to eliminate SOIs

In response to the initial zoning exercise, several components needed to be relocated out of the zone 2 area. This was achieved by redesigning the panel such that it was located in an air-separated section; in this regards, even if the inset section is not sufficiently tight to prevent egress of leaked refrigerant, it should be unable to penetrate the second enclosure. A prototype is included in Figure 130 along with a schematic.

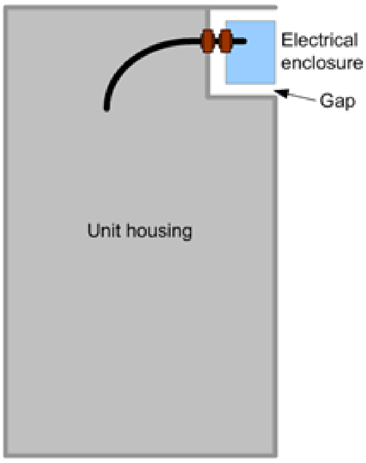


Figure 130: Current (left) and proposed (right) electrical panel

By following the leak simulation test (zoning exercise) detailed in NTC 6228-2, it was demonstrated that the revised construction avoided contact with a concentration exceeding 50% of LFL. The test details are provided in section Appendix F.

By separating the electrical panel, it ensures that if a technician in=advertently fits an unsuitable component after the units has been installed, there remains no residual risk that it could act as a SOI to a refrigerant leak.

An overview of the handling of the potential SOIs is provided in Table 15.

Table 15: Summary evaluation of potential SOIs associated with DACS

Element	Original construction			Stage 6 prototype		
	Items within zone 2	Location	Normal SOI/ protection	Items within zone 2	Location	Normal SOI/ protection
Ducted split AHU	Evaporator fan motor	Internal	Non-sparking	Evaporator fan motor	Internal	Non-sparking
	Evaporator fan blades	Internal	Non-sparking	Evaporator fan blades	Internal	Non-sparking
	Relay	Inset panel	SOI	n/a	Within external panel	n/a
	Start capacitor	Inset panel	Non-sparking	n/a	Within external panel	n/a
	Run capacitor	Inset panel	Non-sparking	n/a	Within external panel	n/a
	Voltage transformer	Inset panel	Non-sparking	n/a	Within external panel	n/a
	Terminals	Inset panel	Non-sparking	n/a	Within external panel	n/a
Ducted split cond unit	Condenser fan motor	Internal	Non-sparking	Condenser fan motor	Internal	Non-sparking
	Condenser fan blades	Internal	Non-sparking	Condenser fan blades	Internal	Non-sparking
	Low pressure switch	Internal	Encapsulated	Low pressure switch	Internal	R290 approved
	High pressure switch	Internal	Encapsulated	High pressure switch	Internal	R290 approved
	Compressor (terminals)	Internal	Non-sparking	Compressor (terminals)	Internal	Non-sparking
	Mains contactor	Inset panel	SOI	n/a	Within external panel	n/a
				Solenoid valve	Internal	R290 approved
Rooftop AHU	Evaporator fan motor	Internal	Non-sparking	Evaporator fan motor	Internal	Non-sparking
	Evaporator fan blades	Internal	Non-sparking	Evaporator fan blades	Internal	Non-sparking
	Relay	Inset panel	SOI	n/a	Within external panel	n/a
	Mains contactor	Inset panel	SOI	n/a	Within external panel	n/a
	Start capacitor	Inset panel	Non-sparking	n/a	Within external panel	n/a
	Run capacitor	Inset panel	Non-sparking	n/a	Within external panel	n/a
	Voltage transformer	Inset panel	Non-sparking	n/a	Within external panel	n/a
	Timer/delay	Inset panel	SOI	n/a	Within external panel	n/a
	Terminals	Inset panel	Non-sparking	n/a	Within external panel	n/a
Rooftop cond unit	Condenser fan motor	Internal	Non-sparking	Condenser fan motor	Internal	Non-sparking

Element	Original construction			Stage 6 prototype		
	Items within zone 2	Location	Normal SOI/ protection	Items within zone 2	Location	Normal SOI/ protection
	Condenser fan blades	Internal	Non-sparking	Condenser fan blades	Internal	Non-sparking
	Low pressure switch	Internal	Encapsulated	Low pressure switch	Internal	R290 approved
	High pressure switch	Internal	Encapsulated	High pressure switch	Internal	R290 approved
	Compressor (terminals)	Internal	Non-sparking	Compressor (terminals)	Internal	R290 approved
				Solenoid valve	Internal	R290 approved

2.7 Limiting of potential consequences

Consideration should be given to possible consequences in the event of ignition of a flammable mixture.

Primary consequences are the initial effects or processes arising from the burning mixture

- Radiated thermal energy
- Evolution of increased pressure or pressure waves

These lead to secondary consequences, such as

- Burning/charring of surfaces including building materials and skin
- Physical (blast) damages to structures and bodies
- Development of secondary fires

Preferred approach to avoiding or minimising severity of consequences is prevention of ignition, through elimination of SOIs and curtailing formation of flammable mixtures.

However, as long as flammable substances are being employed avoidance of these cannot be absolutely guaranteed. Therefore additional consideration should be given to limiting the effects of such consequences. Typical approaches include:

- Physical barriers between potentially flammable mixtures and occupants and combustible materials
- Non-combustible construction materials to avoid secondary combustion
- Sufficient free openings or frangible sections for enclosures that can enable overpressure relief

2.8 Consideration of limits of use and misuse

The extents of possible use and foreseeable misuse must be considered with regards to explosion protection and prevention. The following list identifies the potentially hazardous situations associated with human interaction of the machine according to EN ISO 12100. The subsequent actions was addressed through design and information for the DACS.

Table 16: Evaluation of limits of use and misuse of the DACS]

Consideration
Use limits
Aspects of use limits to be taken into account include:
▪ The different machine operating modes and different intervention procedures for the users, including interventions required by malfunctions of the machine
▪ The use of the machinery (for example, industrial, non-industrial and domestic) by persons identified by sex, age, dominant hand usage, or limiting physical abilities (visual or hearing impairment, size, strength, etc.)
▪ The anticipated levels of training, experience or ability of users including operators, maintenance personnel or technicians, trainees and apprentices, and the general public
▪ Exposure of other persons to the hazards associated with the machinery where it can be reasonably foreseen, such as persons likely to have a good awareness of the specific hazards, such as operators of adjacent machinery, persons with little awareness of the specific hazards but likely to have a good awareness of site safety procedures, authorised routes, etc., such as administration staff and persons likely to have very little awareness of the machine hazards or the site safety procedures, such as visitors or members of the general public, including children
Space limits
Aspects of space limits to be taken into account include:
▪ The range of movement

Consideration
▪ Space requirements for persons interacting with the machine, such as during operation and maintenance
▪ Human interaction such as the operator–machine interface
▪ The machine–power supply interface
Time limits
Aspects of time limits to be taken into account include:
▪ The life limit of the machinery and/or of some of its components (tooling, parts that can wear, electromechanical components, etc.), taking into account its intended use and reasonably foreseeable misuse
▪ Recommended service intervals
Environmental limits
Aspects of environmental limits to be taken into account include:
▪ The recommended minimum and maximum temperatures
▪ Whether the machine can be operated indoors or outdoors, in dry or wet weather, in direct sunlight
▪ Tolerance to dust and wet, etc.
Task identification
▪ Setting
▪ Testing
▪ Teaching/programming
▪ Process/tool changeover
▪ Start-up
▪ All modes of operation
▪ Feeding the machine
▪ Removal of product from machine
▪ Stopping the machine
▪ Stopping the machine in case of emergency
▪ Recovery of operation from jam or blockage
▪ Restart after unscheduled stop
▪ Fault-finding/trouble-shooting (operator intervention)
▪ Cleaning and housekeeping
▪ Preventive maintenance
▪ Corrective maintenance
Possible states of the machine
The machine performs the intended function (the machine operates normally)
The machine does not perform the intended function (i.e. it malfunctions) due to a variety of reasons, including
▪ variation of a property or of a dimension of the processed material or of the workpiece
▪ failure of one or more of its component parts or services
▪ external disturbances (for example, shocks, vibration, electromagnetic interference)
▪ design error or deficiency (for example, software errors)
▪ disturbance of its power supply
▪ surrounding conditions (for example, damaged floor surfaces)
Unintended behaviour of the operator or reasonably foreseeable misuse of the machine
▪ Loss of control of the machine by the operator
▪ Reflex behaviour of a person in case of malfunction, incident or failure during the use of the machine
▪ Behaviour resulting from lack of concentration or carelessness
▪ Behaviour resulting from taking the “line of least resistance” in carrying out a task
▪ Behaviour resulting from pressures to keep the machine running in all circumstances
▪ Behaviour of certain persons (for example, children, disabled persons)

3. Quantitative risk assessment

3.1 General methodology

The QRA is carried out considering the operation (in-use) phase for the two DACS. Accordingly, the various equipment characteristics and environmental conditions that affect the likelihood of ignition of a flammable mixture occurring are taken into account. This requires an analysis of the equipment and the surroundings and the findings being integrated into the basic methodology, which is:

- Select a range of leak hole sizes and determine the frequency of the occurrence of leak hole size
- For each leak hole size, estimate the average mass flow rate of the release
- Identify each relevant operating mode (system on/off-cycle, fan on/off-mode; wherever applicable) and external conditions (infiltration rates, presence of occupants, external SOIs, etc)
- For each of the leak sizes, operating modes and sets of external conditions, estimate gas concentration within the unit compartment, flammable volume within unit compartment, gas concentration within room and flammable volume within room
- Determine the probability of a flammable mixture within unit compartment and the probability of flammable mixture within room
- Nominate a set of potential sources of ignition (SOI) within the room and the unit compartment including activation characteristics and their location
- Determine probability of SOI and the corresponding frequency of ignition
- For each circumstance that leads to an ignition event, estimate the corresponding overpressure and thermal intensity
- Calculate overall risk values

In order to carry out the calculations, it is first necessary to discretise the operation into segments according to the leak hole size, location of SOI, etc. The occurrence of each event requires a probability to be assigned to it. Thus, based on estimation of frequency of a release, size of flammable volumes and probability of active sources of ignition, the ignition frequency and well as the size of the consequent overpressure and thermal intensity can be estimated. These results then enable the risk values to be calculated.

In carrying out the quantification of all of the elements discussed above, empirical data from field information, measurements and other validation techniques are used to improve the confidence of the QRA results. The data, relevant parameters and DACS design and installation characteristics were based on discussions, measurements, taken from previous studies (where relevant) and from the technical literature.

The probability calculations used for the normal operation are described in this section and include three main elements:

- Calculation of ignition frequency, consequence and risk for a given set of conditions
- Calculation of the probability of each set of conditions occurring
- Calculation of the overall ignition frequency and risk for the entire set of conditions

These involve the estimation of contributing events, such as occurrence of flammable concentrations and active sources of ignition and estimations of the probabilities of particular operating modes. In addition, the situation is separated into the risk associated with a release into the condensing unit compartments and a release transferring into the room. Thus, the calculations are carried out according to:

- Ignition of a release within the applicable compartments within the DACS by unintended potential SOI (i.e., a faulty or an incorrectly fitted component)
- Ignition of a release within the room by other potential SOI that are normally present within the room
- Ignition of a release surrounding the outdoor parts of the equipment by other potential SOI that are normally present outside

A potential SOI is a device which could under fault or failure conditions become a SOI, although under normal operation it cannot cause ignition. Examples of this may be the short circuiting of a fan motor windings or a switch whose protective cover has been broken or not affixed correctly.

A detailed description of the calculation of these risk measures is provided in Appendix I. A summary of the important combustion and ignition characteristics of R290 are provided in Appendix A.

3.2 Product and installation characteristics

It is necessary to base the QRA on products with specific design and installation characteristics. The details within section XXX are used as the two selected models.

In addition, the installation characteristics are based on the most common arrangements.

For the ducted split:
- Placed within a closet with louvered doors
- Supplying room(s) corresponding to 35 m^2 area (approximately half the usual design area)
- Supply air ducted upwards and horizontally to four outlets at ceiling level, with a total length of 21 m
- No return air duct; only via return air inlet
- Interconnecting piping passing through a second closed space; practically this may be anything from a small service shaft to a large room, but for the present task it will be assumed to be a corridor/hallway with a length of 8 m, height 2.5 m and width 1.5 m. The piping is run along the wall/ceiling corner and only the suction line is insulated.
- Condensing unit located outside on a 20 cm high plinth and at least 0.5 m from any adjacent wall

For the rooftop unit:
- Placed outside on an elevated surface (roof)
- Supplying room(s) corresponding to 35 m^2 area (approximately half the usual design area)
- Supply air ducted downwards and horizontally to four outlets at ceiling level, with a total length of 22 m
- Return air ducted upwards from a single inlet near floor level and across to return air inlet, with a total length of 9 m
- All interconnecting piping within unit housing

Systems operate on an on-off basis and for equal times (50% on. 50% off).

3.3 Formulation of conditions

In order to quantify the risk of the normal operation, it is necessary describe the generic operating and environmental conditions that could affect the likelihood of ignition. In considering this, it is also necessary to characterise the three co-incident events that are necessary to cause ignition:

- A leak of refrigerant that enters a given control volume (enclosure, room, etc.)
- Formation of a flammable mixture
- At the same time, presence of an active SOI within the condensing unit compartment or room

This general sequence of events is shown in Figure 131.

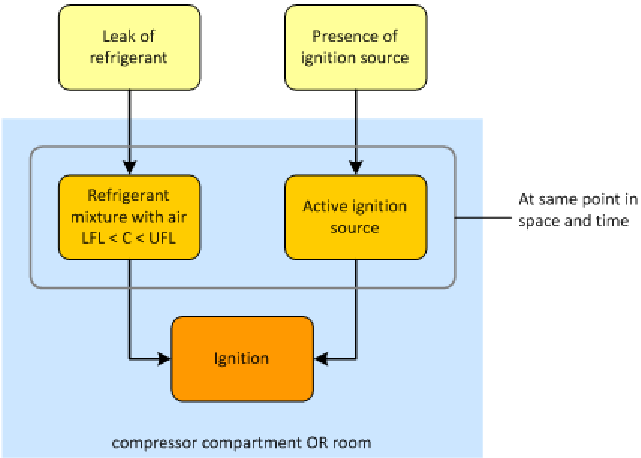


Figure 131: General sequence of events for normal operation

In order to better identify the condition within each stage that could lead to ignition of a release, the variables will be described in more detail.

Leak size: Various leak sizes are considered, ranging from "pin hole" to "catastrophic". A general function for leak size increments is used.

Compressor operating mode: For larger systems, the likelihood of a leak and the release rate can be affected by the compressor operating mode, but for smaller systems with no mechanical joints, such as in the current case, the leak characteristics are considered to be largely unaffected by compressor operation. Therefore this parameter is neglected.

Fan operation: An evaporator blower or condenser fan may or may not be operating on the DACS, creating an internal airflow within enclosure, ducting and the local area.

Ambient air movement: Various forms of airflow can affect the dispersion of the refrigerant and therefore the size and duration of a flammable volume. Inside this can arise from infiltration, thermal convention currents and movement of personnel and additionally outside from wind.

Number of occupants: The severity of the secondary consequence can by indicated by the frequency of fatalities. However, in this study it is found that the consequence of ignition is very unlikely to cause overpressure or a thermal dose that could result in fatality and therefore the number of occupants is not applied, except in terms of their distribution, implying an average distance from the ignition event.

Room dimensions: The size of the room can affect the build-up of gas concentrations and thus the occurrence of a flammable mixture within the room. Only one room size is opted for, which is representative of a particularly small space for where these types of appliances are normally located.

3.4 Fault conditions

Both the DACS have been designed to minimise the likelihood that a flammable mixture could form around in an area beyond the unit housing. However, it is possible that failures occur with the various measures that have been designed into the DACS.

Figure 132 and Figure 133 show the various sequence of events involving a leak and which could affect the development of a flammable mixture within the surrounding area. Included in the figures are the estimated quantities of R290 released and a colour code to indicate the likely size of a flammable mixture. The colour code is according to the following key:

(green)	Flammable mixture highly unlikely
(yellow)	Small, transient flammable mixture possible
(light orange)	Small, transient flammable mixture likely
(orange)	Medium flammable mixture likely
(red)	Large flammable mixture highly likely

Event tree and fault tree analysis are used to determine the probability of each of these failure modes occurring and for each leak hole size.

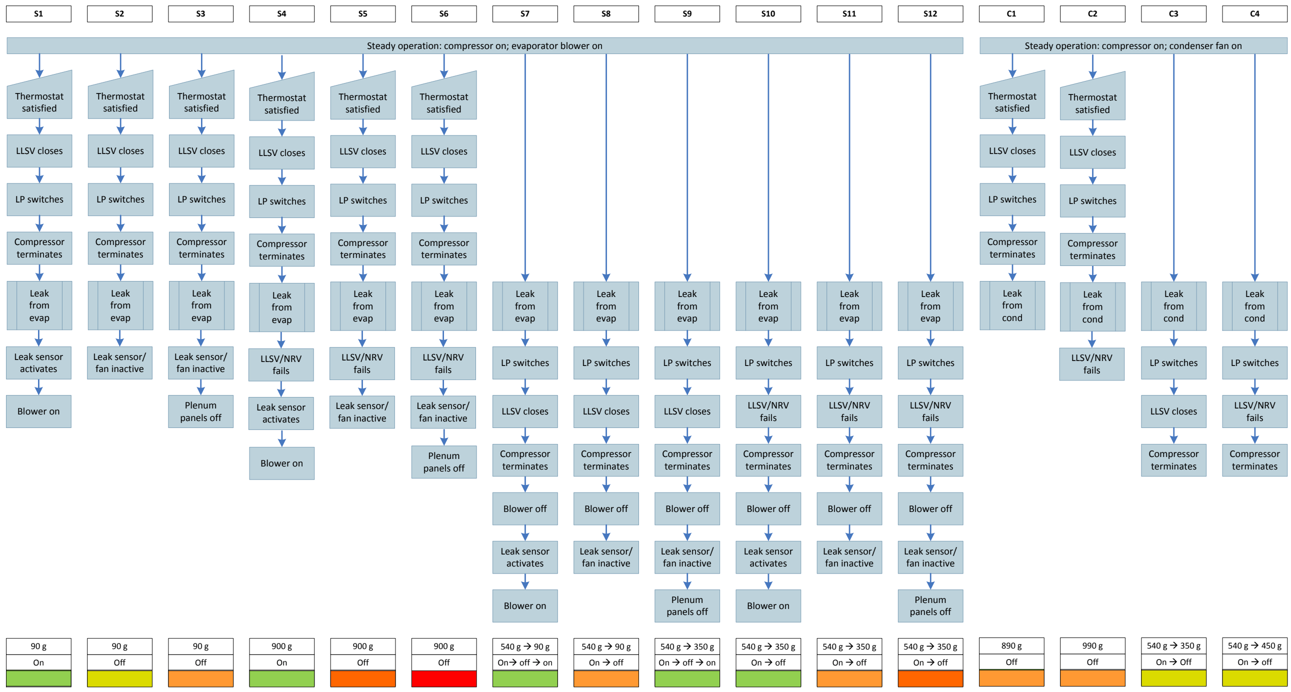


Figure 132: Failure modes for ducted split AHU and condensing unit

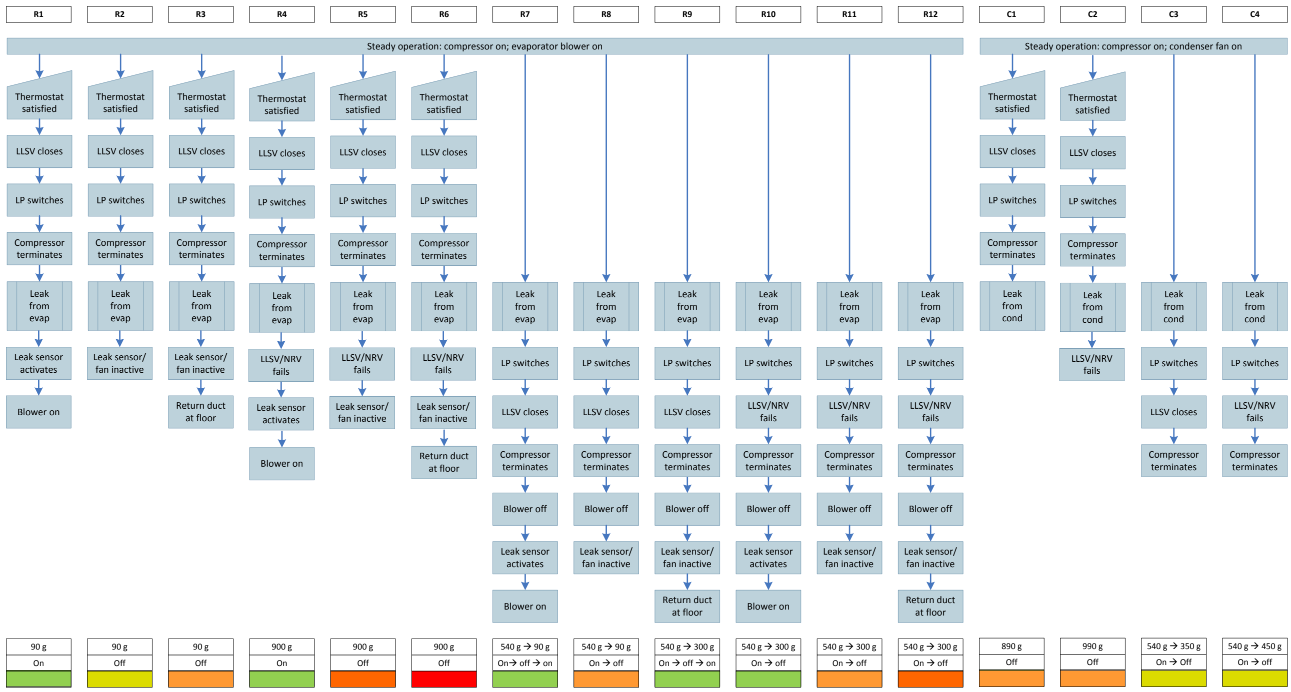


Figure 133: Failure modes for rooftop unit

Where a mitigation feature is employed specifically to minimise the likelihood of the formation of a flammable mixture, assumptions must be made to account for failures. The applicable failures are identified in Table 17, where the values for probability of failure on demand (PFD) are taken from previous work; values are averaged across the DACS lifetime.

Table 17: Failure rates for elements within mitigation features

Element	Failures	Prob. failure on demand	Remark
Ultrasonic leak sensor	Internal fault, no response	0.0005	Limited cause for PFD; mainly elec circuit
Leak controller	Internal fault	0.0002	PCB reliability
Blower fan/motor	Passage blocked, no start	0.0001	Necessary for functioning of DACS; auto-repair
NRV	Stuck open, not sealed	0.0015	Fault not obvious; could exist for DACS lifetime
LLSV	Stuck open, not sealed	0.0015	Fault not obvious; could exist for DACS lifetime
Ducted split AHU panels	Not replaced	0.05	Could be present through service cycle
Rooftop return inlet opening	Installed at floor	0.2	Present for DACS lifetime

3.5 Fault trees

According to Figure 131 and the subsequent discussion, a number of events can occur which affects the probability of ignition. In order to characterise and quantify these, the failure modes were analysed in order to determine the likelihood of events that would lead to ignition of a release of R290. This was achieved by developing a fault tree for ignition within the room surrounding the AHU or duct outlet, within the DACS housings and surrounding the condensing unit parts; standard methods as detailed in EN 31010[4] and BS

[4] prEN 62502 Analysis techniques for dependability – Event tree analysis, BSI, London, 15 June 2009

5760-7[5] were used. By calculating the probabilities of successive nodes within the fault trees, the cumulative probabilities for each 'top event' (in this case, ignition of the flammable mixture) are obtained. Figure 134 and Figure 135 provide an example of the fault trees for the condensing unit compartment and room, respectively. Values for the events within the fault trees are not included as the probabilities vary according to the individual set of conditions, specific behaviour of the different sources of ignition and the likelihood of the presence of the flammable mixture within each control volume.

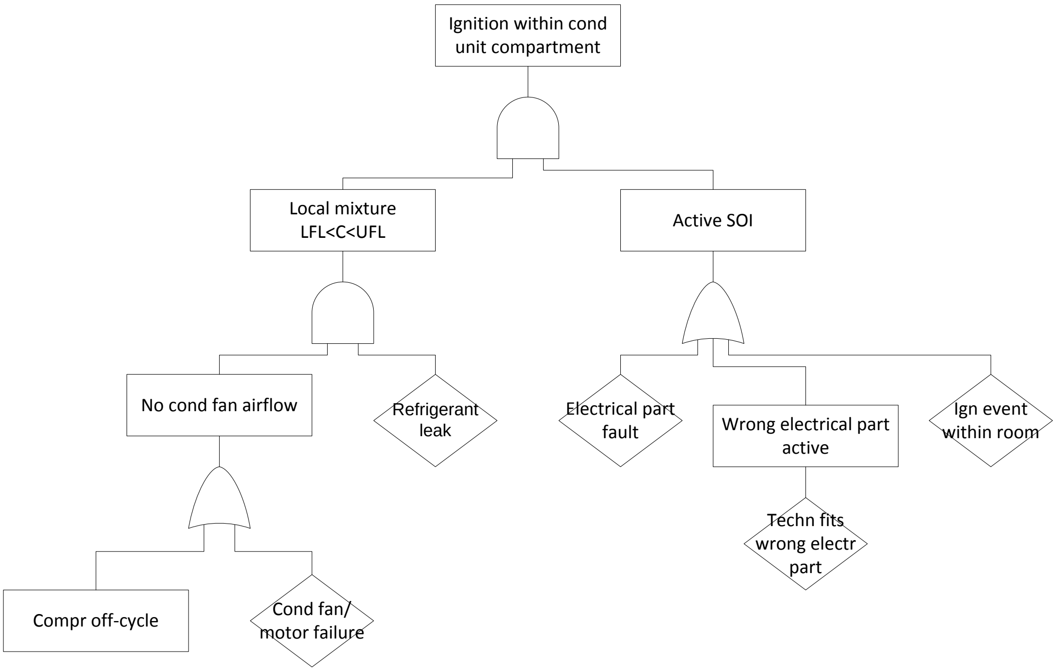


Figure 134: Fault tree for ignition within condensing unit enclosure top event

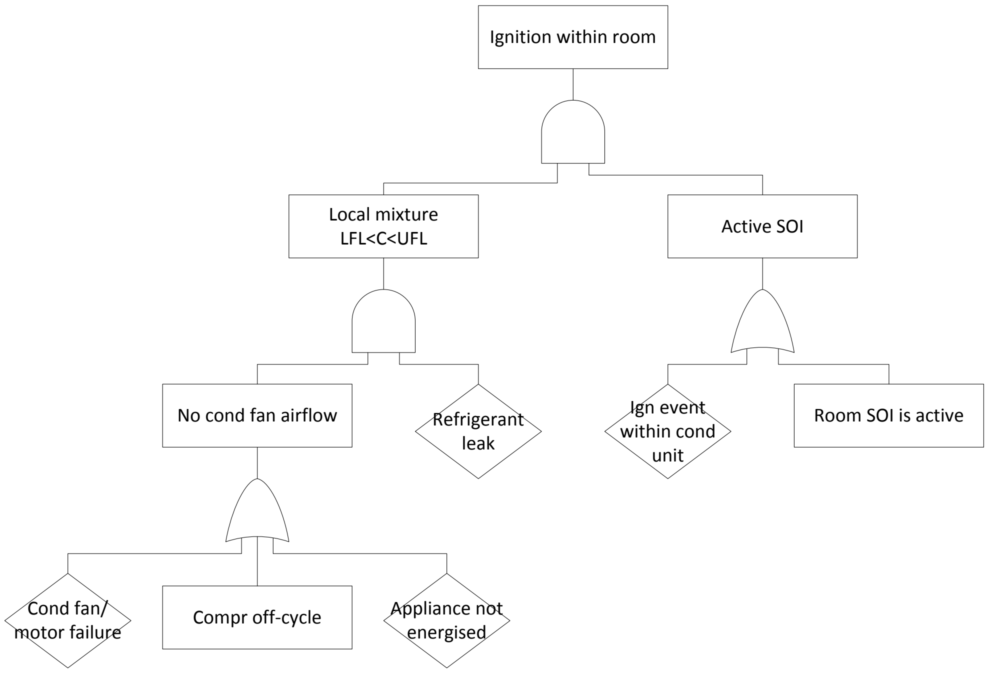


Figure 135: Fault tree for ignition within room top event

[5] BS 5760-7: 1991 Reliability of systems, equipment and components — Part 7: Guide to fault tree analysis

3.6 Leak frequencies

Estimation of realistic leak frequencies is a difficult task since it is dependent upon a wide number of parameters, but primarily because the important data that is necessary for determining the frequency of different leak sizes is virtually never recorded systematically. There are three sources currently available for leak frequencies. The first is sourcing values established in other (related) studies. The second is the use of formulas developed in work relating to industrial (petro-chemical) applications. The third is to utilise empirical data recorded from refrigeration systems.

Table 18 provides a summary of the leak frequencies reported in risk assessments for similar types of refrigerating systems. It can be seen that there is a rather wide variation. However, it should also be noted that these leak frequencies are either given as a single "overall" leak frequency, or divided into two, such as for "small" and "large" leaks. Process industry handbooks (e.g., Lees, 2005[6]) provide industry average values for certain types of equipment such as pumps, valves, etc., however, this can also be considered not strictly applicable to factory-sealed refrigeration appliances since pipe materials, jointing practices and test methods are different. Empirical formulas are not widely available although some works (e.g., Spouge, 1995[7]) present correlations for industrial process systems piping.

Table 18: Leak frequencies used in previous studies

Source	Equipment details	Leak frequency (y^{-1})
EN TR 14739 (2004)[8]	Domestic refrigerator during operation †	2.9×10^{-9}
Van Blanken and Verwords (2001)	Ice cream cabinets, rupture † Ice cream cabinets, 10% leakage †	1×10^{-5} 5×10^{-5}
Wolfer and Seiler (1999)[9]	Supermarket chiller continuous Supermarket chiller spontaneous	5.7×10^{-5} 6.3×10^{-6}
ADL (1998)[10]	Chest freezer, total † Multi-deck freezer, total Remote draft chiller, total Shelf draft chiller, total Bottle cooler, total †	9.3×10^{-6} 1.2×10^{-4} 6.0×10^{-4} 4.0×10^{-3} 2.0×10^{-5}
Goetzler et al (2016)	5T rooftop unit (normal operation) 5T ground rooftop unit (normal operation) · condenser fast · condenser slow · evaporator fast · evaporator slow	1.0×10^{-2} 9.4×10^{-5} 1.8×10^{-3} 3.1×10^{-5} 5.9×10^{-4}
JSRAE (2017)	Commercial split AC · outdoor unit fast · outdoor unit slow · indoor unit fast · indoor unit slow	 1.34×10^{-3} 6.13×10^{-2} 1.5×10^{-5} 1.03×10^{-3}

† These systems are considered to represent the F740h presently under consideration most closely

For the present work, historical leak data was made available by the manufacturer from the 2016-2017 service database for the specific products under consideration. This provided bulk leak frequencies for

[6] Lee's loss prevention in the process industries. 2005. Lee, F., Mannan, S (Ed). Elsevier Butterworth-Heinemann, UK.
[7] Spouge, A., New generic leak frequencies for process equipment, Process Safety Progress (2005), vol. 24, no 4, 249-257
[8] EN TR 14739: 2004. Scheme for carrying out a risk assessment for flammable refrigerants in case of household refrigerators and freezers. BSI, London. 2004
[9] Wolfer, M., Seiler, H. Ammoniak und Kohlenwasserstoffe als kaltemittel: riskoanalyse, produktehaftpflicht und strafrecht. Bundesamtes fur Energie, Switzerland. December 1999
[10] ADL. Risk assessments of flammable refrigerants. Report for Calor Gas Ltd. Arthur D. Little, Cambridge, UK. 1998

indoor (AHU) and outdoor (condensing unit) parts of the system. No leaks were reported for interconnecting piping of ducted splits, so a value was approximated based on corresponding pipe lengths. These bulk leak frequencies were then used to calibrate a leak frequency model, based on an internal database of leakage data (e.g., as described in Colbourne and Suen, 2004a and Colbourne and Espersen, 2013) and other industry studies such as those reported in Table 18 and JARECO (2013[11]). Leak frequencies for the respective parts of the DACS were estimated for three sets of hole size ranges and assigned an average hole size. The breakdown is provided in Table 19.

Table 19: Division of leak frequency according to circuit and hole size

Leak hole size	5 mm^2	1 mm^2	0.1 mm^2
Evap leak hole freq (/y)	3.3E-06	2.0E-05	6.4E-04
Cond leak hole freq (/y)	1.2E-05	7.2E-05	2.3E-03
Interconnting piping* (/y)	5.8E-07	3.5E-06	1.1E-04
Total (rooftop) (/y)	1.5E-05	9.2E-05	3.0E-03
Total (ducted split) (/y)	1.6E-05	9.6E-05	3.1E-03

* Ducted split only

It is assumed that all leak hole occur instantaneously and are repaired at the subsequent service visit, i.e., systems are not re-charged prior to leak repair.

3.7 Estimation of refrigerant release rate and quantity

Measurements were conducted to determine the quantity of refrigerant released and the average mass flux of those releases, under various scenarios. The data is provided in section 2.4 and from this, values have been assigned to each of the failure mode scenarios; Table 5 for the ducted split and Table 21 for the rooftop unit. The two stages (stage 1 and stage 2) refer to the conditions before and after the compressor has terminated whilst the leak persists. Whilst measurements show a decay type change in mass flow rate as a function of time, a constant average mass flow is used for simplicity. Experiments have also shown that – except for the initial moments where two-phase "spitting" may be observed – the majority of the leak involves vapour phase only. Again, for simplicity all releases are assumed to occur as vapour only. Nevertheless, this is also a pessimistic assumption since experiments measuring gas concentration from a simulated leak shows that two-phase releases in fact lead to lower concentrations throughout the room on account of the turbulence causes by the rapid flashing of the liquid (Colbourne and Suen, 2018).

[11] Japan Refrigerants and Environment Conservation Organisation (JRECO)/Japan Industrial Conference for Ozone Layer and Climate Protection (JICOP), 2013. Report of the 2012 Fiscal chemical safety and international regulatory measures promotion (refrigerant management system demonstration business model), 29th March 2013, Tokyo, Japan

Table 20: Release masses and mass flow rates for ducted split

Scenario	Released mass (g)		Average mass flux (g/min/mm2)		Average mass flow rate (g/min)					
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1			Stage 2		
					0.1	1	5	0.1	1	5
D1	90	n/a	15	n/a	1.5	15	75	n/a	n/a	n/a
D2	90	n/a	15	n/a	1.5	15	75	n/a	n/a	n/a
D3	90	n/a	15	n/a	1.5	15	75	n/a	n/a	n/a
D4	900	n/a	25	n/a	2.5	25	125	n/a	n/a	n/a
D5	900	n/a	25	n/a	2.5	25	125	n/a	n/a	n/a
D6	900	n/a	25	n/a	2.5	25	125	n/a	n/a	n/a
D7	540	90	40	15	4	40	200	1.5	15	75
D8	540	90	40	15	4	40	200	1.5	15	75
D9	540	350	40	15	4	40	200	1.5	15	75
D10	540	350	40	25	4	40	200	2.5	25	125
D11	540	350	40	25	4	40	200	2.5	25	125
D12	540	350	40	25	4	40	200	2.5	25	125
C1	890	n/a	240	n/a	24	240	1200	n/a	n/a	n/a
C2	990	n/a	240	n/a	24	240	1200	n/a	n/a	n/a
C3	540	350	340	240	34	340	1700	24	240	1200
C4	540	450	340	240	34	340	1700	24	240	1200

Table 21: Release masses and mass flow rates for the rooftop

Scenario	Released mass (g)		Average mass flux (g/min/mm2)		Average mass flow rate (g/min)					
	stage 1	stage 2	stage 1	stage 2	stage 1			stage 2		
					0.1	1	5	0.1	1	5
D1	90		15		1.5	15	75			
D2	90		15		1.5	15	75			
D3	90		15		1.5	15	75			
D4	900		25		2.5	25	125			
D5	900		25		2.5	25	125			
D6	900		25		2.5	25	125			
D7	610	90	40	15	4	40	200	1.5	15	75
D8	610	90	40	15	4	40	200	1.5	15	75
D9	610	300	40	15	4	40	200	1.5	15	75
D10	610	300	40	25	4	40	200	2.5	25	125
D11	610	300	40	25	4	40	200	2.5	25	125
D12	610	300	40	25	4	40	200	2.5	25	125
C1	890		240		24	240	1200			
C2	990		240		24	240	1200			
C3	540	350	340	240	34	340	1700	24	240	1200
C4	540	450	340	240	34	340	1700	24	240	1200

3.8 Determination of flammable quantities

3.8.1 Control volumes

It is necessary to estimate the mass and the volume of the flammable regions and the duration flammable concentrations are present, in the event of a release. For the present study, three models are used: one for the dispersion of a release within the unit housings and for releases into the room and outside a zonal dispersion model and CFD code. There are certain critical aspects which must be addressed when characterising the flammable quantities. These are:

- Appropriate determination of the control volume, which is a function of the location of refrigerant-containing parts, constraints to refrigerant flow and potential sources of ignition
- Knowledge of the airflow characteristics within those control volumes
- Dimensions of openings within the control volume from where leaked refrigerant could escape

Figure 136 and Figure 137 identifies the various control volumes under consideration for the ducted split and rooftop units, respectively.

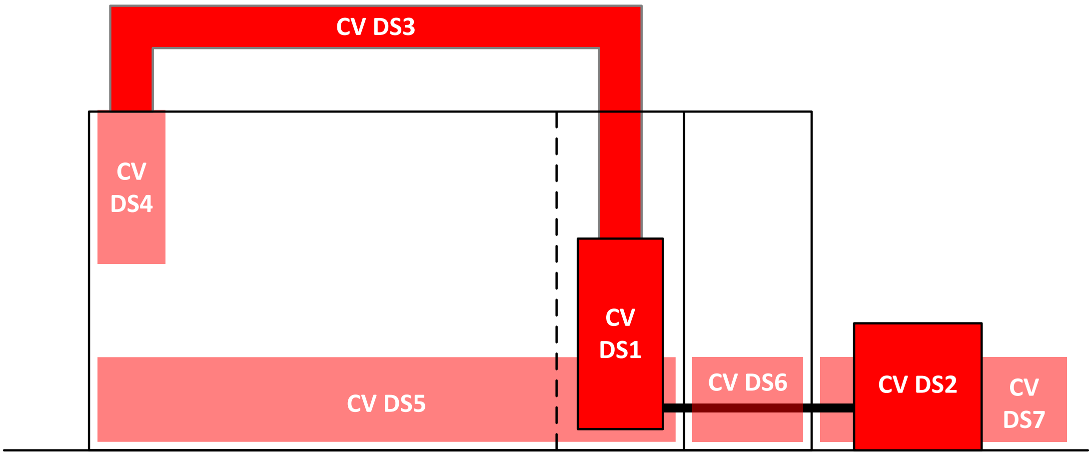


Figure 136: Identification of control volumes for the ducted split

Whilst the ducted split AHU is placed within a separate space, both measurements and CFD calculations indicate that due to the louvers there is limited resistance to flow of the mixture and thus can be treated as a single space.

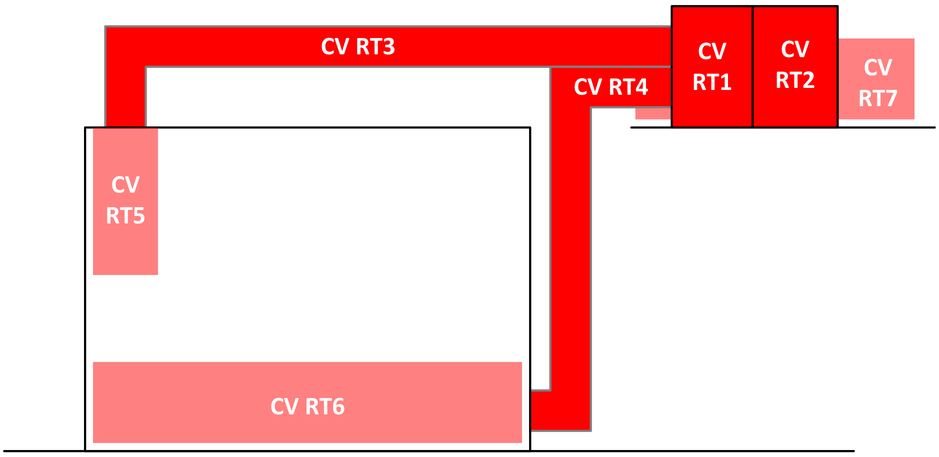


Figure 137: Identification of control volumes for the rooftop unit

A representative dimension needs to be assigned to each control volume in order to relate the developed flammable volume to the potential SOIs that may be present in the same locality as the mixture. For equipment housings, etc., this is relatively straight-forwards, since the boundaries of the enclosures can be employed. However, for large rooms and open spaces, a judgment is required based on the anticipated extent of the flammable mixture.

Table 22: Flammable characteristics for leaks within the room

Control volume	Relevant space	Volume location	Representative volume
CV DS1	AHU	Within housing	0.41 m^3
CV DS2	Condensing unit	Within housing	0.47 m^3
CV DS3	Supply duct	Duct internal volume	2.0 m^3
CV DS4	In room beyond outlet	To 1 m below ceiling	35 m^3
CV DS5	Room/closet floor	To 1 m above floor	35 m^3
CV DS6	Interconnecting pipe space	Entire space	30 m^3
CV DS7	Surrounding cond unit	2.5 m radius around unit	20 m^3
CV RT1	AHU section	Within housing	0.44 m^3
CV RT2	Condensing unit section	Within housing	0.47 m^3
CV RT3	Supply duct	Duct internal volume	2.5 m^3
CV RT4	Return duct	Duct internal volume	1.0 m^3
CV RT5	In room beyond outlet	To 1 m below ceiling	35 m^3
CV RT6	Room floor	To 1 m above floor	35 m^3
CV RT7	Surrounding cond unit	2.5 m radius around unit	20 m^3

3.8.2 Assumptions and boundary conditions

Since flammable volumes cannot be easily measured directly, computational tools are used. The models used are:

- Mixing box model, as described in Colbourne and Suen (2014)[12]
- A zonal decay model, based on Colbourne and Suen (2008)
- Simflow computational fluid dynamics (CFD) package[13]

Simflow offers a wide range of functions; for the current work the basic parameters used were rhoreactingbuoyantFOAM solver, RANS RNG κ-ε turbulence model and a 0.001 – 0.1 m mesh size. Animations for selected CFD cases can be downloaded at https://my.pcloud.com/#page=puplink&code=gBdZKGC8m32uG2SrdLxlM20hqF8PoBlV; note that these results are based on simple assumptions and infer much a much more severe situation than in "real life", i.e., compared to our testing but are nevertheless useful to help understand the behaviour of the leaked R290.

Such tools require reliable inputs for physical characteristics and assumptions for various boundary conditions. The models used include adjustments that can be made to help match the calculated results to direct measurements, since no model can precisely account for every single parameter present in real cases.

Release rates

The release rates detailed in Table 5 and Table 21 are employed in the calculations. Many tests and the visualisation results shown below are based on a nominal 50 g/min release mass flow. According to one

[12] Colbourne, D, Suen, K. O. 2014. Characterisation of a Leak of Flammable Refrigerant within Equipment Enclosures. Proc. 11th IIR Gustav Lorentzen Conference on Natural Refrigerants, Hangzhou, China

[13] https://sim-flow.com/cfd-software/

study in Japan (JARECO, 2013[14]) which surveyed 000's of refrigeration and air conditioning systems ranging in size from about 1 kg to 170 kg of (HFC) refrigerant charge, the average (mean) leak rate across the entire data set was equivalent to 0.16 g/min; assuming vapour only leak, this corresponds to a leak hole of 0.002–0.005 mm^2 (approximately 0.05–0.08 mm diameter) depending upon the system pressure. The largest leak rate was just under 3 g/min, corresponding to a leak hole of 0.04–0.07 mm^2 (or 0.2–0.3 mm diameter) depending upon pressure. Another study from Japan (JSRAE, 2014[15]) carried out a survey of maximum leak hole sizes in multi-split air conditioning systems. The mass flow rate of vapour and liquid refrigerant was measured in the samples and the largest leak from indoor units have about 6 g/min of R32 vapour at 10°C and 67 g/min of liquid at 63°C; this equates to a hole of 0.045 mm^2 or 0.23 mm diameter. For outdoor units the largest leak gave 58 g/min of R32 vapour and 660 g/min of liquid; this is equivalent to a hole of 0.45 mm^2 of 0.76 mm in diameter. From another study currently underway (EU LIFE FRONT[16]) the largest leak hole size (do far) corresponds to about 0.7 mm^2 (albeit from a botched repair). Taking the largest leak hole of all these studies and the maximum release mass flux from the simulated AHU leaks (40 g/min per mm^2) yields a "maximum" leak rate of 28 g/min. Thus for purposes of useful representation, an assumed release of 50 g/min may still be considered pessimistic.

Room and equipment dimensions
Physical dimensions are closely matched in the models.

Space congestion/obstructions
Whilst test set-up typically involve some degree of congestion, whether it is unmovable objects within the space, piping and components within equipment housing or non-smooth geometry surfaces. With certain computational models (e.g., CFD) these can in principle be accounted for but would result in excessive calculation time. With others, adjustment factors are employed to provide a blunt means of accommodating the variations they infer.

Space air movement
Airflow within the rooms and spaces assists with dispersion of leaked refrigerant, thereby reducing the gas concentrations, the size of flammable volumes and thus the risk. Within a space several sources of airflow may be present:

- Forced airflow from air conditioning or cooling or extract fans
- Forced air movement from room occupants
- Natural convention from thermal sources within the room, including from occupants
- Natural convention from infiltration with the outside conditions

Thus it is difficult to estimate what the airflow may be. In a "still" room, i.e., absent of all the sources listed above, the average air speed may be around 0.03 – 0.05 m/s. Where one or more of these sources are present, the air speed can approach 0.3 m/s or higher, although it varies depending upon the position within a room. Nevertheless, since the presence and characteristics of air conditioning, cooling and extract fans, other drinks dispensing appliances, the behaviour of occupants and thermal sources are usually unknown, the possible effect of these will be neglected, thus leading to a more pessimistic condition.

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[14] Japan Refrigerants and Environment Conservation Organisation (JRECO)/Japan Industrial Conference for Ozone Layer and Climate Protection (JICOP), 2013. Report of the 2012 Fiscal chemical safety and international regulatory measures promotion (refrigerant management system demonstration business model), 29th March 2013, Tokyo, Japan
[15] Japan Society of Refrigerating and Air Conditioning Engineers (JSRAE), 2014. Risk Assessment of Mildly Flammable Refrigerants, 2013 Progress Report; Section 8.2 Progress of SWG for VRF System Risk Assessment. Tokyo, Japan
[16] http://lifefront.eu/

Infiltration is nearly always present, but the air change rates vary widely according to building construction and weather conditions. Figure 138 provides an example of the proportion of time that infiltration air changes occur for a generic building with fixed envelope tightness of 5 air changes per hour at 50 Pa pressure difference. The literature (e.g., Orme et al, 1998[17]) contains empirical data for tightness of samples of certain types of buildings. This indicates that the average building envelope tightness can vary from around 2 to 20 air changes per hour at 50 Pa. Whilst calculation of dispersion of a refrigerant leak over a range of infiltration rates could be carried out, the quantity of refrigerant involved and the majority of the release rates used will lead to very small flammable volumes and subsequent risk. Therefore the additional (lengthy) calculation time necessary to account for the different infiltration rates is not justified. Nevertheless, some example test results are provided in Figure 139 to give an indication of the effect of room concentrations arising from natural ventilation (Colbourne and Suen, 2018)[18]; the percentages in the figure legend are the proportion of total refrigerant remaining in the room at the time that the release has ceased. Thus even with relatively small ventilation openings a significant proportion of the leaked refrigerant is removed from the space.

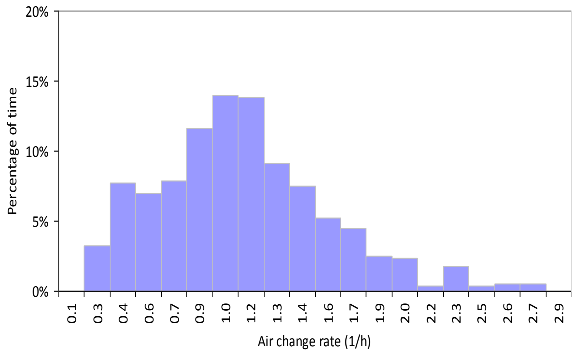


Figure 138: Example distribution of infiltration air change rates for envelope tightness of 10 air changes per hour at 50 Pa, based on UK weather

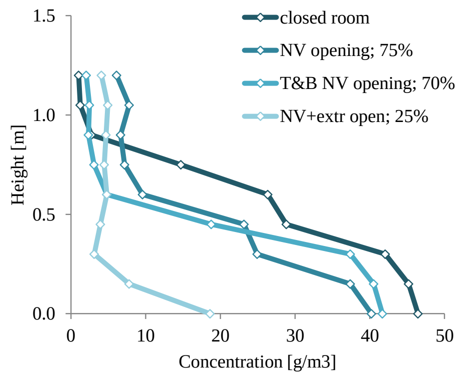


Figure 139: Effect of natural ventilation on a 440 g R290 release at 1 m unit height

Airflow is also generated by movement of persons or equipment. Figure 140 illustrated the effectiveness of this source, where the greyed area of the graph shows the effect of a personal slowly strolling across the room rapidly dilutes a stratified mixture within a few tens of seconds. Figure 141 is another example where the thermal convection currents from four thermal manikins and mock PCs (all 100 W each) are able to homogenously mix a stratified layer with 1.3 kg R290 in a 40 m^2 room, within a few minutes.

Due to the calculation time, these various sources of residual air movement are not taken into account. However, the results from the QRA should be considered to represent highly pessimistic (and unusual) conditions.

[17] Orme, M., Liddament, M. W., Wilson, A. Numerical data for air infiltration and natural ventilation calculations. Air Infiltration and Ventilation Centre, Coventry, UK, 1998

[18] Colbourne, D., Suen, K. O. 2018. Assessment of factors affecting R290 concentrations arising from leaks in room air conditioners. Proc. 13th IIR Gustav Lorentzen Conference, Valencia, Spain

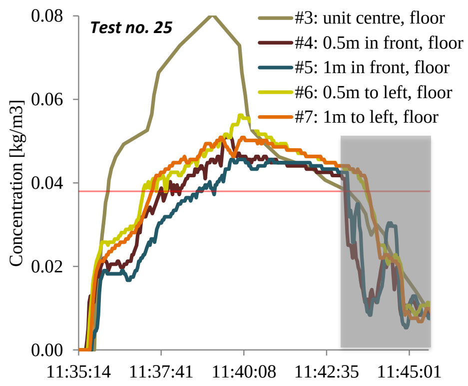


Figure 140: Effect of "strolling" through a stratified layer (during greyed duration)

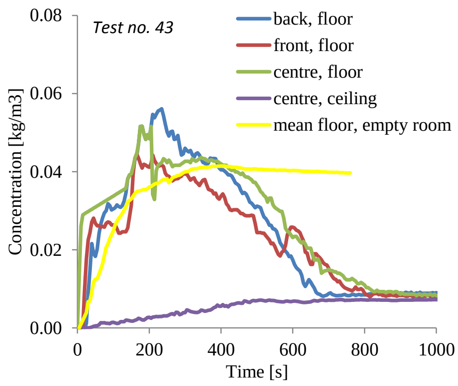


Figure 141: Effect of four thermal manikins and mock PCs on mixing of a release compared to "empty" room

Release source

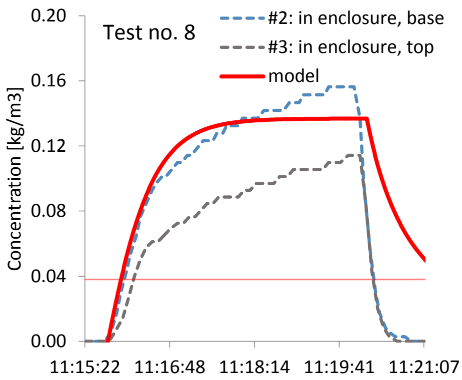
Due to the complexity and variability of conditions close to the actual refrigerant leak hole, the local mixing process is not modelled. Instead assumptions are made in terms of the result of that local mixing and thus the state (concentration) of the mixture exiting a specific region. This process is supported by adopting values from measurements (section XXX), for instance, at the outlet/base of a particular enclosure.

Selected flammable quantity

Under many scenarios, the refrigerant release is such that steady conditions are not achieved and thus the flammable volume, for example, will continue to grow over time, until some moments following cessation of the leak. In order to provide an accurate representation of the probability of the flammable mixture coinciding with an SOI (for the probability model employed), a time-averaged flammable volume is obtained. This has the effect that when calculating consequences (e.g. overpressure) the result will be lower than if the peak flammable volume were used. However, since many pessimistic assumptions are already inherent in the determination of flammable volumes, such an outcome is not considered unreasonable.

3.8.3 CV DS1 – within ducted split AHU

Measurements were carried out to determine concentrations within the AHU under various release mass flow rates and blower operation (see section 2.5.4). These results were used to calibrate the mixing model to help determine flammable; volumes and times. Some examples of these checks are provided in Figure 142. Differences in internal measured concentrations occur according to internal leak position, but the model overlooks this assuming fairly even mixing, provided release velocity and volume flow is high relative to the internal volume.



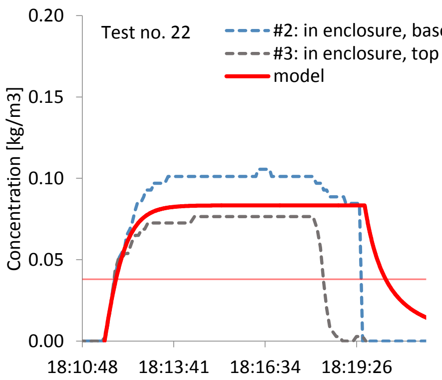


Figure 142: Example comparison of concentrations measurements inside the ducted split AHU and the model for estimating flammable volume and time

3.8.4 CV DS2 – within ducted split condensing unit

Whilst measurements were not conducted specifically on the ducted split condensing unit, they were done with the rooftop condensing unit, against which the model was calibrated (see CV RT2). Characteristics of the ducted split condensing unit were used within that model to determine flammable volumes.

3.8.5 CV DS3 – within ducted split supply duct

Measurements were carried out to determine concentrations within the supply duct under various release mass flow rates and blower operation (see section 2.5.4). Whenever the blower was operating, even with lowest fan speed setting, the concentration throughout the entire supply ducting was a fraction of the LFL, inferring negligible flammable concentration. Similarly, in the event that there is a leak from inside the AHU and the blower is off, since R290 is denser than air it was never found to migrate upwards along the supply duct, again indicating no flammable mixture within the duct. The only condition where a flammable mixture may become present is following initiation of the blower moments after a large leak. However, measurements indicated that the flammable mixture would only be present at any point along the duct for one or two seconds. In this regards, it may also be deemed negligible (especially since at the flow velocity through the duct combustion could not be sustained).

3.8.6 CV DS4 – beyond ducted split supply duct outlet (within room)

Concentration measurements were carried out at various positions at and beyond the supply duct outlet under various release mass flow rates and blower operation. As with CV DS3, concentrations approaching LFL do not normally arise with or without airflow, except for the case where airflow initiates following a major leak. Description of the measurements and analysis of this situation are provided under section 3.8.14. A flammable volume of 0.05 m^3 for 15 s is taken for all cases where the blower starts following a leak.

3.8.7 CV DS5 – across room floor

Extensive measurements were carried out to determine concentrations arising within the room surrounding AHU, both when it was placed in a room and within a closet with louvered doors (see section 2.5.4). Whilst the blower is operating, concentrations approaching LFL were never recorded. Similarly, due to the internal volume of the AHU housing, there is a notable time delay from the beginning of the release until the mixture migrated onto the room floor; this indicates that leak detection will prevent formation of a flammable mixture in the surrounding area. Thus flammable volumes may only arise in certain failure modes. An example of the formation of a flammable mixture is illustrated in Figure 143.

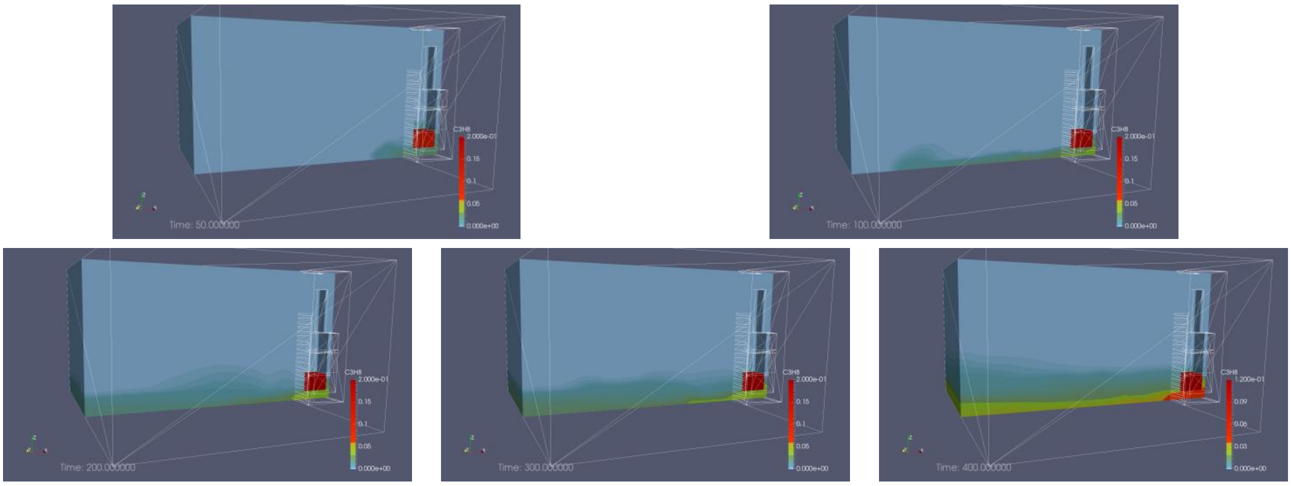


Figure 143: Example CFD results for the case of 400 g R290 leaking inside the AHU at 50 g/min

Whilst the AHU has been re-designed to ensure that the formation of a flammable mixture in the surrounding area is minimised, there is a possibility that during service and maintenance activities, a technician forgets to replace certain base panels. In this event, leaked refrigerant would migrate directly to the floor. Simulations were also carried out to mimic this scenario (Figure 145) and the estimated flammable volumes were used for the particular failure mode.

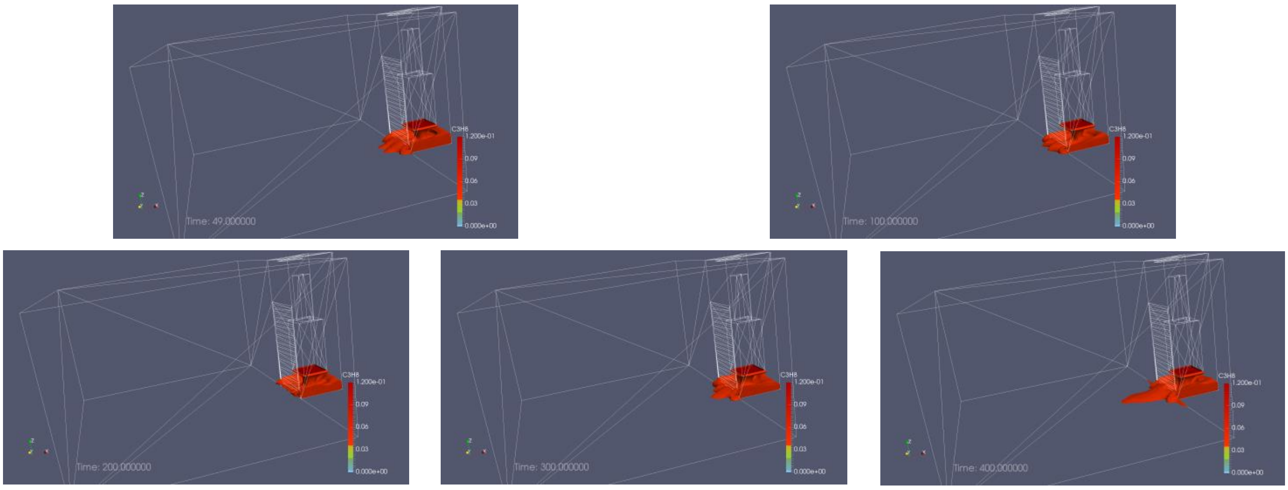


Figure 144: Example CFD results for the case of 400 g R290 leaking inside the AHU at 50 g/min

3.8.8 CV DS6 – around interconnecting piping

Under the current project, measurements specifically investigating concentrations arising from leaks from exposed or insulated pipework runs were not performed; although data from previous work has been drawn upon. The main challenge, though, is making assumptions for the size and shape of the space through which the piping is passing through, what the local airflow conditions are, the use and/or condition of insulation and the positioning of the piping. Assumed characteristics of the space are detailed previously. The suction line is usually insulated so any leak therein will migrate along both directions of the piping to either the space housing the AHU or to the outside and as the suction pressure is usually low and that part of the system is normally subject to mitigation measures (pump-down, etc.). Whilst leaks from the suction line can be neglected, they are nevertheless accounted for. Conversely the liquid line will usually be exposed, which means that a leak will take the form of a high momentum jet directly into the space. To determine the flammable volume for the respective assumed hole sizes and back pressures, the calculations have been based on model of Webber et al (2012). Pipes could be run along any surface of the room so an assumption of a relatively confined (two sides)/shielded location has been used whereby draining of the mixture would have a delay associated with it.

3.8.9 CV DS7 – surrounding condensing unit

A number of measurements were made surrounding the rooftop unit with various release scenarios (section 2.5.4). These were used to establish boundary conditions for CFD simulations. A typical "low" outside air speed is considered to be 0.5 m/s (as stated in IEC 60079-10-1), which was used as the basis for the calculations.

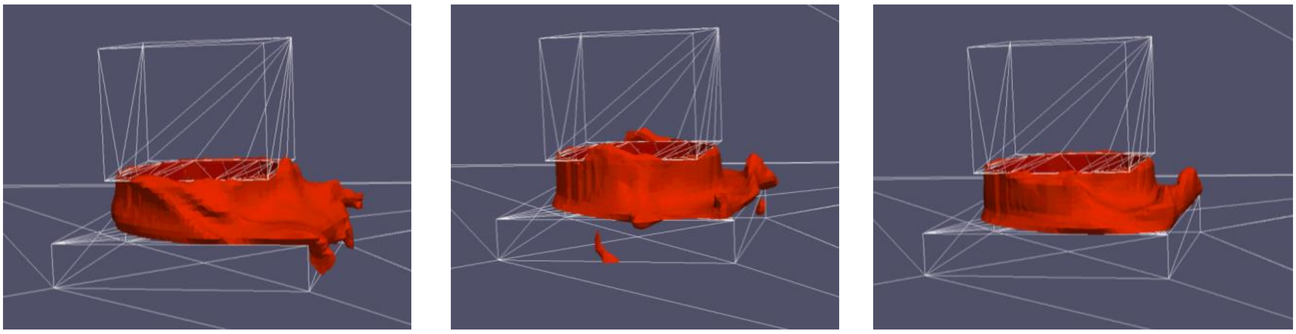


Figure 145: Example CFD results for the case of 100 g R290 leaking inside the condensing unit at 250 g/min; after 60 s (left), 120 s (middle) and 180 s (right)

Figure 145 and Figure 146 show results of flammable volume contours for a leak rate of 250 g/min and 1200 g/min, respectively. There is no accumulation of refrigerant and after a few moments other than the fluctuations the flammable volume can be taken as a steady value.

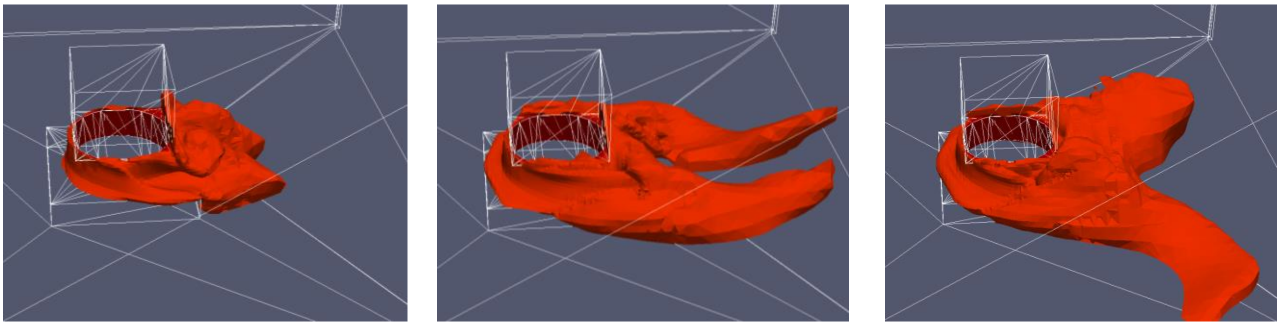


Figure 146: Example CFD results for the case of 100 g R290 leaking inside the condensing unit at 1200 g/min; after 10 s (left), 30 s (middle) and 50 s (right)

Whilst the results in Figure 145 and Figure 146 assumed a low airspeed, weather data gives the average annual wind speed in Colombia (Barranquilla, for instance) at 4.0 m/s. A third simulation used this condition along with the 1200 g/min leak rate and the flammable volume contours are shown in Figure 147. Compared to the 0.5 m/s wind speed case, the flammable volume over the release period with 4 m/s is approximately 10%.

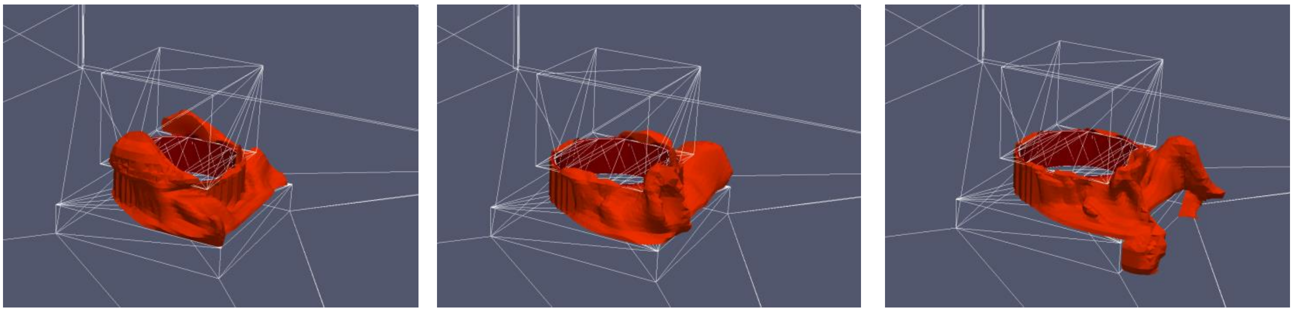


Figure 147: Example CFD results for the case of 100 g R290 leaking inside the condensing unit at 1200 g/min with a wind speed of 4.0 m/s; after 10 s (left), 30 s (middle) and 50 s (right)

3.8.10 CV RT1 – within rooftop AHU

Measurements were carried out to determine concentrations within the AHU under various release mass flow rates and blower operation (see section 2.5.4). As with the ducted split AHU, results were used to calibrate the mixing model to help determine flammable volumes and times. Some examples of these checks are provided in Figure 148. (Note that the rapid decay in the measurements for test #29 is due to the blower being switched on.)

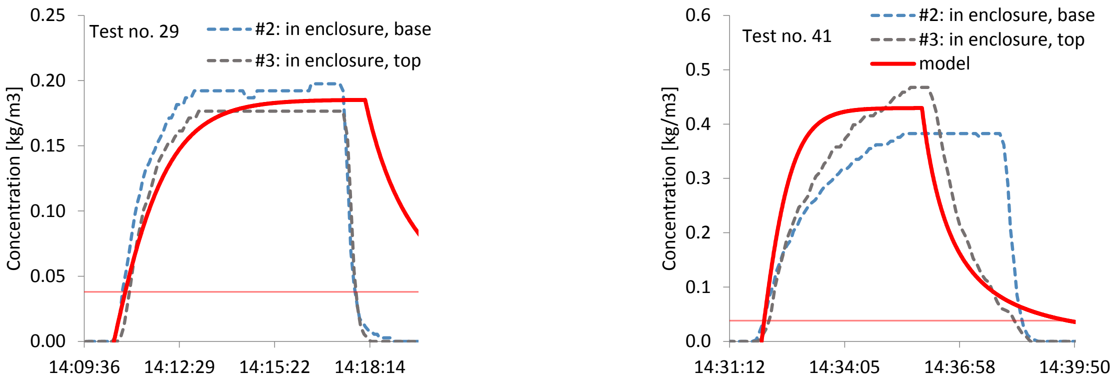


Figure 148: Example comparison of concentrations measurements inside the rooftop AHU and the model for estimating flammable volume and time

3.8.11 CV RT2 – within rooftop condensing unit

Measurements were carried out to determine concentrations within the condensing unit part under various release mass flow rates and fan operation (see section 2.5.4). These results were used to calibrate the mixing model and some examples are provided in Figure 149. Generally there is a poor match between the measured concentrations within the condensing unit and the model, which is because of the very large free wall area relative to the enclosure volume. Nevertheless, the use of the model is retained since it will only result in exaggerated values of flammable volume.

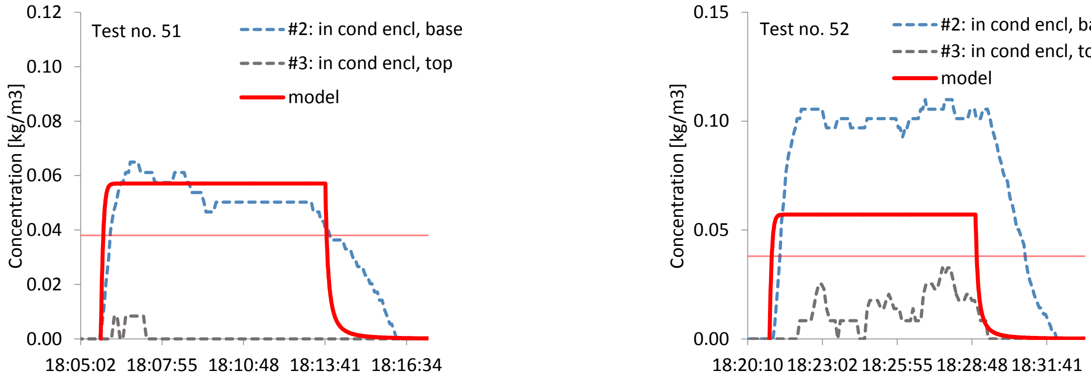


Figure 149: Example comparison of concentrations measurements inside the rooftop condensing unit and the model for estimating flammable volume and time

3.8.12 CV RT3 – rooftop supply duct

Measurements were carried out to determine concentrations within the supply ducting under various release conditions (see section 2.5.4). Whenever the blower is operating, even with lowest fan speed setting, the concentration throughout the entire supply ducting was a fraction of the LFL, inferring negligible flammable concentration. Conversely, in the event that there is a leak from inside the AHU when the blower is off and if there is a horizontal and/or downwards passage to the duct outlets the refrigerant will flow along the ducts; provided the leak rate is sufficient the entire duct cross section can fill with a flammable mixture. Figure 150 and Figure 153 show simulation results for a release flowing along a single duct and a duct with four branches, respectively. With a single duct (and a release of 50 g/min) it can be seen that the duct is almost filled with a flammable mixture. However with the four duct branches, only the main duct is mostly filled whereas the branch ducts are approximately half filled. This was also validated by the measurements.

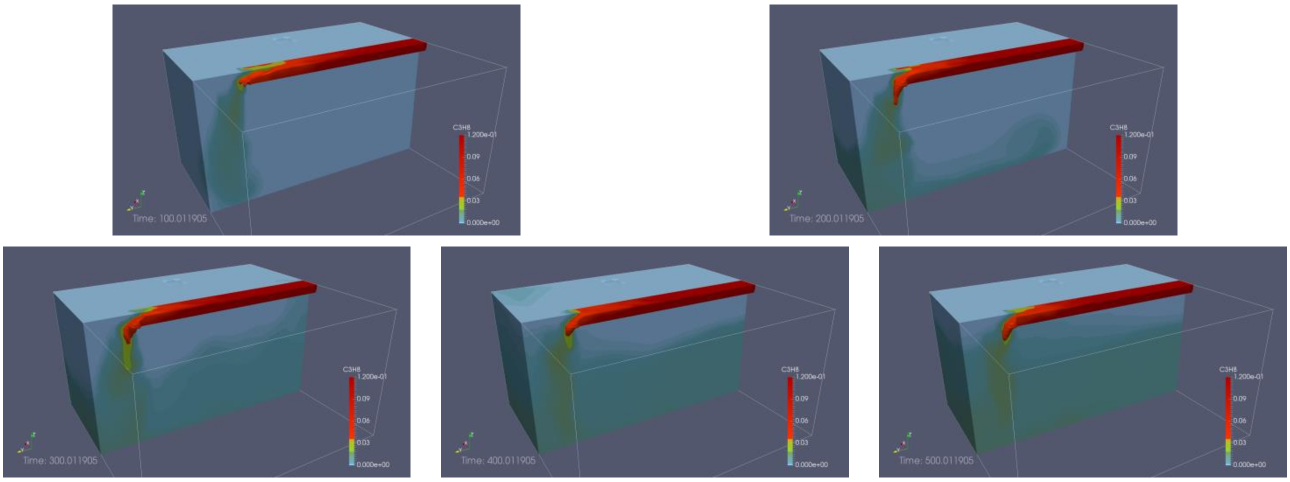


Figure 150: Example CFD results for the case of 50 g/min R290 flowing along a single supply duct

3.8.13 CV RT4 – rooftop return duct

Measurements were similarly carried out to determine concentrations within the return ducting under various release conditions (see section 2.5.4). As with the supply duct, if the blower is operating the concentration throughout the entire return ducting remains at a fraction of the LFL. Conversely, if the leak occurs from the AHU when the blower is off and there is free passage to the duct outlets the refrigerant will flow back along the ducts. Figure 151 and Figure 154 show simulation results for a release flowing along a single return duct that terminates at floor level and at 1 m above the floor, respectively. In both cases, the duct is almost entirely filled with a flammable mixture.

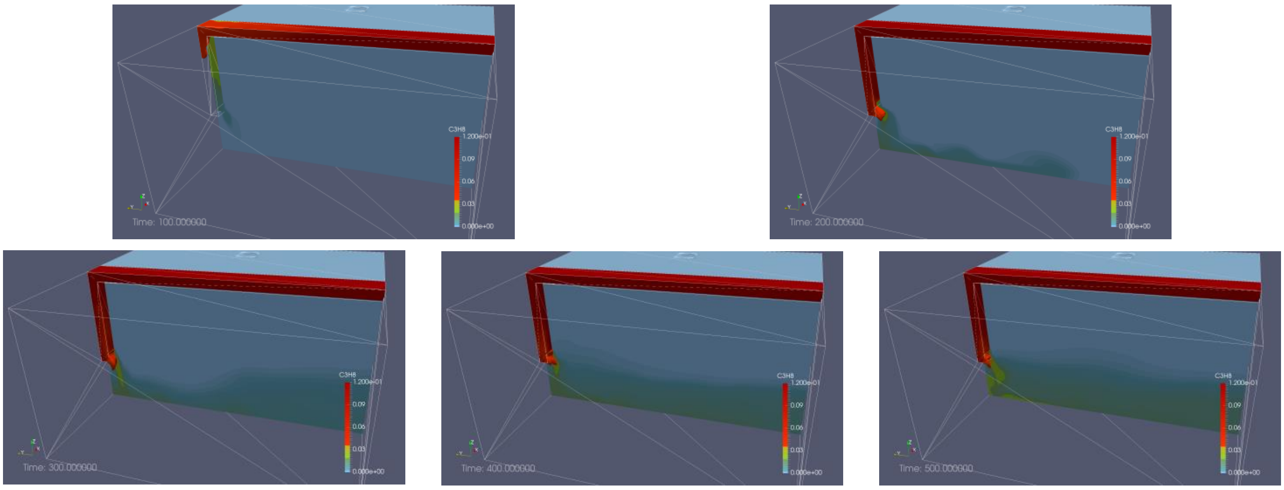


Figure 151: Example CFD results for the case of R290 flowing back down a single return duct with an inlet at 1 m above floor level

3.8.14 CV RT5 – beyond rooftop supply duct outlet (within room)

Concentration measurements were carried out at various positions at and beyond the supply duct outlet under various release mass flow rates and blower operation. As with CV RT3, concentrations approaching LFL do not normally arise when the blower is on, except for the case where airflow initiates following a major leak. Extensive measurements are detailed within section 2.5.4and from this the size and direction of the flammable mixture were estimated. Figure 152 provides a visualisation of the process. However, the size and shape of the flammable mixture is considerably exaggerated compared to the actual measurements, which gave a flammable volume of approximately 0.05 m^3 (compared to the CFD result of 9 m^3); this difference indicates that in reality there is significant additional dilution as the mixtures travels along the ducting as well as draining of refrigerant mixture from within the AHU housing before the blower initiates. In both the simulation and measurements, the flammable mixture only persists for 10 s to 15 s. A flammable volume of 0.05 m^3 for 15 s is taken for all cases where the blower starts following a leak.

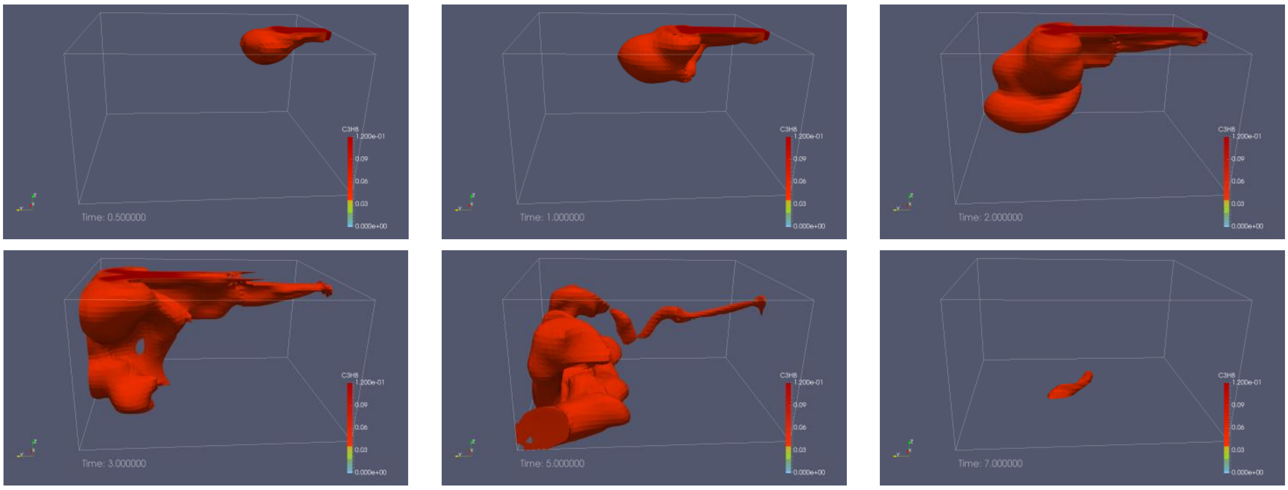


Figure 152: Example CFD results for the case of 1000 g R290 being discharged from the AHU, along the supply duct and out of the duct outlet at the instant the blower is initiated; surface contour is LFL of R290

When the blower is off, measurements indicated that a flammable mixture could also arise just beyond the duct outlet, since a leak from within the AHU could eventually overflow into the supply duct and migrate along the horizontal duct to the outlet (see section 2.5.4). The number of duct branches has an effect on the concentrations at outlets since additional branches reduce the flow rate available to each outlet.

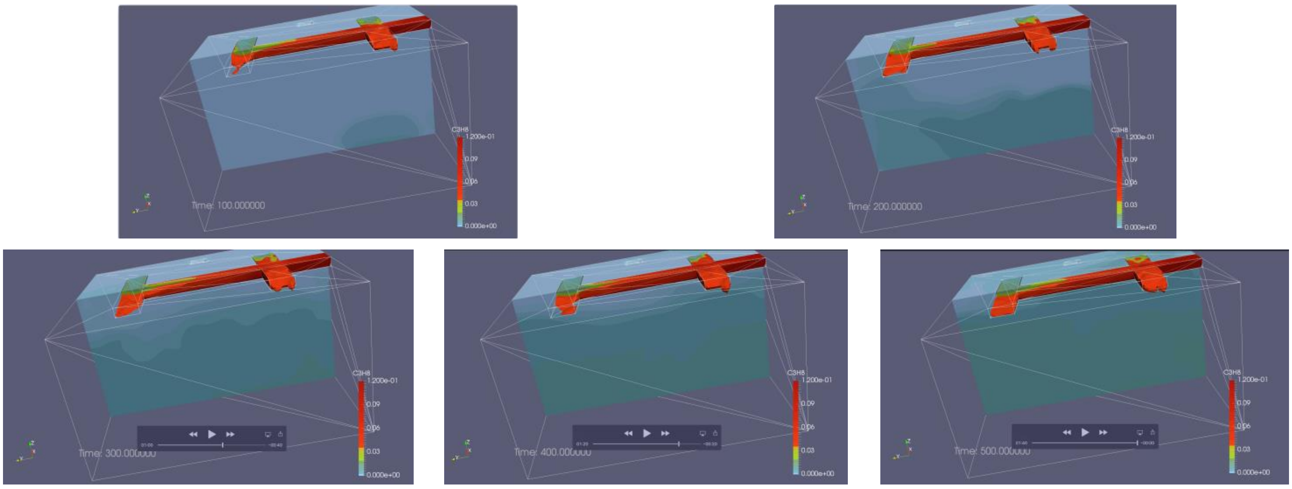


Figure 153: Example CFD results for the case of 50 g/min R290 flowing along a four duct branches

3.8.15 CV RT6 – across room floor

A number of measurements were carried out to determine room floor concentrations for releases within the AHU which had then flowed along and down return ducting that terminated at or near the room floor. These are described in section XXX. In order to minimise formation of flammable mixtures within the room, the product information prescribes that the return duct inlet should be at least 1 m above flor level. However, it is possible that such a rule is not always followed so calculations also include for return duct inlets at floor level. Results for these two scenarios are given in Figure 151and Figure 154; the finding as from measurements are replicated here, which show that inlets at floor level and lead to flammable concentrations within the room whilst an elevated return air inlet essentially eliminates that occurrence.

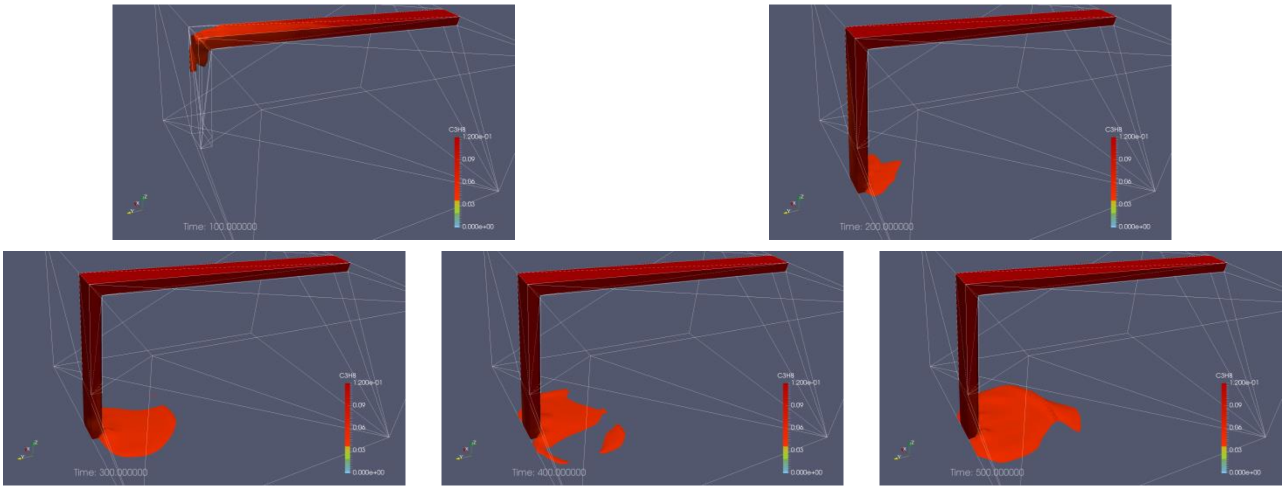


Figure 154: Example CFD results for the case of R290 flowing back down a single return duct with an inlet at floor level

3.8.16 CV RT7 – surrounding condensing unit

A number of measurements were made surrounding the rooftop unit with various release scenarios from the condensing unit section (see section 2.5.4). These were used to establish boundary conditions for CFD simulations. For this, a typical “low” outside air speed is considered to be 0.5 m/s (as stated in IEC 60079-10-1), which was used as the basis for the calculations. The results –for the equivalent case of the ducted split condensing unit – are shown in Figure 145 and Figure 146. With the largest leak rate of 1200 g/min the flammable region does not extend by more than about 2.5 m from the unit centre.

3.8.17 Results for flammable volumes and time

Appendix G provides a compilation of the calculated volumes and durations of the developed flammable mixtures associated with each control volume under each failure mode.

3.9 Potential sources of ignition

There are a variety of different types of potential SOIs and their presence within any of the control volumes need to be assigned, as well as their particular characteristics. An initial filtering of potential SOIs is carried out (according to EN 1127-1[19]) and a summary is given in Table 13. Practical examples of the potential SOIs which are applicable to HCs are provided in the GIZ Proklima handbook[20]. With respect to some of the possible SOIs indicated in Table 13, further discussion is provided in Appendix E.

Table 23: Filtering for potential sources of ignition

Type	Possible sources present	Relevant control volume
Hot surfaces	Lamps, friction from moving parts, compressors, heaters, electrical faults	Room, AHUs, condensing units
Flames and hot gases (including hot particles)	Cigarettes, lighters, candles, stoves	Room, AHUs, condensing units
Mechanically generated sparks	Hammers	Not applicable
Electrical apparatus	Any electrical components where arcing is possible	Room, AHUs, condensing units
Stray electric currents	Any electrical parts where short-circuiting is possible	Room, AHUs, condensing units
Static electricity	Occupants (e.g., cleaning)	Room
Lightning	None	Not applicable
Radio frequency (RF) electromagnetic waves from 10^4 Hz to 3×10^{11} Hz	Radio, wireless transmitters/ receivers,	Not applicable
Electromagnetic waves from 3×10^{11} Hz to 3×10^{15} Hz (microwave, infrared)	Microwave ovens, remote controls, lasers	Not applicable
Ionising radiation	X-rays, medical equipment using radioactive materials	Not applicable
Ultrasonics	Welders, sensing equipment, humidifiers	Not applicable
Adiabatic compression and shock waves	Compressor (internal)	Not applicable
Exothermic reactions	None	Not applicable

For SOIs within rooms or outside, the number, location and characteristics of individual items can vary widely from room to room and from time to time. Therefore a generic set of SOIs characteristics has been assigned, broadly based on previous observations of such locations; these are listed in Table 24.

Based on discussions with the manufacturers and installers, it was been confirmed that there are never any potential SOIs located in the ducts for the size of equipment addressed within this study. Thus the only

[19] EN 1127-1: 2011, Explosive atmospheres. Explosion prevention and protection. Basic concepts and methodology
[20] Guidelines for the safe use of hydrocarbon refrigerants, GTZ Proklima, Eschborn, Germany, 2010; section 5.5

ignition source for the supply and return ducts are an ignition event at any one of the connected control; volumes. Therefore the number of active events corresponds to the ignition frequency within either of those connected control volumes.

Considering typical installation environments for rooftop units and condensing units, it is reasonable to assume the presence of non-R290 units in the near vicinity; mains contactors of two additional condensing units are therefore accounted for.

Table 24: Assigned SOIs according to control volume

Control volume	Relevant space	Number	Time/ duration of SOI event (s)*	No of SOI active events per 24 h
CV DS1	AHU	Table 26		
CV DS2	Condensing unit	Table 25		
CV DS3	Supply duct	2	1	As f^*_{ign} in conn CVs
CV DS4	In room beyond outlet	2	1	2
CV DS5	Room/closet floor	10	1	8
CV DS6	Interconnecting pipe space	5	1	4
CV DS7	Surrounding cond unit	2	1	20
CV RT1	AHU section	Table 26		
CV RT2	Condensing unit section	Table 25		
CV RT3	Supply duct	1	1	As f^*_{ign} in conn CVs
CV RT4	Return duct	2	1	As f^*_{ign} in conn CVs
CV RT5	In room beyond outlet	2	1	2
CV RT6	Room floor	10	1	8
CV RT7	Surrounding cond unit	2	1	20

* Active time for a spark is milliseconds, but is taken as 1 s

For the equipment enclosures, potential SOIs are assumed to arise from electrical faults or replacement with new components that are unsuitable. Condensing units and AHUs are is designed and constructed according to the applicable safety standards implying that none of the electrical or other items could act as SOIs under normal operation. As such, all the components are deemed not to be SOIs under normal operation. If there is a fault with the component or interconnecting wiring, there is a possibility of arcing or sufficiently high temperature that a SOI arises. Alternatively, in the event of a fault (when no flammable mixture is present), it is conceivable that a technician could replace the protected component with an unprotected one, which could therefore be a potential SOI. Table 25 and Table 26 provide characteristics data for the condensing unit and AHU SOIs, with regards to:

- The current level of protection applied
- Whether it could be an active SOI during normal operation
- Whether it could be an active SOI under fault conditions, the reasons for such a fault and the probability of a fault
- Whether that item could be replaced with non-protected component and if so, whether the new components could be a SOI under normal operation
- The expected SOI characteristics of the replaced component

For fault conditions the most likely fault and the frequency of the fault occurring are estimated from safety handbooks[21] and some are provided by manufacturers. It is assumed that once the fault occurs, unit will cease to operate correctly and the operation terminated (i.e., the faulty part is replaced before the unit of operate again). For the case of the terminals working loose or the wires short-circuiting, sparking is assumed to occur for some nominal amount of time before it finally loses contact permanently. It is also important to acknowledge that whilst the failure rates used simply imply a fault, the assumption in the present study is that such a fault will result in an active SOI; in reality this is seldom the case and therefore represents a conservative assumption.

In the case of a failure of a particular component, it is possible that the (suitable, protected) component could be replaced by (unintentionally) by an incorrect (unsuitable, unprotected) component. This is relevant for the thermal overload and the compressor relay. The probability that a technician may replace a faulty component with an inappropriate unprotected component is set at 30%.

Table 25: Condensing unit potential SOIs

Item	No.	Protection	Fault SOI?	Reason	Probability	Can replace with sparking?	Probability	Replaced SOI events/24 h
Compr (+ elec box)	1	60079-15	yes	overload	0.0001	no	0.0001	0.0001
Cond fan/motor	1	Non-sparking	yes	short	0.00002	no	0.00002	0.00002
Pressurstat	2	sealed	yes	damaged	0.0002	yes	0.0002	8
Wires	10	none	yes	short	0.00005	no	0.00005	0.00005
Terminals	20	none	yes	short	0.0005	no	0.0005	0.0005

Table 26: AHU potential SOIs

Item	No.	Protection	Fault SOI?	Reason	Probability	Can replace with sparking?	Probability	Replaced SOI events/24 h
Blower fan/motor	1	Non-sparking	yes	short	0.00002	no	0.00002	0.00002
Wires	5	none	yes	short	0.00005	no	0.00005	0.00005
Terminals	10	none	yes	short	0.0005	no	0.0005	0.0005

3.10 Consequences

The two primary consequences of ignition considered in this study are thermal intensity (TI), which can be used to quantify degrees of burns to people or likelihood of secondary fire, and overpressure (OP) that causes damage to building structure and injury to people. An outcome of high TI and/or OP includes damage to buildings, their contents, injury to people and fatalities. A further consequence of ignition is a secondary fire, either caused by direct impingement of a sustained jet flame on a combustible material, or ignition of materials due to sufficient thermal dose which is sometimes termed “flashover”. The likelihood of a secondary fire can be estimated from the thermal intensity.

The basic approach to calculate TI and OP as a result of igniting flammable material within a room are detailed in Colbourne and Suen (2004)[22], but is also summarised in Appendix I. These models demand flammable property data of refrigerants such heat of combustion and these are normally quoted for stoichiometric concentrations. However, the mean concentration within flammable volumes is not always

[21] Lee’s loss prevention in the process industries. 2005. Lee, F., Mannan, S (Ed). Elsevier ButterworthHeinemann, UK.
[22] D. Colbourne, K. O. Suen, Appraising the flammability hazards of hydrocarbon refrigerants using quantitative risk assessment model Part I: modelling approach, Int. J. Refrig. 27 (2004) 774–783

at stoichiometric. Since flammable properties at concentrations other than stoichiometric can differ, the models used properties at a mean concentration corresponding to the calculated flammable regions were employed.

As inputs, the construction characteristics of the room and the condensing unit compartment are based on the data in Table 27.

Table 27: Additional details for spaces for consequence calculations

Control volume	Relevant space	Space volume	Free opening area	Forced opening area	Flam volume shape
CV DS1	AHU	0.41 m^3	0.32 m^2	n/a	3D
CV DS2	Condensing unit	0.47 m^3	1.22 m^2	n/a	3D
CV DS3	Supply duct	2.0 m^3	0.2 m^2	n/a	3D
CV DS4	In room beyond outlet	100 m^3	0.2 m^2	1.5 m^2 (door)	3D
CV DS5	Room/closet floor	100 m^3	0.2 m^2	1.5 m^2 (door)	flat
CV DS6	Interconnecting pipe space	30 m^3	2.0 m^2	1.5 m^2 (door)	flat
CV DS7	Surrounding cond unit	Open	Open	n/a	flat
CV RT1	AHU section	0.44 m^3	0.29 m^2	n/a	3D
CV RT2	Condensing unit section	0.47 m^3	1.22 m^2	n/a	3D
CV RT3	Supply duct	2.5 m^3	0.2 m^2	n/a	3D
CV RT4	Return duct	1.0 m^3	0.2 m^2	n/a	3D
CV RT5	In room beyond outlet	100 m^3	0.2 m^2	1.5 m^2 (door)	3D
CV RT6	Room floor	100 m^3	0.2 m^2	1.5 m^2 (door)	flat
CV RT7	Surrounding cond unit	Open	Open	n/a	flat

For secondary consequences such as secondary fire, thermal intensity is determined as the maximum of that arising from a flash fire and that from a the continuously burning jet leak, taking the recipient distance as a quarter of the average distance to any surface within the control volume. The threshold value for initiating a secondary fire is 150 $s(kW/m^2)^{4/3}$, assuming the recipient material is easily ignited (e.g., paper, hair, etc.)

Frequency of fatality is determined according to one or more of the following:

- Sufficient TI to cause fatality (set at 1000 $s(kW/m^2)^{4/3}$, yielding a probability of fatality of 2.5%)
- Peak overpressure exceeding 17 kPa; whilst this in itself in insufficient to cause fatality directly, it is enough to damage weak building structure and produce projectiles from enclosure which could result in severe physical damage to persons (set at 25% of cases)
- 1% of secondary fires will result in a fatality

For each ignition event that could satisfy the above criteria, the ignition frequency is used to determine frequency of fatality.

3.11 Results

Results are presented as follows:

- Ignition frequency within each control volume
- Maximum severity of consequence (thermal intensity and overpressure) for each ignition event
- Frequency of secondary fire
- Frequency of fatality as a result of all primary and secondary consequences

Values are given for both ducted split and rooftop units.

3.11.1 Ducted split

Results for the relevant risk measures associated with the various control volumes are given in Table 28. The main observations concerning ignition frequency are:

- Both AHU and condensing unit have extremely low ignition frequencies, corresponding to less than one ignition event per million-million units per year; such a frequency is so low it may be considered negligible.
- Ignition within the supply duct is also negligible (on account that the only ignition source is another ignition event within an adjacent space).
- Ignition within the room floor region is very small, less than one ignition event per 1,000 million units per year and as such also has no significance.
- Ignition frequency within the space through which the interconnecting piping runs is fairly small (about two ignition events per 10 million units per year).
- The control volume which experiences the highest ignition frequency is the area surrounding the condensing unit, with about three ignition events per millions units per year.

The main reason for the comparatively high ignition frequency for the room with interconnecting piping is because there are no local mitigation measures present, which for example apply to the AHU (such as forced airflow or limited releasable charge). Primarily whenever there is a leak from the liquid line, a large proportion of the total charge will be released and no response action can help respond to that occurrence.

With ignition in the region surrounding the condensing unit, the relatively high value is dominated in fact by the high probability of the “small” leak (0.1 mm^2) being ignited whilst the condenser fan is off, on account that it persisting for a long time in relation to the regular SOI active events. Since the flammable mixture is unlikely to extend as far as the SOIs within adjacent condensing units for this small leak the calculation result is broadly unrealistically high; in the case of a leak within a room the positioning of an SOIs relative to the flammable volume is effectively random, whilst in the present case it is likely that the adjacent condensing unit electrical panel would be more than 20 cm or so from the leaking R290 condensing unit. A simple evaluation of the situation indicates the calculated ignition frequency is more likely to be lower by a factor of 100 or so.

Table 28: Risk measures of ducted split according control volume

Control volume		Ignition freq (y^{-1})	Max TI ($s(kW/m^2)^{4/3}$)	Max OP (kPa)	Risk of TI	Risk of OP	Risk of sec fire (y^{-1})	Risk of fatality (y^{-1})
CV DS1	AHU	1E-17	228	7	4E-16	5E-17	1E-19	1E-21
CV DS2	Cond unit	1E-12	34	1	3E-12	1E-13	3E-13	3E-15
CV DS3	Supply duct	0	n/a	n/a	0E+00	0E+00	0E+00	0E+00
CV DS4	Supply outlet	9E-18	15	1	1E-16	8E-18	0E+00	0E+00
CV DS5	Room floor	1E-10	638	15	1E-09	4E-11	3E-12	3E-14
CV DS6	Intercon room	2E-07	1321	5	6E-05	2E-07	1E-07	1E-09
CV DS7	Surr cond unit	3E-06	18	0	1E-06	0E+00	0E+00	0E+00
Overall		3E-06	1321	15	6E-05	2E-07	1E-07	1E-09

Maximum values of TI and OP are provided and are seen to span a wide range. However, a more useful means to express values of TI and OP is to plot them against the corresponding ignition frequency; as shown in Figure 155 and Figure 156. This helps to identify the probability of “extreme” consequences. Whilst the TI and OP associated with ignition within the AHU, condensing unit and ducting is sometimes fairly high, such occurrences are seen to be so rare that they have no importance. These severe events only arise when there are multiple failures of the mitigation measures, such as absence of airflow, LLSV leaking and open ducting close to the floor level.

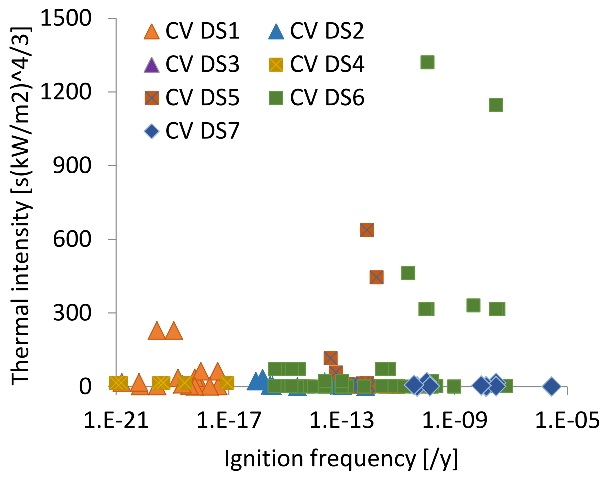


Figure 155: Probability distribution of thermal intensity consequence

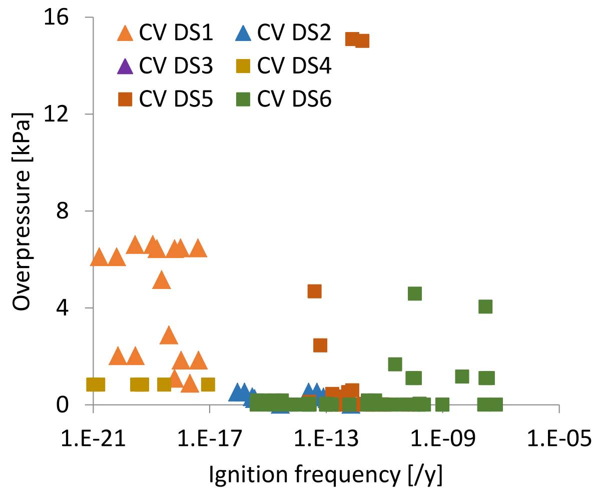


Figure 156: Probability distribution of overpressure consequence

With ignition at the room floor both TI and OP are more severe but again their likelihood is extremely rare, i.e., in the order of one in a million-million units per year. Whilst the area surrounding the condensing unit showed the greatest ignition frequency the severity of the consequence is effectively negligible due to the small flammable volume arising from the smallest leak hole. Lastly, the consequences associated with ignition of a leak from interconnecting piping yield the greatest TI and also fairly high OP, but at a much high frequency than with the other control volumes. Whilst these severe consequences are estimated to occur about once in 10 million units per year, these results suggest some attention should be paid to possible additional mitigation measures.

Comparison of overall risk of TI and risk of OP highlights need for attention here, as seen in Figure 157 (summation of ignition frequency × severity of consequence). Whilst these two risk categories cannot be compared directly, values for each control volume can be. These suggest that the risk associated with the AHU, condensing unit and ducting present the lowest risk, whereas the room with the interconnecting piping poses the greatest risk, in the order of about 100 to 1000 times greater than any other control volume.

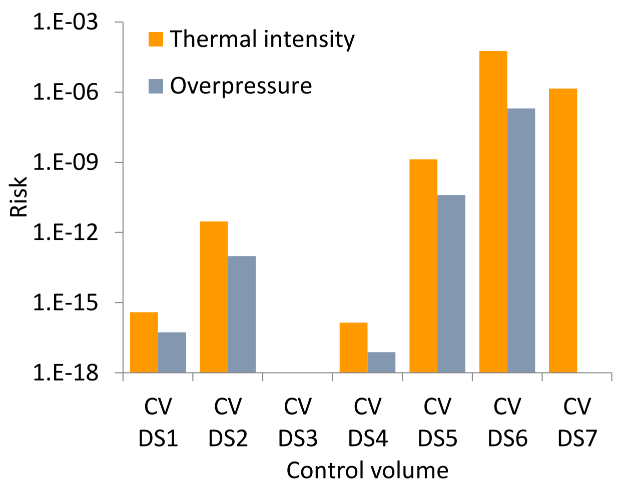


Figure 157: Overall risk value for each control volume

The risk of secondary fire and fatality from Table 28 follow these observations. All other control volumes exhibit a negligible risk of secondary fire, but ignition of a leak from interconnecting piping still leads to about one secondary fore per 10 million units per year. Overall risk of fatality also follows this, where one fatality is anticipated per 1000 million units per year.

3.11.2 Rooftop

Results for the relevant risk measures associated with the various control volumes are given in Table 29. The main observations concerning ignition frequency are:

- Both AHU and condensing unit section have extremely low ignition frequencies, corresponding to less than one ignition event per million-million units per year; such a frequency is so low it may be considered negligible.
- Ignition within both with the supply and return duct is also negligible (on account that the only ignition source is another ignition event within an adjacent space).
- Ignition within the room floor region is very small indeed, about one ignition event per million-million units per year and as such is negligible.
- The control volume which experiences the highest ignition frequency is the area surrounding the condensing unit, with about three ignition events per millions units per year.

With ignition in the region surrounding the condensing unit, the relatively high value is dominated in fact by the high probability of the "small" leak (0.1 mm^2) being ignited whilst the condenser fan is off, on account that it persisting for a long time in relation to the regular SOI active events. Since the flammable mixture is unlikely to extend as far as the SOIs within adjacent condensing units for this small leak the calculation result is broadly unrealistically high; in the case of a leak within a room the positioning of an SOIs relative to the flammable volume is effectively random, whilst in the present case it is likely that the adjacent condensing unit electrical panel would be more than 20 cm or so from the leaking R290 condensing unit section. A simple evaluation of the situation indicates the calculated ignition frequency is more likely to be lower by a factor of 100 or so.

Table 29: Risk measures of rooftop unit according control volume

Control volume		Ignition freq (y^{-1})	Max TI ($s(kW/m^2)^{4/3}$)	Max OP (kPa)	Risk of TI	Risk of OP	Risk of sec fire (y^{-1})	Risk of fatality (y^{-1})
CV RT1	AHU	1E-17	228	9	4E-16	6E-17	1E-19	1E-21
CV RT2	Cond unit	1E-12	34	1	3E-12	1E-13	3E-13	3E-15
CV RT3	Supply duct	0E+00			0E+00	0E+00	0E+00	0E+00
CV RT4	Return duct	3E-16	590	10	1E-13	3E-15	3E-16	3E-18
CV RT5	Supply outlet	1E-14	5	0	2E-15	2E-16	0E+00	0E+00
CV RT6	Room floor	3E-12	182	7	7E-11	3E-12	4E-13	4E-15
CV RT7	Surr cond unit	3E-06	18	0	1E-06	0E+00	0E+00	0E+00
Overall		3E-06	3E-06	590	10	1E-06	3E-12	7E-13

Maximum values of TI and OP are provided and are seen to span a wide range. However, a more useful means to express values of TI and OP is to plot them against the corresponding ignition frequency; as shown in Figure 158 and Figure 159. This helps to identify the probability of "extreme" consequences. Whilst the TI and OP associated with ignition within the AHU and return ducting is sometimes fairly high, such occurrences are seen to be so rare that they have no importance. These severe events only arise when there are multiple failures of the mitigation measures, such as absence of airflow and leaking LLSV.

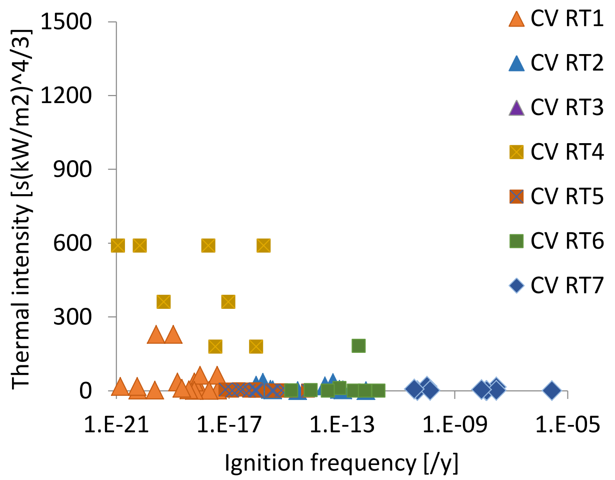


Figure 158: Probability distribution of thermal intensity consequence

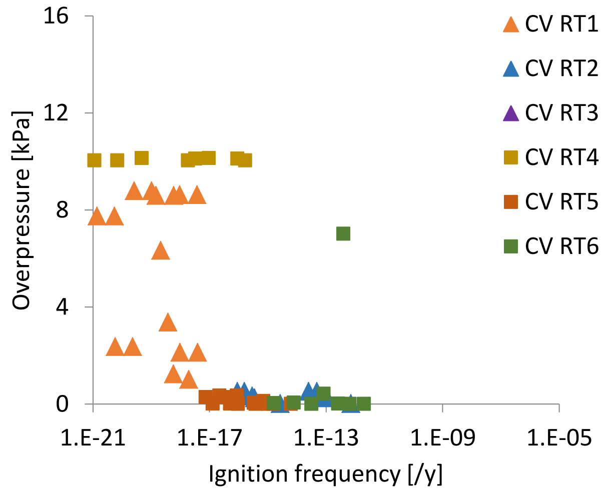


Figure 159: Probability distribution of overpressure consequence

With ignition at the room floor both TI and OP can be seen to be sometimes severe but again the likelihood is extremely rare, i.e., in the order of one in a million-million units per year. Whilst the area surrounding the condensing unit showed the greatest ignition frequency the severity of the consequence is effectively negligible due to the small flammable volume arising from the smallest leak hole.

Comparison of overall risk of TI and risk of OP helps identify situations which are most vulnerable. Figure 157 shows overall risk (summation of ignition frequency × severity of consequence) for each control volume. Whilst these two risk categories cannot be compared directly, values for each control volume can be. These suggest that the risk associated with the AHU, condensing unit and ducting present the lowest risk, whereas the room floor is marginally higher (at least by a factor of 10) and the region around the condensing unit posing the greatest risk.

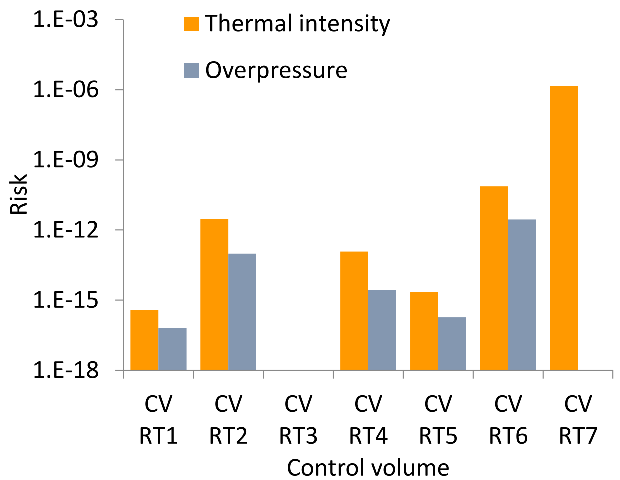


Figure 160: Overall risk value for each control volume

The risk of secondary fire and fatality from Table 28 shows that despite the region surrounding the condensing unit having the highest risk of TI, the likelihood of secondary fire and fatality is non-existent. Such secondary consequences are most prevalent in the case of ignition on the room floor and within the condensing unit, but again the values are so extremely low they have no significance. Thus overall risk of secondary fire and fatality are anticipated to be about one event per million-million units per year.

3.11.3 Comparison of ducted split and rooftop units

Results in Table 28 and Table 29 can be compared to understand the differences in risk measures between the two types of DACS. Firstly, all risk measures associated with the AHU, supply duct, condensing unit and surrounding the condensing unit are almost the same for both DACS; this is to be expected since the design and construction is broadly the same. Although the ducted split was selected not to include a return duct the values associated with the return duct of the rooftop unit were so small it has no significance. Similarly the supply duct outlet of both units, whilst somewhat different, maybe considered to be broadly the same.

A major difference, though, is seen with ignition events within the room floor region. The rooftop unit has an ignition frequency lower by a factor of 30 and maximum TI and OP are about a half to a quarter of the ducted split values. Overall risk of TI, OP, secondary fire and fatality for the rooftop are about one tenth of that for the ducted split. This is primarily due to any leak occurring within the rooftop AHU forms a small flammable mixture within the room on account of better dilution when flowing through and out of the ducting.

Overall, the total ignition frequency of the two DACS is almost the same, but this is because of the dominant contribution of ignition surrounding the condensing unit, which as described above, actually presents almost no consequence. But when considering the risk of TI and particularly OP, secondary fire and fatality, the rooftop unit yields a value between 100 and 10,000 times lower than the ducted split. (Note that whilst this seems to be a huge reduction, relative to risk measure thresholds – such as tolerable risk of fatality – it only corresponds to a 0.15% reduction.) The most obvious impact associated with the ducted split is due to the presence of the interconnecting piping and the corresponding absence of the mitigation measures present in the AHU and condensing unit (to some extent). Thus, in absence of the interconnecting piping passing through an “uncontrolled” space, for example the AHU and condensing unit being positioned either side of an exterior wall the overall risk for the ducted split would be almost identical to the rooftop unit.

3.11.4 Effectiveness of mitigation measures

As developed in Section 2 (and specifically detailed later in Section 5), it was opted to adopt several flammability risk mitigation measures in the design of the DACS. Using the QRA, the effectiveness of such measures can be evaluated (for brevity, with respect to ignition frequency and risk of secondary fire, since these represent all other risk values closely). For both rooftop and ducted split, the following measures were assessed:

- Use of ultrasonic leak detector to initiate AHU blower in the event of a leak
- Inclusion of LLSV and NRV for functioning of a pump-down cycle
- Construction (AHU) or specification for (rooftop return duct) and elevated inlet opening

Note that potential failure/absence of all of these measures was already integrated into the QRA according to historical failure data.

Figure 161 and Figure 162 show for the ducted split the effect on ignition frequency and risk of secondary fire of neglecting one of each set of mitigation measures in isolation. It can be seen that for some control volumes – the condensing unit, supply duct and outlet, room with interconnecting piping and surrounding the condensing unit – the presence of the mitigation measures has limited impact. The element that is most affected by the mitigation measures is the room floor control volume and to some extent the AHU. Removing any of the measures increases the risk for the room control volume, although the effect is least pronounced for the presence of the return duct outlet panels.

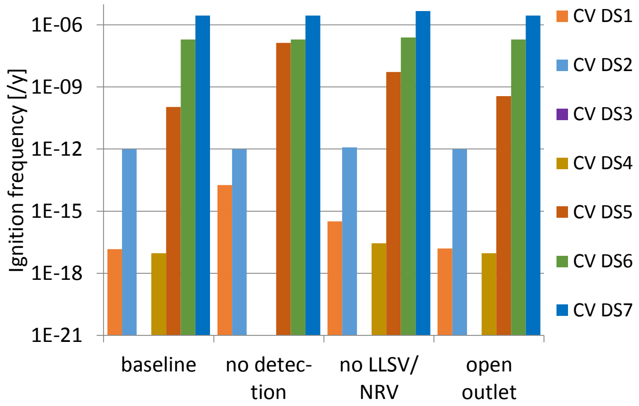


Figure 161: Variation of ignition frequency without certain mitigation measures for ducted split

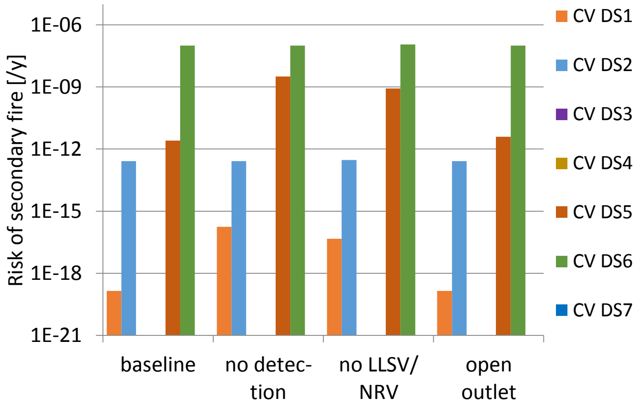


Figure 162: Variation of risk of secondary fire without certain mitigation measures for ducted split

Figure 163 and Figure 164 show for the rooftop unit the effect on ignition frequency and risk of secondary fire of neglecting one of each set of mitigation measures in isolation. It can be seen that only the condensing unit and the surrounding area are unaffected by the presence of the mitigation measures. The element most affected by the mitigation measures is the room floor control volume and along with the other control volumes, absence of the elevated return duct height ("open outlet") seems to have least impact on increasing the risk.

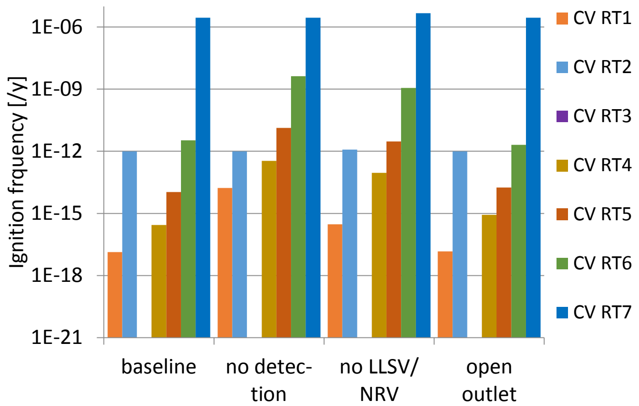


Figure 163: Variation of ignition frequency without certain mitigation measures for rooftop unit

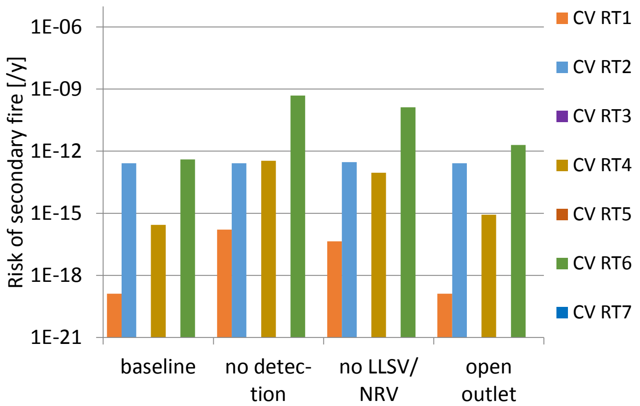


Figure 164: Variation of risk of secondary fire without certain mitigation measures for rooftop unit

A more focussed comparison is shown in Figure 165 and Figure 166 for the ducted split and rooftop units, respectively, where the sum of the indoor control volume risk values is given as a ratio to the baseline case. As inferred above, absence of the elevated/closed return duct outlet has a fairly minor impact compared to the other two mitigation measures. Generally inclusion of the LLSV/NRV will reduce risk indoors by a factor of about 400 whereas the detection initiating AHU blower reducing risk by a factor of 1000. Such a difference between these two measures is anticipated since the actual releasable mass becomes irrelevant if there is always airflow to disperse the leak.

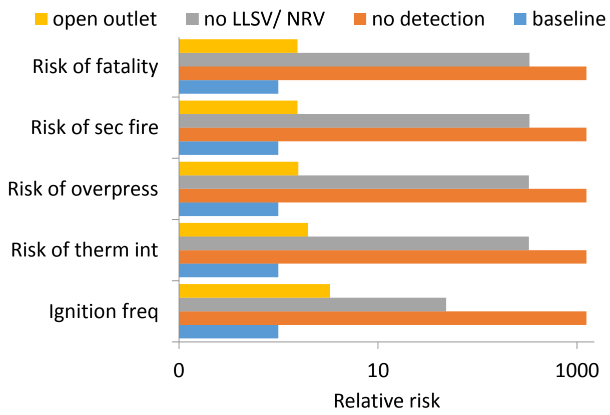


Figure 165: Variation of risk values without certain mitigation measures for ducted split

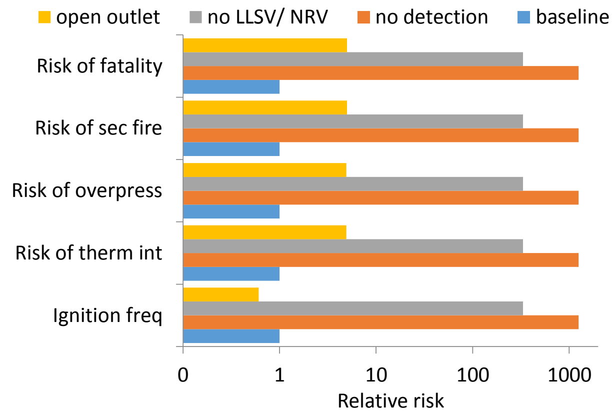


Figure 166: Variation of risk values without certain mitigation measures for rooftop unit

It should be recognised that the QRA assumes an equal leak frequency irrespective of whether the system (compressor) is on or off; were the assumptions changed so that a higher leak frequency occurred when the compressor is operating (as is probably the case) the difference between the impact of using detection/blower and LLSV/NRV would be lessened.

Lastly, the effect of improved system tightness (achieved through implementation of the various measured detailed in Section 2.2) has not been evaluated, primarily due to the difficulty in quantifying this aspect. If an assumption of, say, reduction in leak frequency by a factor of 10 is used, then the overall effect on the various risk values can be estimated accordingly (i. e., proportionally).

3.12 Discussion and concluding remarks

The various risk values presented previously do not clearly express the level of safety associated with the R290 DACS. Therefore such values should be gauges against other comparable quantities, such as those obtained from exiting similar equipment for comparable hazards and also those established by relevant authorities for the purpose of judging risk. Appendix H provides a detailed overview of how such a comparison can be made and reports on data used for such purposes. Table 30 and Table 31 make the comparisons between tolerable risk values and those determined for the DACS. These tables show that the various criteria are easily passed for both DACS. There are questionable values when considering the actual ignition frequency, but as mentioned previously this is on account of the calculation of the ignition frequency surrounding the condensing unit.

Table 30: Comparison of "tolerable" risk criteria with results for baseline ducted split

Criteria	"Tolerable" to members of public	Result for ducted split baseline
Frequency of ignition (y^{-1})	< 1×10^{-5}	3×10^{-6} (2×10^{-7})
Freq of secondary fire (/yr)	< 1×10^{-6}	1×10^{-7}
Overpressure (kPa)	< 17	15
Thermal intensity (s (kW $m^{-2})^{4/3}$)	< 1050	1321
Frequency of fatality (y^{-1})	< 1×10^{-6}	1×10^{-9}
Risk of TI (s (kW $m^{-2})^{4/3}$ y^{-1})	< 6×10^{-3}	6×10^{-5}
Risk of OP (kPa y^{-1})	< 4×10^{-4}	2×10^{-7}

Also, by comparison, the fire risk for residential air conditioners in North America is in the order of 2×10^{-5} per year, which again indicates that the additional fire risk from using R290 is less than 1% for the ducted split and substantially less than 0.01% for the rooftop.

Table 31: Comparison of "tolerable" risk criteria with results for baseline rooftop unit

Criteria	"Tolerable" to members of public	Result for rooftop baseline
Frequency of ignition (y^{-1})	< 1×10^{-5}	3×10^{-6} (3×10^{-12})
Freq of secondary fire (/yr)	< 1×10^{-6}	2×10^{-12}
Overpressure (kPa)	< 17	10
Thermal intensity (s (kW $m^{-2})^{4/3}$)	< 1050	590
Frequency of fatality (y^{-1})	< 1×10^{-6}	2×10^{-14}
Risk of TI (s (kW $m^{-2})^{4/3}$ y^{-1})	< 6×10^{-3}	1×10^{-6}
Risk of OP (kPa y^{-1})	< 4×10^{-4}	1×10^{-11}

Lastly, all results must be considered with respect to the boundaries and limitations of the QRA. When assigning values and assumptions in the QRA model, those which are deemed to represent a "pessimistic average" are applied, however when there is a wide range of uncertainty associated with any particular parameter the selected input is according to the "worse realistic" value. This principle helps to ensure that the output results will be as realistic as possible yet erring on the side of least optimism.[23] Across the various input values, those related to the following may be considered to err on the least optimistic:

- Parity between leak frequency during compressor on and off;
- All leak holes occur simultaneously (as opposed to evolution from infinitesimally small leak hole to the assigned hole size used above);
- Constant leak mass flow rate and vapour phase only;
- Releases in absence of DACS airflow are only under quiescent conditions thus causing larger flammable volumes and longer persistence;
- All assumed SOIs are 100% effective in igniting any flammable mixture of R290 and air (which may not always be possible if the concentration is closer to the flammable limits or the spark occurs within an enclosure without open paths for flame movement;
- Fairly course localised modelling of presence of SOIs in relation to flammable volume (such as with surrounding condensing unit control volume);
- Etc.

Previous analysis suggests that if these and other assumptions were precisely taken into account through much more detailed discretisation of conditions and variables, the overall ignition frequency and other risk values can be lower by a factor of 10 to 1000. Whilst all possible circumstances cannot easily be taken into account and unanticipated higher-risk scenarios cannot necessarily be known, considering the results presented above within the context of the pessimistic approach to input assumptions provide confidence that the risk posed by the R290 DACS is acceptably low.

[23] For instance, in the event of a leak into a space without forced airflow from the DACS fan or blower, flammable volume calculations are based on limited residual air movement – according to controlled experiments – in the case of a closed room without forced movement from human or other sources and significant thermal gradients. However, in practical circumstances it is highly likely that natural ventilation from external wind/stack effects, thermal convention due to electrical and electronic equipment and walls and surfaces subjected to differential heat load, forced convention arising from human or mechanical movements and so on. Thus the idealistic assumption of absolutely no air movement except that caused by the negative buoyancy of the moving refrigerant release is totally improbable. But accounting for all of the causes of background air movement may only be a reasonable assumption in a moderate proportion of cases. So calculation of flammable volume based on practical residual air movement is a reasonable but not unrealistic reference condition.

4. Conformity to safety standards

4.1 Introduction

Applicable safety standards for the DACS under consideration include IEC 60335-2-40, ISO 5149 and EN 378. However, since there is a national safety standard, NTC 6228[24], this should be the prioritised choice.

NTC 6228-1 and NTC 6228-2 are applicable to products and therefore only these two parts will be addressed for conformity to the prototype DACS.

For requirements not specifically related to the application of R290, it is the responsibility of the manufacturer to address them as appropriate.

4.2 NTC 6228-1

Clause	Remark
5. Clasificación	
5.1 Clasificación de ocupaciones	DACS to be located in all occupancies, with occupancy A being the most stringent
5.2 Clasificación de sistemas	DACS are direct systems
5.3 Clasificación de la localización de los sistemas de refrigeración	DACS are system location II
5.4 Clasificación del refrigerante	R290 is Class A3
6. Cantidad de refrigerante por espacio ocupado	Refer to Table A.2., and Annex A.4.
7. Cálculos de volumen-espacio	Based on a single room space
8. Fluido de transferencia de calor	Not applicable

From Table A.2:

Tabla A.2. (Final)

Clases de Inflama-bilidad	Categoría de ocupación			Clasificación de la ubicación I	Clasificación de la ubicación II	Clasificación de la ubicación III	Clasificación de la ubicación IV
3	a	Confort humano y otras aplicaciones	Subterráneo	De acuerdo al literal A.4 y no más de 1,5 x m_2[a]		No más de m_3[b]	
			Sobre la superficie				
	b	Confort humano y otras aplicaciones	Subterráneo	De acuerdo al literal A.4 y no más de 1,5 x m_2[a]		No más de 2 x m_3[b]	
			Sobre la superficie	De acuerdo al literal A.4 y no más de 2,5 x m_2[a]			
	c	Confort humano y otras aplicaciones	Subterráneo	De acuerdo al literal A.4 y no más de 1,5 x m_2[a]		Sin restricciones de carga[c]	
			Sobre la superficie	De acuerdo al literal A.4 y no más de 2 x m_3[b]	De acuerdo al literal A.4 y no más de 5 x m_3[b]		

a m_2 = 26 m^3 x LFL.
b m_3 = 130 m^3 x LFL.
c NTC 6228-3:, aplican numerales 5.2 y 8.1.

Charge amounts shall not exceed: 1.5 x 26 x 38 = 1480 g of R290.

From Table A.4, the minimum room area fir the DACS can be determined according to:

[24] Norma Técnica Colombiana NTC 6228: 2016, Sistemas de refrigeración y bombas de calor. Requerimientos de seguridad y medioambientales.

Method for determining charge	Clause	For DACS
No additional measures	A.4.1	n/a
Improved tightness	A.4.2	n/a
Systems with integral airflow	A.4.3	Applicable during on mode
Charge determination by test	A.4.4	n/a
With limited releasable charge	A.4.5	Applicable during off mode

Following clauses A.4.3 and A.4.5, Table 32 gives the results for (expected) releasable charge (in off-mode) and the minimum room area (using F = 0.5) and minimum airflow rate (for on-mode). Since there is no room size constraint for systems with a releasable charge of less than 150 g of R290, the only limit is that listed in the table. All products currently exceed the minimum airflow requirement.

Table 32: Releasable charge, minimum room area and minimum airflow rate

	Rooftop			Ducted split		
Model number	EPAC-036-	EPAC-048-	EPAC-060-	CV036-	CV048-	CV060-
Nominal capacity	10.5 kW	14 kW	17.5 kW	10.5 kW	14 kW	17.5 kW
R290 charge	*560 g	*760 g	950 g	*600 g	*800 g	1000 g
Releasable mass	56 g	76 g	95 g	60 g	80 g	100 g
Min room area	13 m^2	18 m^2	23 m^2	14 m^2	19 m^2	24 m^2
Min airflow rate	480 m^3/h	604 m^3/h	714 m^3/h	506 m^3/h	627 m^3/h	742 m^3/h

* Expected

4.3 NTC 6228-2

Clause	Remark
4 Requirements for components and piping	General; for manufacturer
4.1 General requirements	General; for manufacturer
4.2 Specific requirements for particular components	General; for manufacturer
4.2.1 Piping joints	General; for manufacturer
4.2.2 Isolating valves	General; for manufacturer
4.3 Materials	General; for manufacturer
4.3.1 Cast iron and malleable iron	General; for manufacturer
4.3.2 Steel, cast steel, carbon steel, and low-alloy steel	General; for manufacturer
4.3.3 High-alloy steel	General; for manufacturer
4.3.4 Stainless steel	General; for manufacturer
4.3.5 Copper and copper alloys	General; for manufacturer
4.3.6 Aluminium and aluminium alloys	General; for manufacturer
4.3.7 Magnesium and magnesium alloys	General; for manufacturer
4.3.8 Zinc and zinc alloys	General; for manufacturer
4.3.9 Soldering alloys	General; for manufacturer
4.3.10 Brazing alloys	General; for manufacturer
4.3.11 Tin and lead tin alloys	General; for manufacturer
4.3.12 Gasket and packing materials	General; for manufacturer
4.3.13 Glass	General; for manufacturer
4.3.14 Asbestos	General; for manufacturer
4.3.15 Plastics	General; for manufacturer
4.4 Testing	General; for manufacturer
4.4.1 General	General; for manufacturer
4.4.2 Strength-pressure test for components	General; for manufacturer
4.4.2.1 General	General; for manufacturer
4.4.2.2 Individual strength-pressure test	General; for manufacturer

4.4.2.3 Type-approved strength-pressure test	General; for manufacturer
4.4.2.4 Fatigue test	General; for manufacturer
4.4.2.5 Acceptance criteria	General; for manufacturer
4.4.3 Tightness	General; for manufacturer
4.5 Marking and documentation	General; for manufacturer
4.5.1 General	General; for manufacturer
e) the design pressure or maximum allowable pressure;	To be determined by manufacturer is usual way
f) the applicable refrigerant (where appropriate);	State use of R290 in marking and documentation
4.5.2 Documentation	General; for manufacturer
The documentation shall include the following information: - indication of the refrigerant, for example, “suitable for halocarbons”, “suitable for all refrigerants listed in ISO 817”,	Documentation should state “suitable for use with R290”
4.5.3 Fusible plugs	General; for manufacturer
5.1 General	General; for manufacturer
5.2 Design and construction	General; for manufacturer
5.2.1 General	General; for manufacturer
5.2.2 Pressure requirements	General; for manufacturer
5.2.2.1 Maximum allowable pressure (PS)	General; for manufacturer
5.2.2.2 Component maximum allowable pressure	General; for manufacturer
5.2.2.3 Pressure relationships to max allowable pressure	General; for manufacturer
5.2.3 Piping and fitting	General; for manufacturer
5.2.3.1 General	General; for manufacturer
5.2.3.2 Flanged joints	General; for manufacturer
5.2.3.3 Flared joints	General; for manufacturer
5.2.3.4 Taper pipe threads	General; for manufacturer
5.2.3.5 Compression joints	General; for manufacturer
5.2.3.6 Requirements for piping installed at site	General; for manufacturer
— No valves and detachable joints shall be located in areas accessible to the general public where group A2, B1, B2, A3, or B3 refrigerants are used. For all refrigerants, the valves and detachable joints in areas accessible to the general public shall be protected against an unauthorized operation or disconnection.	All interconnecting piping must be brazed or press-sealed; must be stated in installation instructions
5.2.3.7 Specific requirements for the installation of piping for equipment intended to use A2, A3, B2, or B3 refrigerants, excluding A1, B1, A2L, and B2L refrigerants: Piping and joints of a split system shall be made with permanent joints when inside an occupied space, except joints directly connecting the piping to indoor units. Components shall be shipped without refrigerant charge.	A single set of detachable joints can be used for connecting the AHU
5.2.3.8 Spacing for pipe supports	General; for manufacturer
5.2.3.9 Protection of piping	General; for manufacturer
5.2.3.10 Piping in ducts or shafts	General; for manufacturer
5.2.3.11 Location	General; for manufacturer
5.2.3.12 Accessibility of piping and joints	General; for manufacturer
5.2.3.13 Piping for accessories and measurements	General; for manufacturer
5.2.3.14 Drain and vent connections	General; for manufacturer
5.2.3.14.1 General	General; for manufacturer
5.2.3.14.2 Special requirements	General; for manufacturer
5.2.4 Shut-off devices	General; for manufacturer
5.2.4.1 Isolating valves	General; for manufacturer
5.2.4.2 Hand-operated valves	General; for manufacturer
5.2.4.3 Change of gland packing/seal	General; for manufacturer
5.2.4.4 High-risk release areas	General; for manufacturer
5.2.4.5 Arrangement of shut-off devices	General; for manufacturer
5.2.5 Setting of protection devices	General; for manufacturer
5.2.5.1 General	General; for manufacturer

5.2.5.2 Press relief to atmosphere from the low-press side	General; for manufacturer
5.2.6 Safety switching devices for limiting the pressure	General; for manufacturer
5.2.6.1 Safety switching devices for limiting the pressure	General; for manufacturer
5.2.6.2 Electronic safety switching for limiting pressure	General; for manufacturer
5.2.6.3 Arrangement of safety switching devices	General; for manufacturer
5.2.7 Size calculations for pressure relief devices	General; for manufacturer
5.2.7.1 Calculations	General; for manufacturer
5.2.7.2 Fusible plugs	General; for manufacturer
5.2.7.3 Bursting disc	General; for manufacturer
5.2.7.4 Discharge capacity	General; for manufacturer
5.2.8 Discharge piping from pressure relief devices	General; for manufacturer
5.2.8.1 General	General; for manufacturer
5.2.8.2 Indication device for pressure relief devices	General; for manufacturer
5.2.9 Application of the protection devices	General; for manufacturer
5.2.9.1 General	General; for manufacturer
5.2.9.2 Protection of the system against excessive press	General; for manufacturer
5.2.9.3 Overflow valves	General; for manufacturer
5.2.9.4 Isolation/arrangement system protection devices	General; for manufacturer
5.2.9.5 Protection of secondary cooling system	General; for manufacturer
5.2.10 Indicating and measuring instruments (monitoring)	General; for manufacturer
5.2.10.1 General	General; for manufacturer
5.2.10.2 Arrangement of refrigerant pressure indicators	General; for manufacturer
5.2.10.3 Liquid level indicators	General; for manufacturer
5.2.11 Electrical requirements	General; for manufacturer
5.2.12 Protection against hot surfaces The equipment shall comply with the IEC 60335 series or IEC 60204-1 so that persons shall not be endangered by hot surfaces in combination with the following requirements. Temperatures on surfaces that can be exposed to leakage of refrigerants shall not exceed the autoignition temperature except for A1, B1, A2L, and B2L refrigerants.	All DACS units have been evaluated for high surface temperatures; see section 2.6
5.2.13 Protection against moving parts	General; for manufacturer
5.2.14 Safe handling of equipment	General; for manufacturer
5.2.15 Standstill conditions during transportation	General; for manufacturer
5.2.16 Protection against explosion hazards [As 6.2.14 from EN 378-2]	Requirements have been satisfied as documented in section 2.6
5.2.17 Requirements for ventilated enclosures	General; for manufacturer
5.3 Testing	General; for manufacturer
5.3.1 Tests	General; for manufacturer
5.3.2 Strength-pressure test	General; for manufacturer
5.3.3 Tightness test	General; for manufacturer
5.3.3.1 General	General; for manufacturer
5.3.3.2 Self-contained systems with charge less than 5 kg	General; for manufacturer
5.3.3.3 For systems not covered by 5.3.3.2	General; for manufacturer
5.3.3.3.1 Factory test	General; for manufacturer
5.3.3.3.2 Acceptance criteria	General; for manufacturer
5.3.3.3.3 Site tests	General; for manufacturer
5.3.4 Test of the complete installation before operation	General; for manufacturer
5.3.4.1 General	General; for manufacturer
5.3.4.2 Inspection of refrigerating system	General; for manufacturer
5.3.4.3 Verification of safety devices	General; for manufacturer
5.3.4.3.1 Fitting	General; for manufacturer
5.3.4.3.2 Compliance with appropriate standards	General; for manufacturer
5.3.4.3.3 Switching devices for limiting the pressure	General; for manufacturer
5.3.4.3.4 External pressure relief valves	General; for manufacturer
5.3.4.3.5 Bursting discs	General; for manufacturer
5.3.4.3.6 Fusible plugs	General; for manufacturer
5.3.4.4 Refrigerant piping	General; for manufacturer

5.3.4.5 Visual inspection of the complete installation	General; for manufacturer
5.4 Marking and documentation	General; for manufacturer
5.4.1 General	General; for manufacturer
5.4.2 Marking	General; for manufacturer
5.4.2.1 General Service access points to equipment operating with flammable refrigerants shall be marked with the flame symbol according to ISO 7010:2011, W021.	Flammable gas triangle stickers applied
5.4.2.2 Refrigerating systems A clearly readable identification plate shall be located near or on the refrigerating system. The identification plate shall contain at least the following data: d) the number designation of the refrigerant in accordance with ISO 817 (see also Annex B of ISO 5149-1); e) the refrigerant charge; f) the maximum allowable pressure, high- and low-pressure sides; g) when flammable refrigerants are used, the flame symbol according to W021 of ISO 7010:2011, shall be displayed with a minimum height of 10 mm, and the symbol need not be in colour.	Data-plate yet to be checked Flammable gas triangle stickers applied
5.4.2.3 Piping and valves	General; for manufacturer
5.4.3 Documentation	General; for manufacturer
5.4.3.1 Certificates	General; for manufacturer
5.4.3.2 Documentation at operating site	General; for manufacturer
5.4.3.3 Instruction manual The manufacturer or installer shall supply an adequate number of instruction manuals or leaflets and shall also provide safety instructions. The instruction manual shall at least contain the following information, if relevant: e) the instructions concerning the disposal of operating fluid and equipment; f) the causes of the most common defects and measures to be taken, e.g. instructions concerning leakage detecting by authorized personnel and the need to contact competent maintenance technicians in the event of leakage or breakdown; j) a reference to protective measures, first aid provisions, and procedures to be followed in the event of emergencies, e.g. leakage, fire, explosion; k) the maintenance instructions for the entire system with a time schedule for preventive maintenance with respect to leakage (see ISO 5149-4); l) the instructions concerning the charging and discharging of refrigerant; m) the instructions concerning the handling of refrigerant and the hazards associated with it; n) the instructions concerning the function and maintenance of safety, protective, and first aid equipment, alarm devices, and pilot lamps;	Manual yet to be checked
5.4.3.4 Drawings	General; for manufacturer
5.4.3.5 Logbook	General; for manufacturer
Annex ??? Leak simulation tests	Test completed as detailed in Appendix F

5. Specific design changes

5.1 Introduction

Numerous approaches have been established for providing protection against ignition of a flammable mixtures arising from a refrigerant leak, as introduced in Section 2. Extensive testing, measurement and computational analysis have been carried out in order to determine the most effective options for the DACS addressed here. This section provides a summary of the concluded measures and discussed possible future targets for refined measures.

5.2 Minimisation of leaks

Principle
As discussed in section 2.2, as much as possible should be done to minimise the likelihood and the size of refrigerant leaks, especially within the parts of the system that could leak directly to indoors; specifically, the evaporator, expansion device and – when applicable – interconnecting piping. Principally, detachable joints should be avoided, all piping to be protected from external impact, vibration, chaffing, corrosion, etc. and factory built parts should be subject to rigorous quality control (such as helium leak checks, field surveillance, etc.)

Current
The most important criteria are listed in Appendix B and are understood to have been followed.

Future target
Continuous monitoring should be carried out on sold products so that leak locations and causes can be determined. Findings must be fed back into the production methods.

5.3 Reduction of refrigerant charge

Principle
Refrigerant charge should be reduced as much as is practicable so that the ultimate maximum releasable mass is as low as possible and this flammable volumes arising from leakage. Section 2.3 addresses the principle of charge reduction.

Current
For the current DACS the measures providing the most effective reduction include use of narrow tube or micro-channel condensers. A reasonable target is 70 g R290 per kW of nominal cooling capacity, which the current rooftop and ducted split DACS exceed (at about 55 g/kW).

Future target
Use of smaller condenser tubes, e.g., 5 mm instead of the current 7 mm diameter would provide significantly greater improvements. Evaporators can also benefit from smaller tubes, provided circuitry is designed appropriately.

5.4 Limiting releasable charge

Principle
The system should be configured so that in the event of a leak from the indoor-connected parts, as small an amount as possible can be released. The approach is examined within Section 2.4.

Current design
This is primarily achieved through the use of a liquid line solenoid valve (LLSV) fitted within the condensing unit and – with the current compressor configuration – a non-return valve (NRV) / check valve. Thus in the event of shut-down (compressor off and LLSV closing simultaneously) or pump-down (LLSV closing and compressor continuing to operate until LP switch terminates it) about 30% or 10%, respectively, of the system charge is trapped in the low side of the system meaning that a significantly reduced amount of refrigerant could leak out. It is preferable to employ a pump-down cycle, but in the event that this causes reliability issues with the compressor, then shut-down remains an effective and desirable option.

Future target
The pump-down cycle should be retained if at all possible. However, new compressors should be sought that include a "tight" internal NRV so as to minimise the pressure drop and associated degradation in system performance as is currently the case with the inclusion of a second (tight) external NRV.

5.5 Blower operation

Principle
Experiments described in section 2.5 showed that operation of the blower is extremely useful to ensure no flammable mixture occurring within supply and return ducts and also within the conditioned space. According to detailed analysis (e.g., Colbourne and Suen, 2018) the minimum airflow rate to ensure LFL is avoided is about 750 m^3/h.

Current
Blower airflow rate, even at minimum fan speed, achieves at least three times the above stated value and was found to provide adequate mixing.

Future target
Provided the airflow is operating adequately no further improvements are necessary.

5.6 Leak detection

Principle
For the periods that the compressor is off, it is undesirable to operate the blower, just on the off-chance that there is a leak from the AHU. Therefore use of leak detection system can be applied to initiate the blower as and when needed. Whilst it is convention to adopt gas sensing methods to determine whether a leak has occurred, all economically available technologies today are considered unreliable and function of a major mitigation measure should not be dependent upon them. Other methods such as ultrasonic detection and monitoring system parameters can be substantially more reliable over the lifetime of the equipment, albeit less sensitive to smaller leaks.

Current
An ultrasonic receiver with applicable PCB has been developed and fitted into the AHU and has been shown to be effective and functional.

Future target
Additional development and refinement of the detection method is recommended, especially to ensure all leaks from throughout the AHU are able to be identified.

5.7 Elevated duct inlet/outlet

Principle

As indicated in section 2.5, an elevated inlet or outlet opening to the supply or return duct, respectively, is important to help ensuring that in the event of a medium or large leak, a flammable concentration will not develop within the conditioned space.

Current

An extended AHU has been developed for the ducted split which uses a second internal space whereby the return air is drawn in via a 1 m high opening (as opposed to an opening at the AHU base). For the rooftop unit, instructions should include a specification to ensure any return duct opening be elevated to at least 1 m above floor level.

Future target

The modified AHU is considerably more bulky and difficult to handle, compared to the current (non-R290) model. Also, expecting installation technicians to follow such precise instructions may be considered rather optimistic and ultimately unreliable. According to the QRA in Section 3, such as approach may not be necessary of the other measures are in place.

5.8 Ducting drainage

Principle

As discussed above, use of a “U-bend” or “plenum chamber” is desirable to ensure that the mixture exiting the AHU does not result in a flammable mixture within the room it is also undesirable to create a situation where a flammable mixture persists for a significant period of time. With the rooftop unit, having a supply and return ducts that are elevated above the height of the AHU means that a leak of refrigerant cannot easily flow out of the equipment and thus presents a residual explosion risk. Some means of providing draining is necessary without leading to loss of unit efficiency (i.e., through air leakage).

Current

It is necessary to introduce a “drain hole” in the base of either AHU where a “bucket” could be formed, such that any accumulated mixture can bleed from the space within a sufficiently fast time, thereby minimising the duration that it could be ignited. Based on measurements and analysis, a hole size corresponding to an area (in mm^2) of:

$$A = \frac{85}{3.5\sqrt{h}}$$

where h is the height (in m) of the gas layer inside the housing, which can be approximated to the height of the plenum chamber top edge. The hole area may be split into more than one openings, which would be more favourable for avoiding external flammable mixtures.

Future target

Carry out additional testing to provide verification of effectiveness.

5.9 Elimination of potential SOIs

Principle

It is essential to ensure that no SOIs are present within the DACS.

Current
The approach taken is to reposition all electrical components that could arc or spark under normal operation into a special double-walled panel whereby even in the event of a severe leak, no refrigerant could migrate into that panel. Other non-sparking components are also positioned within this panel when possible.

Future target:
For those non-sparking components that cannot be positioned out of the potentially flammable zone (e.g., fan motor and electrical wiring), they should be subject to external assessment against the applicable clauses within the relevant IEC 60079-series standards to confirm a very low likelihood of active ignition source even under normal operation.

5.10 Interconnecting piping

Principle
The QRA in Section 3 revealed that the most vulnerable element of the ducted split equipment was the interconnecting piping that may pass through an additional space; in the event of a leak there are no dedicated mitigation measures to help deal with the leak.

Current
No specific measures are introduced at present except for guidelines within the instructions.

Future target
Ideally some form of sheathing could be applied to such piping so that any leak is easily transferred away into the conditioned space, ducting or preferable to the outside. Such an option requires further consideration and evaluation.

5.11 Limiting severity of consequence

Principle
Severity of consequences is primarily achieved by means of limiting size of flammable mixtures arising from a leak. However, in the event that an unanticipated catastrophic leak does occur, the construction of DACS should be such that the potential for development of a large overpressure is constrained. This is realised by ensuring sufficient free/open area within all equipment enclosures.

Current
Through modelling exercises it was established that the current design satisfied this requirement (i.e., on account of the air inlet and outlet openings). Thus, no further modifications are deemed necessary.

Future target
As current.

6. Concluding remarks

6.1 Overview

This report addresses the re-design requirements associated with applying R290 to a series of ducted split and rooftop DACS. General aspects associated with products safety (such as mechanical, electrical, toxicity, etc.) as not addressed since they should be already integrated irrespective of the refrigerant used. Similarly, other safety issues that are influenced by refrigerant choice but not specifically dictated by the flammability hazard imposed by R290 are identified – broadly through conformity to the national safety standard – but not covered in detail. Again, most the requirements that fall into this category should already be handled (such as system pressure rating and pressure safety devices, leak tightness, etc.). Thus the report focuses primarily on flammability implications and the measures necessary to reduce the risk to "tolerable" levels.

6.2 Product analysis and design

The conventional approach to explosion protection was applied to the philosophy, analysis and design of the RACS when integrating R290; these are identified in EN 1127-1 as well as the GIZ HC Handbook and BS PD 6686[25]. In general this involves:

- Ensuring improved leak tightness
- Minimisation of refrigerant charge and measures to reduce releasable mass of refrigerant
- Construction to limit the accumulation of flammable mixtures inside and beyond the DACS including airflow to disperse releases
- Application of a control system to minimise the possibility of releases and to help disperse them
- Avoidance of potential sources of ignition associated with the DACS
- Designs to limit the severity of possible consequences
- Provision of necessary marking, installation information and instructions

These have been integrated as far as is practicable without incurring undigestible costs whilst maintaining a sufficiently low level of risk.

6.3 Installation requirements

Features to help minimise incorrect or accidental errors associated with technician or other mishandling of the DACS that could lead to a flammability hazard have been integrated as much as possible into the product design. The principle has been to impose as many barriers or hurdles as possible to encourage possible offenders to stop and contemplate their next actions prior to taking next steps. These include:

- Appropriate marking on external cover plates/panels
- Marking inside enclosures near and on refrigerant-containing parts
- Eliminating detachable joints
- Comprehensive user and technician instructions and warnings therein (see Appendix H)
- Imposition of an end user agreement linked to warrantee

Note that except for the marking and jointing, most of the other measures are not directly a function of product design but rather related to company and national infrastructure.

[25] PD 6686:2006 Guidance on directives, regulations and standards related to prevention of fire and explosion in the process industries (*Note: now superseded and withdrawn*)

6.4 Technician requirements

Previous studies have identified that refrigerant handling activities (such as during service, maintenance and repair) pose a substantially greater risk than does the equipment under normal operating conditions (e.g., Colbourne, 2011[26]). This is due to the increased probability of a release occurring (within a given time frame) and similarly a greater likelihood that active SOIs are present within close proximity of refrigerant-containing parts at certain control volumes. On the other hand, the presence of an aware technician can help to offset this additional risk through taking appropriate response actions once a potentially hazardous situation or indeed a release has been recognised. Thus, a major objective is to ensure a high level of awareness and competence with as many technicians and contractors as possible. This further applies to ensuring the intended design measures of the DACS are always maintained and that technicians do not interfere with them.

As mentioned above, there is only limited amount that can be applied to the DACS design to present human error. Therefore ensuring technician and installation/service contractor awareness, training and certification are primarily societal and capacity-building matters and are therefore not addressed in detail here.

6.5 Quantification of flammability risk

Comprehensive QRA was carried out in order to estimate the flammability risk – in terms of ignition frequency, risk of overpressure, thermal intensity, likelihood of secondary fire and fatality – in order to judge the suitability of the proposed designs. Advanced leakage, dispersion and probability modelling was used along with a database of leakage and broad experience of applying such methods to ACR systems and equipment. The results indicated that the level of risk attained with the new design is significantly below the "tolerable" and "negligible" thresholds for flammability and fire risk, despite inclusion of a number of pessimistic assumptions used to help streamline the process. Accordingly, some such measures may be deemed unnecessary to apply universally.

6.6 Response to Excom project objectives

According to the document submitted and approved in the 75th meeting of the Executive Committee of the Multilateral Fund held in Montreal in November 2015, the project objectives are:

1. To demonstrate the safe use of R-290 (propane) as a low GWP refrigerant in the commercial production of air-conditioning with ranging from 3.5 kW (1 ton of refrigeration) to 17.5 kW (5 tons of refrigeration), thus contributing to the phase out of HCFC-22 use in the RAC manufacturing sector in the context of Article 5 Party. The aim is to develop HC-based AC equipment with good performance with a minimum incremental operating cost.

2. To assure safe handling and good risk management for the introduction of flammable refrigerants in the commercial air-conditioning sector in the context of Article 5 Party.

The elements of these objectives are responded to as follows:

- "*To demonstrate the safe use of R-290 (propane) as a low GWP refrigerant in the commercial production of air-conditioning*"

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[26] Colbourne, D. (2011) Risk analysis of flammable refrigerant handling during service and maintenance activities. Proc. 23rd IIR International Congress of Refrigeration: Prague, Czech Republic

Developed DACS use R290. Commercial production has not yet begun, however, there are a few prototype DACS already installed and are being monitored. Through QRA and using – typically pessimistic – assumptions about the installation and operational conditions, the developed products can be considered as "safe" (i.e., not posing an unacceptable high flammability safety risk, compared to residual fire risks associated with comparable DACS).

- "*Ranging from 3.5 kW (1 ton of refrigeration) to 17.5 kW (5 tons of refrigeration)*"

To date, the only DACS developed on R290 are the 17.5 kW ducted split and rooftop models, with the QRA carried out on both of these. Development of 7 kW ("2 TR") and 10 kW ("3 TR") models were not completed to the present time. In principle, though, the same concepts will be applied equally to these smaller units as for the 17.5 kW unit. According to previous experience and understanding of the physical and theoretical processes involved, it is well known that smaller DACS will lead to a (marginally) lower flammability risk than larger units so provided the design elements are replicated, the flammability risk of smaller models is extremely unlikely to exceed those of the 17.5 kW DACS.

- "*Contributing to the phase out of HCFC-22 use in the RAC manufacturing sector in the context of Article 5 Party*."

According to current design, each kg of HCFC22 can be replaced with approximately 0.4 kg of R290 in any DACS of broadly the same design and construction, with a charge size approaching 30 kW (based on extrapolation of the risk model and assuming flammability mitigation approaches are suitably extended) and that a given countries national legislation on use and application of flammable substances does not form regulatory barriers and that national safety standards that apply to DACS are not obstructive or that they are suitably revised. The safety concepts introduced in the current project are broadly applicable and repeatable to all comparable DACS (and indeed other AC equipment) within this class.

- "*Develop HC-based AC equipment with good performance*"

Throughout the development process prototypes were regularly checked for performance. The most recent findings indicated the same cooling capacity (at "factory conditions") as the baseline DACS and a lower electrical power consumption, thus giving a higher COP. This applied equally to ducted split and rooftop units. The project is awaiting formal results from an independent test facility.

- "*A minimum incremental operating cost*"

A selection of specific design features have been developed to help mitigate flammability risk. Several of these incur incremental ("operating") costs. Specifically additional: LLSV, NRV, ultrasonic receiver and associated PCB, panelling for an elevated return air duct and double-skin electrical panel. All of these have some incremental cost associated with them. Such elements leading to an increase in incremental should be considered within a broader context. As a side-benefit, the LLSV provides reduced power consumption during part-load. It is hoped that a new design of R290 compressor will include a "tight" internal NRV so that the additional NRV will not be required. The ultrasonic receiver itself has minimal cost and the associated PCB has no additional cost in the event that the functionality is integrated into the standard PCB controller. Additional panelling for elevated return duct only applies to the ducted split but nevertheless, the QRA indicated the cost vs risk reduction benefit is marginal. The additional material for the double-skinned electrical panel is negligible. The most significant cost implication is associated with the R290 compressor; in terms of capital materials cost there is no reason why the compressor should demand a greater cost than an R290 or R407C compressor of the same capacity, so the primary reason for the elevated price is due to the manufacturer's margin for risks associated with a new product, initial R&D and certification and detriment to finance on smaller-scale production. Eventually the differential cost should asymptote to zero.

- "*To assure safe handling and good risk management for the introduction of flammable refrigerants in the commercial air-conditioning sector in the context of Article 5 Party*."

Necessary features and conditions have been integrated in to the DACS design as far as is practicable. However, addressing safe handling and good flammability risk management is predominantly achieved through company-wide and national technician training, assessment, certification and registration (TACR) schemes and associated changes to company conditions of sale and warrantee agreements; this is beyond the remit of product design and development.

6.7 Outstanding actions

There are several issues that were not concluded by the completion date of the project. These are identified at various points throughout the report, but are compiled and listed here for clarity:

- Re-calculation of electric equipment fault probability based on service database [DC]
- Estimated likelihood that technicians may not replace one or more of the base panels on the new AHU following a service or would not follow instructions that air return ducts should be installed at least 1 m above the floor
- Redesign options for finned-tube evaporator for further charge reduction [DC]
- Additional measurements to demonstrate effectiveness of ultrasonic leak detection
- Confirmation on the type of internal overload protectors on the blower fan motors and assessment certificate for fan motors to IEC 60079
- Assessment certificate for low and high pressure switches to IEC 60079
- Finalised instructions (manual) with R290 handling guidelines
- Explanation and calculations for latest factory performance testing
- Submission of and receipt of results for independent DACS performance testing

Appendix A: Flammability characteristics

Table 33 provides a number of different combustion and ignition characteristics of R290 (from different sources).

Table 33: Combustion and ignition characteristics of R-290

Characteristic	Value	Source
Lower flammability limit (LFL)	2.1% v/v; 0.038 kg/m3	ISO 5149
Upper flammability limit (UFL)	9.5%; 0.171 kg/m3	ISO 5149
Flash point	-104°C	Woodward (1998)
Stoichiometric concentration	4.2%; 0.072 kg/m3	IEC 60079-20-1
Minimum igniting current ratio (24 V d.c.)	0.82	IEC 60079-20-1
Maximum experimental safe gap (MESG)	0.92 mm	IEC 60079-20-1
Critical slot width	1.75 mm	Lee and Mannan (2005)
Heat of combustion	50500 kJ/kg	Woodward (1998)
Limiting oxygen concentration (LOC)	N2 in air: 11.5% O2 CO2 in air: 14.5% O2	Lee and Mannan (2005)
Minimum ignition energy	0.25 mJ	Woodward (1998)
Minimum ignition temperature	450°C	IEC 60079-20-1
Adiabatic flame temperature	1970°C	Lee and Mannan (2005)
Laminar flame speed	0.43 m/s	Lee and Mannan (2005)
Maximum explosion pressure	8.1 bar	Lees and Mannan (2005)

Appendix B: Guidelines for system tightness

Systems that are technically durably tight

According to EN 1127-1, equipment is regarded as durably technically tight, if:

- It is constructed such that it remains technically tight due to its design; or
- Its tightness is permanently ensured by means of maintenance and supervision.

Systems that are durably technically tight include:

- Welded or brazed systems with:
  - detachable components where the required detachable connections are rarely detached due to operation and are designed like the below-mentioned detachable pipework connections (except for metallically sealing connections);
  - detachable connections with pipework, fittings or blind covers where the required detachable connections are rarely detached and are designed like the below-mentioned detachable pipework connections;
- Joints with double-acting axial seal rings
- Components where the sealing of the spindle passage is by means of bellows or safety glands, gland seals with self-adjusting packings;

Pipework connections that are durably technically tight include:

- Non-detachable connections, e.g. welded or brazed;
- Detachable connections which are rarely detached due to operation, e.g.
  - weld-lip seal flanges;
  - metallically sealing connections, with the exception of cutting and clamping ring connections, in lines of diameters exceeding DN 32.
  - No flare joints

Provided they are rarely detached, durably technically tight connections for fittings are, for example:

- The above-mentioned pipework connections and
- NPT threads (National Pipe Taper Threads) or other tapered pipe threads with gaskets in threads of up to DN 50, as long as they are not subject to cyclic thermal stress (Dt > 100 °C).

Additional design measures

Protection against ice damage

The heat exchangers and the control of the system shall be designed to prevent damage due to ice formation of freezing.

Protection against fan breakage

Refrigerant-containing parts shall be protected against fan breakage or the fan is designed to prevent breakage.

Protection against fretting

No refrigerant containing parts shall be in contact or could be moved to become in contact with one another so as to avoid fretting. Any non-secured piping or refrigerant containing parts shall be moved towards other metal parts with a force of no less than 10 N. There shall be no less than 10 mm separation distance between the parts.

Protection against external mechanical damage
Refrigerant piping shall be installed in such way that it is protected against accidental damage. Refrigerant containing parts shall be securely mounted and guarded such that accidental rupture cannot occur from such events as moving furniture or reconstruction activities.

Protection against vibration
Precautions shall be taken to avoid excessive vibration or pulsation. Particular attention shall be paid to preventing direct transmission of noise or vibration to or through the supporting structure.

Protection against adverse environmental conditions
Protection devices, piping, and fittings shall be protected as far as possible against adverse environmental effects, for example, the danger of water collecting and freezing in relief pipes or the accumulation of dirt and debris. Provision shall be made for expansion and contraction of lengths of piping.

Protection against liquid hammer
Refrigerant piping shall be designed and installed to minimise the likelihood of liquid hammer (hydraulic shock) damaging the system, in particular, solenoid valves shall be correctly positioned in the piping to avoid liquid hammer. Solenoid valves and other valves that can stop the flow of refrigerant instantaneously shall not be posited at a distance of more than 0.5 m below any head of liquid.

Appendix C: Finned tube condenser coil arrangement

Introduction

Considering the design of the condenser coil for the 5TR unit, a number of simulations were carried out with alternate coil arrangements in order to help identify optimum coil designs. The objective is to identify any obvious and simple modifications that can be made to the coil design to facilitate the use of R290.

General approach is to evaluate different coil designs, whilst maintaining the same coil dimensions, fins, volumetric airflow rates, etc., with respect to achieving:

- Greatest reduction in refrigerant charge
- At least the same cooling capacity as the baseline
- At least the same cooling COP as the baseline

The most notable constraint is that only 9.5 mm and 7.9 mm tube diameters are available. Since the primary purpose is to minimise refrigerant charge this means that the majority of evaluated designs use 7.9 mm tubes.

It should be recognised that whilst a comprehensive coil and cycle simulation programme[27] was employed, many practical aspects associated with coil construction (e.g., fin-to-tube contact quality) and operation (e.g., effect of circulating oil) are not easily accounted for. Deviations of at least ±3% should be anticipated.

Baseline

Table 34 lists the basic characteristics of the current R22 condenser coil and the variations applies for R290 coil evaluation.

Table 34: Baseline condenser coil characteristics and variations for R290 coils

Refrigerant	R22	R290
Nominal condensing temperature	49°C	49°C
Refrigerant inlet temperature	95°C, 85°C	95°C, 85°C, 75°C, 67°C
Condenser air inlet temperature	35°C	35°C
Air volume flow rat	7135 m3/h	7135 m3/h
Applicable subcooling	5 K	5 K
Tube type	Plain	Plain
Tube diameter	9.5 mm	9.5 mm, 7.9 mm
Tube thickness	0.3 mm	0.3 mm
No. of tubes	1 horizontal × 32 vertical	1 horizontal × 32 vertical
No. of circuits	3	3, 4, 5, 6 (see Table 35)
Fin type	Wavy	Wavy
Fin thickness	0.13 mm	0.13 mm
Nominal capacity	22.85 kW	–
HTC enhancement factor*	95°C inlet: 1.82; 85°C inlet: 1.97	95°C inlet: 1.82; 85°C inlet: 1.97

*Enhancement factor applied equally to refrigerant side and air side heat transfer coefficient in order to match the model to the nominal rated capacity of the condenser coil.

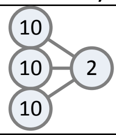
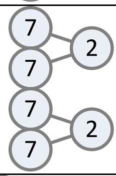
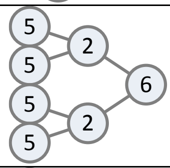
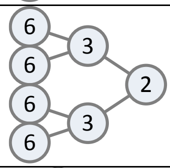
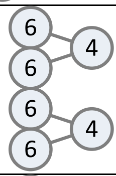
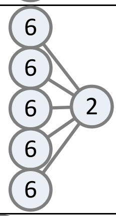
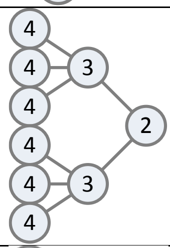
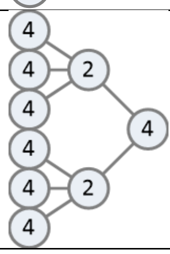
The refrigerant inlet temperature for R290 is set 20 K lower than for R22, to reflect the lower compressor discharge temperature based on cycle calculations at rating conditions.

[27] http://www.imst-art.com/

Evaluated designs

Overall, eight coil designs were evaluated, as detailed in Table 35. These represent a selection of the various circuitry strategies available, considering the limits imposed by a single column of tubes. Note that the basic philosophy is to offset the additional pressure drop incurred from smaller diameter tubes by increasing the number of circuit, whilst extending the length of the subcooling region (to increase local heat transfer coefficient where pressure drop is not excessive).

Table 35: Characteristics of evaluated condenser coils for R290

Reference	Tube diameter	Circuitry
Cond0	9.5 mm	
Cond1	7.9 mm	
Cond2	7.9 mm	
Cond3	7.9 mm	
Cond4	7.9 mm	
Cond5	7.9 mm	
Cond6	7.9 mm	
Cond7	7.9 mm	

Coil calculation output

Numerical output results for the coil calculations are provided in Table 36. A comparison of the three key parameters is shown in Figure 167 for the baseline condenser coil for both R22 and R290 with different compressor discharge (condenser inlet) temperatures. In general, when employing R290:

- Refrigerant mass is reduced by about 55%
- Pressure drop (based on saturation temperature) is 10 to 25% lower
- Nominal capacity is increased by about 6% if the same discharge temperature is used, or reduced by 1% if the “equivalent” discharge temperature is used

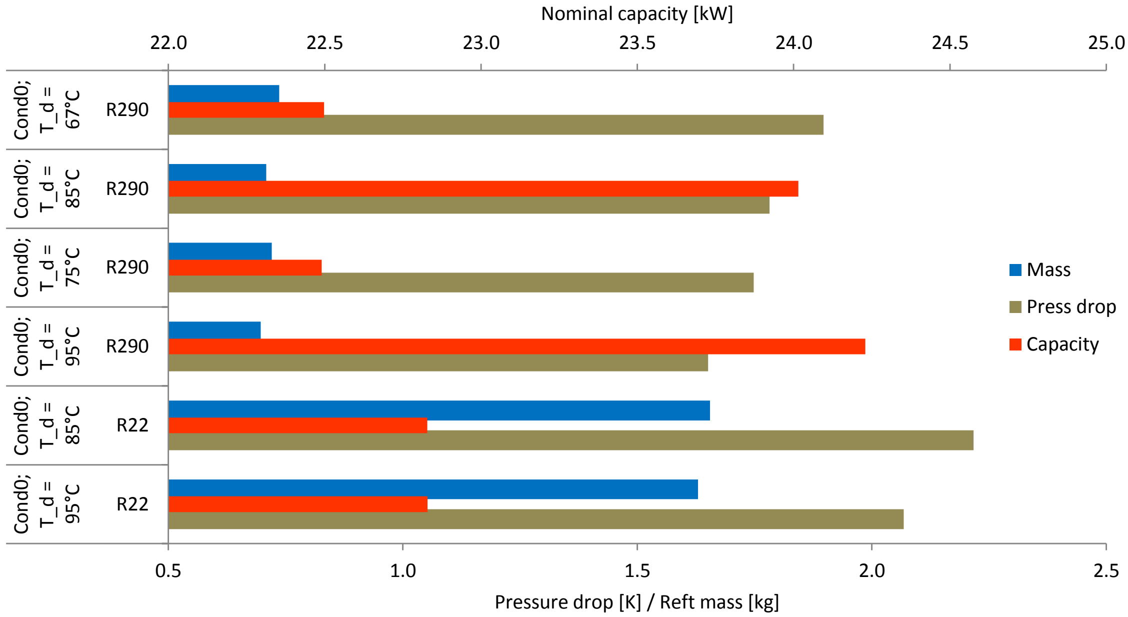


Figure 167: Comparison of Nominal capacity and working charge for different coil arrangements

Specifically for the various coil arrangements, outputs for capacity, R290 mass and pressure drop are shown in the three graphs in Figure 168, relative to the baseline coil (“Cond0”). Main observations are:

- Although nominal capacity for all coil arrangements is lower than the baseline, the reduction in capacity is within 2% for all cases (except one, i.e., Cond2) – given the accuracy of the calculation, they can be considered as providing the same capacity.
- Due to the smaller tube diameter (7.9 mm) refrigerant mass is reduced by about 30% to 35%.
- Pressure drop varies quite widely and all except for two exhibit higher pressure drops than the baseline coil.

Based on these observations, coils Cond2, Cond3, Cond5 and Cond7 may be eliminated.

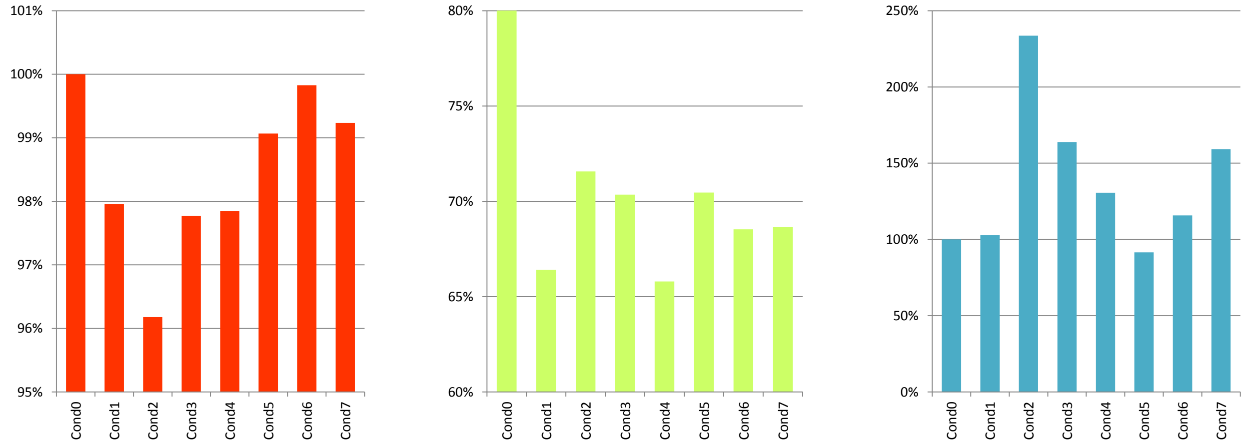


Figure 168: Comparison of nominal capacity (left), refrigerant mass (centre) and pressure drop (right) for the different coil arrangements

A further comparison is provided in Figure 169, where the ratio of capacity to refrigerant mass is plotted against pressure drop. The target designs may be considered as those towards the top-left of the graph. This supports the preference for coils Cond1, Cond4 and Cond6.

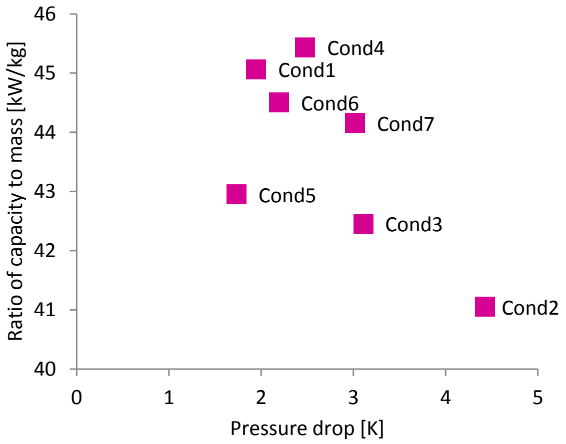


Figure 169: Further comparison of coil arrangements

Cycle calculation output

Coil performance should not be considered in isolation and their behaviour within the total refrigeration cycle should be checked. The entire cycle was simulated with each coil arrangement, along with:

- Generic scroll compressor model, with displacement matched to 5TR unit rated capacity
- Evaporator coil corresponding to the current R22 design
- Fixed 5 K subcooling and 7 K evaporator superheat
- Standard rating conditions of 35°C condenser and 27°C evaporator air-on temperatures

Numerical output results for the cycle calculations are provided in of the Annex.

System cooling capacity, system working charge mass and system COP, all relative to using the baseline coil, are shown in Figure 170.For all coil arrangements, each of these three parameters are improved compared to the baseline coil. However, the performance improvement is relatively small, i.e. increases in capacity and COP are all within 2% and charge reduction is within ±2% of the various coil arrangements.

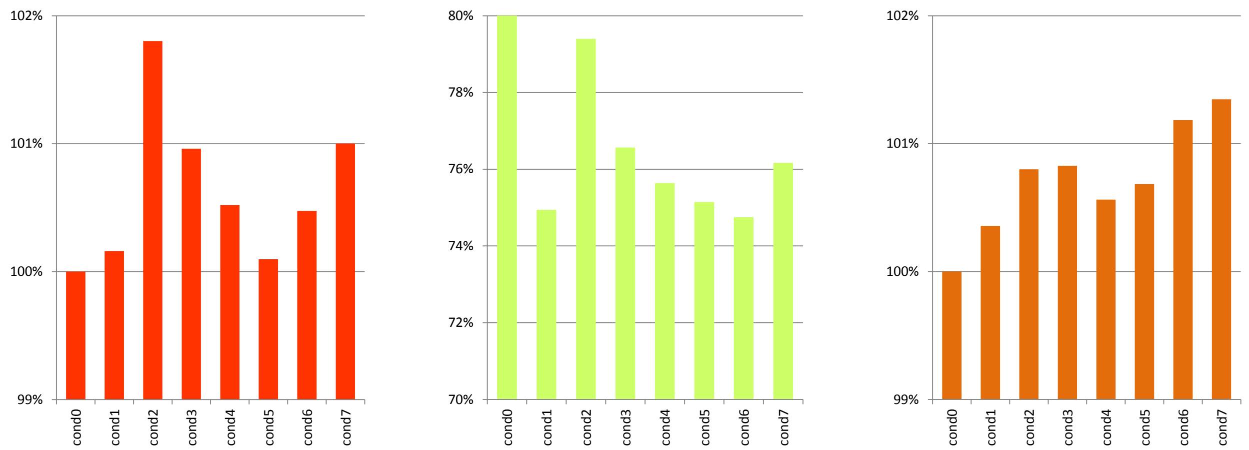


Figure 170: Comparison of nominal capacity (left), refrigerant mass (centre) and pressure drop (right) for the different coil arrangements within cycle

Again, comparing the ratio of capacity to refrigerant charge in this case against COP, further judgements can be made, from Figure 171 where the target position is the top-right of the graph. This analysis suggests that Cond6 provides the optimum performance. However, Cond1 and Cond4 need not be rejected entirely as their relative degradation in COP is less than 1% of Cond6.

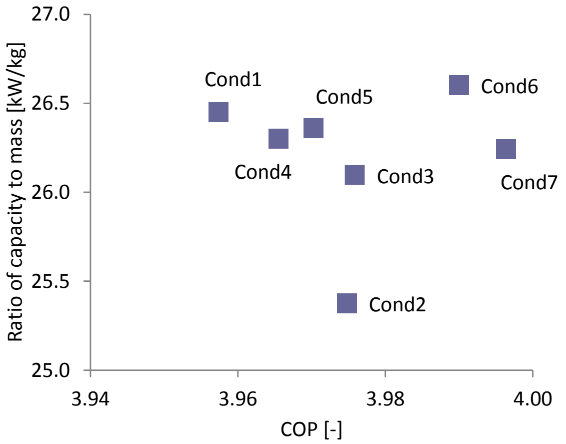


Figure 171: Further comparison of coil arrangements within cycle

Final remarks

Based on the presented simulations, a condenser coil with the arrangements of Cond1, Cond4 and Cond6 will likely provide the best performance with least refrigerant charge. However, due to the constraint of a single vertical tube row, the variability across all coil arrangements is fairly minor and thus differences in performance (except for maybe Cond2) is unlikely to be measurable. In this respect, the most practicable and readily available arrangement could be opted for.

If any option is viable then Cond1, Cond4 or Cond6 would be preferred. Although Cond6 ultimately indicates (marginally) better performance, the larger number of circuits can lead to mal-distribution of the refrigerant if the circuits are not sufficiently well balanced, thus resulting in degradation of performance. If this cannot be guaranteed then Cond1 or Cond4 should be selected.

Table 36: Calculation outputs for condenser coil performance

		Cond0; T_d = 95°C	Cond0; T_d = 85°C	Cond0; T_d = 95°C	Cond0; T_d = 75°C	Cond0; T_d = 85°C	Cond0; T_d = 67°C	Cond1; T_d = 67°C	Cond2; T_d = 67°C	Cond3; T_d = 67°C	Cond4; T_d = 67°C	Cond5; T_d = 67°C	Cond6; T_d = 67°C	Cond7; T_d = 67°C
Refrigerant		R22	R22	R290	R290	R290	R290	R290	R290	R290	R290	R290	R290	R290
AS/RS HTC EF	-	1.82	1.97	1.82	1.82	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97
Capacity	kW	22.829	22.828	24.229	22.49	24.015	22.498	22.039	21.638	21.997	22.014	22.288	22.459	22.326
Mass Flowrate	kg/s	0.10944	0.11414	0.058763	0.061148	0.061525	0.064258	0.062919	0.060533	0.062203	0.062574	0.063742	0.063988	0.06318
Inlet Sat. Temp	°C	49	49	49	49	49	49	49	49	49	49	49	49	49
Outlet Sat. Temp	°C	46.932	46.783	47.349	47.252	47.218	47.103	47.051	44.569	45.891	46.521	47.264	46.804	45.981
Inlet Temp	°C	95	85	95	75	85	67	67	67	67	67	67	67	67
Outlet Temp	°C	41.932	41.783	42.349	42.252	42.218	42.103	42.051	39.569	40.891	41.521	42.264	41.804	40.981
Inlet Superheat	K	46	36	46	26	36	18	18	18	18	18	18	18	18
Outlet Subcool	K	5	5	5	5	5	5	5	5	5	5	5	5	5
Pressure Drop	kPa	89.432	95.63	60.133	63.508	64.698	68.739	70.566	157.22	111.19	89.137	63.096	79.215	108.06
Reft Area	m²	2.0517	2.0517	2.0517	2.0517	2.0517	2.0517	1.6837	1.6837	1.6837	1.6837	1.6837	1.6837	1.6837
De-supht area	%	12.095	10.529	14.207	10.614	12.477	8.4101	8.3142	8.0808	8.2422	8.2793	9.0193	9.4217	9.2704
2-phase Area	%	82.758	84.168	80.129	83.417	81.662	85.409	85.453	83.219	84.374	85.108	84.566	83.751	83.229
Subcool Area	%	5.1476	5.3028	5.6635	5.9686	5.8611	6.1813	6.2326	8.7001	7.3843	6.613	6.4149	6.8268	7.5003
Heat Transf Coeff.	W/m² K	5727.6	6455.8	5955.1	6254.2	6736.5	7108.4	7841.2	8964.5	8447.8	8173	6968.5	6986.3	7154.5
Inlet Pressure	kPa	1899.1	1899.1	1676.9	1676.9	1676.9	1676.9	1676.9	1676.9	1676.9	1676.9	1676.9	1676.9	1676.9
Outlet Press	kPa	1809.7	1803.5	1616.8	1613.4	1612.2	1608.2	1606.3	1519.7	1565.7	1587.8	1613.8	1597.7	1568.8
Total Press Drop	kPa	89.432	95.63	60.133	63.508	64.698	68.739	70.566	157.22	111.19	89.137	63.096	79.215	108.06
Total Fluid Vol	cm³	4747.4	4747.4	4747.4	4747.4	4747.4	4747.4	3198.7	3239	3250.8	3192	3240.7	3259.2	3254.1
Total Mass	kg	1.629	1.655	0.697	0.721	0.709	0.736	0.489	0.527	0.518	0.485	0.519	0.505	0.506
Sec Fluid		Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air
Flowrate	m³/h	7135	7135	7135	7135	7135	7135	7135	7135	7135	7135	7135	7135	7135
Face Vel	m/s	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657
Inlet Temp	°C	35	35	35	35	35	35	35	35	35	35	35	35	35
Outlet Temp	°C	44.958	44.957	45.568	44.81	45.475	44.813	44.613	44.438	44.595	44.602	44.721	44.796	44.738
Press Drop	Pa	7.0241	7.0241	7.0241	7.0241	7.0241	7.0241	6.2585	6.2585	6.2585	6.2585	6.2585	6.2585	6.2585

Appendix D: Measurements to determine refrigerant leak amount

Measurements were carried out in order to determine the amount of refrigerant that would be leaked from the system.

The general functional procedure in Figure 172 was followed; in some instances, certain actions were bypassed.

The test procedures followed the steps:

- empty collection bag
- weigh collection bag (and squeeze out residual refrigerant if mass is greater than 1 g above mass of original empty bag)
- evacuate refrigeration system for approximately 1 hour, checking vacuum pressure
- charge refrigerant into system (target charge of 300 g)
- carry out functional procedure (Figure 172)
- weigh refrigerant and bag, determine mass of refrigerant within the bag

When determining the actual mass of refrigerant (M_{act}) within the bag, the apparent mass (M_{app}) must be adjusted using Archimedes rule (equation 1).

$$M_{act} = M_{app} \times \frac{1}{1 - \rho_a / \rho_r} \qquad (1)$$

Where ρ_a and ρ_r are the density of the air and refrigerant vapour at the atmospheric pressure and ambient temperature of the test conditions.

The cumulative uncertainty of the mass of released refrigerant is ±13 g, due to the resolution of the charging balance (±10 g) and the resolution of the balanced used to measure the balance, adjusted for Archimedes rule (±3 g).

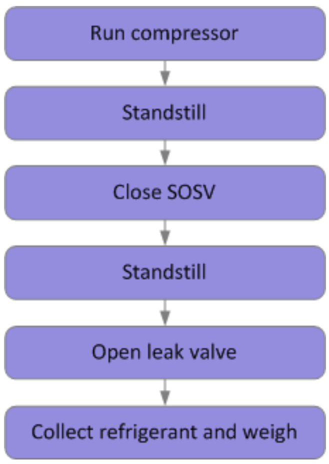


Figure 172: General functional procedure for simulating a leak

Appendix E: Leak simulation tests

Leak simulation tests were carried out which measured refrigerant concentrations under a number of different situations in order to characterise the dispersion or accumulation of refrigerant in the event of a leak. The results of these tests are used throughout the study.

The basic test procedure followed the steps:

- position equipment, gas analysers, leak hole and other relevant apparatus
- ventilate the area and ensure there is no background gas within the air
- open cylinder valve, manifold gauge set valves, zero balance
- record starting conditions (pressure, time, cylinder mass, etc)
- apply equipment settings (e.g., initiate ventilation, opening of solenoid valves, etc)
- initial release by opening hose stop valve
- monitor balance until desired mass is achieved
- close hose stop valve and record conditions (pressure, time, cylinder mass, etc)
- continue to monitor concentrations until appropriate end

All pressure, temperature, mass and time data is manually recorded. Concentration data from the gas analysers is internally logged and downloaded following each series of tests. The data is then converted into the relevant common format.

A common arrangement was used for the tests, as illustrated in Figure 173.

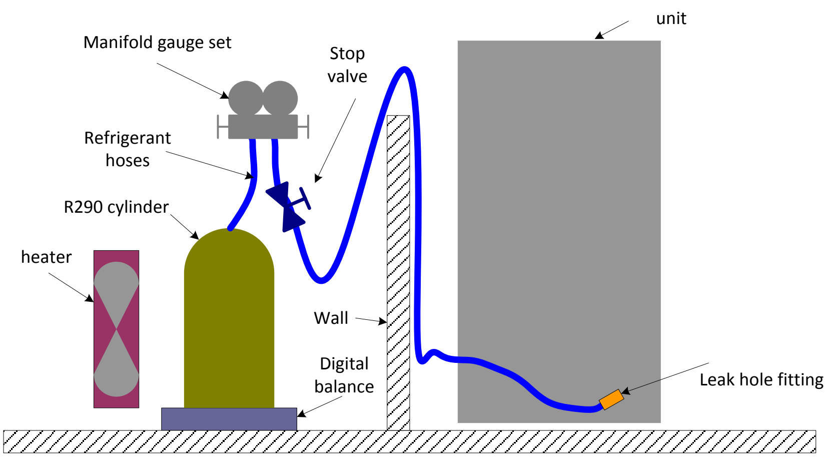


Figure 173: Typical arrangement for leak simulation tests

The cumulative uncertainty of the mass of released refrigerant is ±20 g, due to the resolution of the charging balance (±10 g) and observed variation in measured weight of the assembly arising from movement of connected hoses when opening or closing the stop valve (±10 g). It is assumed that there is no error associated with residual gas within the refrigerant hoses since this must be identical for each test. The resolution of the gas concentration measurements depends on the particular analyser, which is listed in Table 37, along with other details of the gas analysers used.

Table 37: Gas analysers used in the leak simulation tests

Number	Model	Calibration	Range	Resolution

Appendix F: Leak simulation test results

Leak simulation tests were carried out according to NTC 6228-2. Table 38 includes the test results.

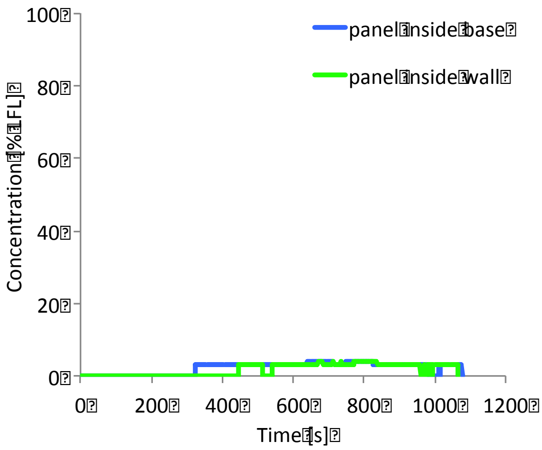
Table 38: Results of leak simulation tests

Test no.	Unit	Leak position	Notes	Release rate	Max concentration	Outcome
1	Ducted split AHU	Evaporator return bends	No internal panel	65 g/min	36% LFL	Pass
2	Ducted split AHU	Evaporator return bends	With internal panel	65 g/min	4% LFL	Pass; no need to repeat
3	Rooftop	Evaporator return bends	With internal panel	65 g/min	0% LFL	Pass
4	Rooftop	Evaporator return bends	With internal panel	65 g/min	0% LFL	Pass
5	Rooftop	Evaporator return bends	With internal panel	65 g/min	0% LFL	Pass
6	Ducted split cond unit	Condenser return bends	Leak point A	65 g/min	0% LFL	Pass
7	Ducted split cond unit	Condenser return bends	Leak point A	65 g/min	0% LFL	Pass
8	Ducted split cond unit	Condenser return bends	Leak point B	65 g/min	10% LFL	Pass
9	Ducted split cond unit	Condenser return bends	Leak point B	65 g/min	33% LFL	Pass
10	Ducted split cond unit	Condenser return bends	Leak point B	65 g/min	24% LFL	Pass

Split AHU

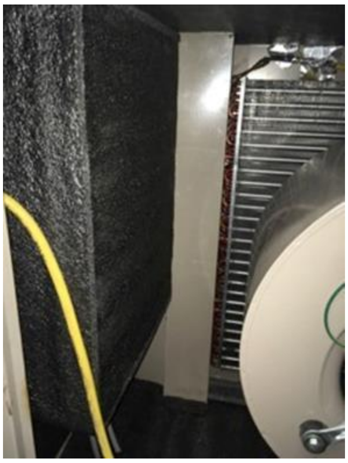
Ducted split AHU release position

Ducted split AHT electrical panel and sampling points



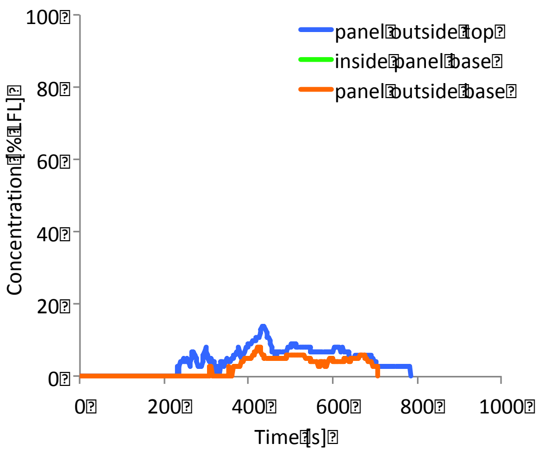
Results for test no 2

Rooftop

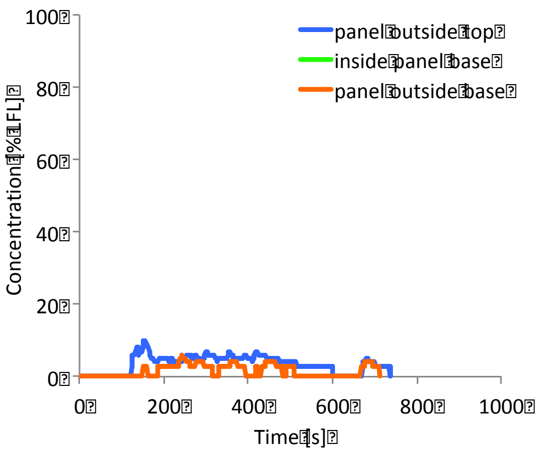


Rooftop unit release position

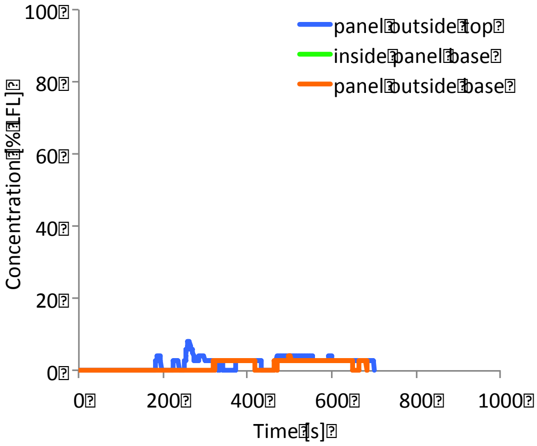
Rooftop unit electrical panel and sampling points



Results for test no. 3



Results for test no. 4



Results for test no. 5

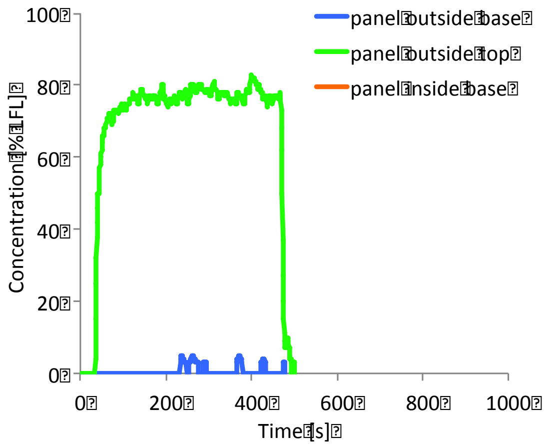
Split condensing unit

Split condensing unit release position A

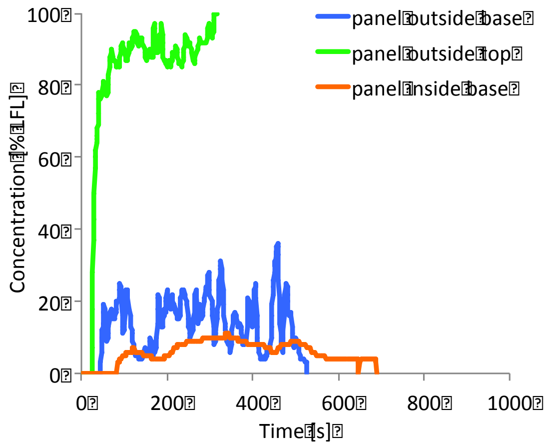
Split condensing unit release position B

Split condensing unit electrical panel and sampling points

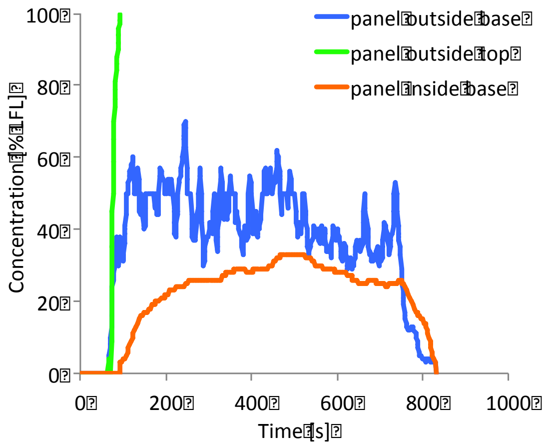
Split condensing unit electrical panel and sampling points



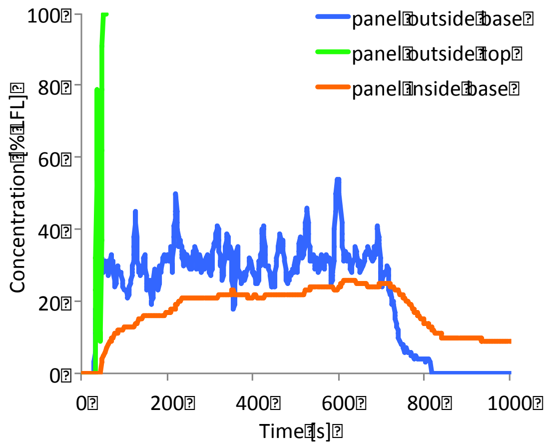
Results for test no. 7



Results for test no. 8



Results for test no. 9



Results for test no. 10

Appendix G: QRA flammable quantity input data

Table 39, Table 40 and Table 41 provide flammable volume ("FV" in m^3) and flammable time ("Ft" in s) for the ducted split for the 0.1 mm^2, 1 mm^2 and 5 mm^2 leak hole sizes, respectively.

Table 39: Flammable quantities for 0.1 mm^2 leaks in ducted split

CV		Stage 1															
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	C1	C2	C3	C4
CV DS1	FV	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0	0	0	0	0
	Ft	3690	3690	3690	21690	21690	21690	8100	8100	8100	8100	8100	8100	0	0	0	0
CV DS2	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	2315	2565	0	0
CV DS3	FV	0.752	0.752	0.752	0.752	0.752	0.752	0	0	0	0	0	0	0	0	0	0
	Ft	0	0	0	0	0	0	8100	8100	8100	8100	8100	8100	0	0	0	0
CV DS4	FV	0.000	0.000	0.000	0.050	0.000	0.000	0	0	0	0	0	0	0	0	0	0
	Ft	15	15	15	15	15	15	8100	8100	8100	8100	8100	8100	0	0	0	0
CV DS5	FV	0.000	0.000	0.000	0.000	0.002	0.001	0	0	0	0	0	0	0	0	0	0
	Ft	3600	3600	3600	21600	21601	21601	8100	8100	8100	8100	8100	8100	0	0	0	0
CV DS6	FV	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.018	0.018	0.032	0.032
	Ft	3609	3609	3609	21615	21615	21615	8124	8124	8124	8124	8124	8124	2369	2619	1157	1157
CV DS7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.000
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	2285	2535	0	0
		Stage 2															
CV DS1	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
	Ft	0	0	0	0	0	0	3690	3690	3690	8490	8490	8490	0	0	0	0
CV DS2	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	965	1215
CV DS3	FV	0	0	0	0	0	0	0.752	0.752	0.752	0.752	0.752	0.752	0	0	0	0
	Ft	0	0	0	0	0	0	3660	3660	3660	8460	8460	8460	0	0	0	0
CV DS4	FV	0	0	0	0	0	0	0.050	0.000	0.000	0.050	0.000	0.000	0	0	0	0
	Ft	0	0	0	0	0	0	15	15	15	15	15	15	0	0	0	0
CV DS5	FV	0	0	0	0	0	0	0.000	0.000	0.002	0.000	0.008	0.001	0	0	0	0
	Ft	0	0	0	0	0	0	3600	3600	3601	8400	8404	8400	0	0	0	0
CV DS6	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.018
	Ft	0	0	0	0	0	0	3609	3609	3609	8415	8415	8415	0	0	1019	1269
CV DS7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.055	0.071
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	935	1185

Table 40: Flammable quantities for 1 mm^2 leaks in ducted split

CV		Stage 1															
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	C1	C2	C3	C4
CV DS1	FV	0.000	0.010	0.010	0.000	0.100	0.100	0	0	0	0	0	0	0	0	0	0
	Ft	450	450	450	2250	2250	2250	0	0	0	0	0	0	0	0	0	0
CV DS2	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.015	0.015	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	313	338	0	0
CV DS3	FV	1.337	1.337	1.337	1.337	1.337	1.337	0	0	0	0	0	0	0	0	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

CV		Stage 1															
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	C1	C2	C3	C4
CV DS4	FV	0.000	0.000	0.000	0.050	0.000	0.000	0	0	0	0	0	0	0	0	0	0
	Ft	15	15	15	15	15	15	0	0	0	0	0	0	0	0	0	0
CV DS5	FV	0.000	0.002	0.003	0.000	0.089	0.073	0	0	0	0	0	0	0	0	0	0
	Ft	360	361	362	2160	2218	2206	0	0	0	0	0	0	0	0	0	0
CV DS6	FV	0.008	0.008	0.008	0.019	0.019	0.019	0.042	0.042	0.042	0.042	0.042	0.042	0.890	0.890	1.421	1.421
	Ft	450	450	450	2310	2310	2310	1050	1050	1050	1050	1050	1050	1663	1688	2135	2135
CV DS7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.028	0.031	0.000	0.000
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	283	308	0	0
		Stage 2															
CV DS1	FV	0	0	0	0	0	0	0.000	0.005	0.006	0.000	0.011	0.011	0	0	0	0
	Ft	0	0	0	0	0	0	450	450	450	930	930	930	0	0	0	0
CV DS2	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.021
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	178	203
CV DS3	FV	0	0	0	0	0	0	1.337	1.337	1.337	1.337	1.337	1.337	0	0	0	0
	Ft	0	0	0	0	0	0	420	420	420	900	900	900	0	0	0	0
CV DS4	FV	0	0	0	0	0	0	0.050	0.000	0.000	0.050	0.000	0.000	0	0	0	0
	Ft	0	0	0	0	0	0	15	15	15	15	15	15	0	0	0	0
CV DS5	FV	0	0	0	0	0	0	0.000	0.002	0.016	0.000	0.060	0.031	0	0	0	0
	Ft	0	0	0	0	0	0	360	361	370	840	878	859	0	0	0	0
CV DS6	FV	0	0	0	0	0	0	0.008	0.008	0.008	0.019	0.019	0.019	0.000	0.000	0.890	0.890
	Ft	0	0	0	0	0	0	450	450	450	990	990	990	0	0	1528	1553
CV DS7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.120	0.154
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	148	173

Table 41: Flammable quantities for 5 mm^2 leaks in ducted split

CV	Value	Stage 1															
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	C1	C2	C3	C4
CV DS1	FV	0.000	0.160	0.160	0.000	0.460	0.460	0	0	0	0	0	0	0	0	0	0
	Ft	162	162	162	522	522	522	0	0	0	0	0	0	0	0	0	0
CV DS2	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.094	0.097	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	135	140	0	0
CV DS3	FV	2.000	2.000	2.000	2.000	2.000	2.000	0	0	0	0	0	0	0	0	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CV DS4	FV	0.000	0.000	0.000	0.050	0.000	0.000	0	0	0	0	0	0	0	0	0	0
	Ft	15	15	15	15	15	15	0	0	0	0	0	0	0	0	0	0
CV DS5	FV	0.000	0.022	0.034	0.000	1.174	1.539	0	0	0	0	0	0	0	0	0	0
	Ft	72	85	92	432	2277	3328	0	0	0	0	0	0	0	0	0	0
CV DS6	FV	0.123	0.123	0.123	0.294	0.294	0.294	0.653	0.653	0.653	0.653	0.653	0.653	2.342	2.605	1.421	1.421
	Ft	522	522	522	1182	1182	1182	1362	1362	1362	1362	1362	1362	7245	7250	10219	10219
CV DS7	FV	0	0	0	0	0	0	0	0	0	0	0	0	1.006	1.119	0.000	0.000
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	105	110	0	0
		Stage 2															
CV DS1	FV	0	0	0	0	0	0	0.000	0.016	0.036	0.000	0.054	0.054	0	0	0	0
	Ft	0	0	0	0	0	0	162	162	162	258	258	258	0	0	0	0

CV	Value	Stage 1															
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	C1	C2	C3	C4
CV DS2	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.061	0.070
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108	113
CV DS3	FV	0	0	0	0	0	0	2.000	2.000	2.000	2.000	2.000	2.000	0	0	0	0
	Ft	0	0	0	0	0	0	132	132	132	228	228	228	0	0	0	0
CV DS4	FV	0	0	0	0	0	0	0.050	0.000	0.000	0.050	0.000	0.000	0	0	0	0
	Ft	0	0	0	0	0	0	15	15	15	15	15	15	0	0	0	0
CV DS5	FV	0	0	0	0	0	0	0.000	0.022	0.081	0.000	0.254	0.427	0	0	0	0
	Ft	0	0	0	0	0	0	72	85	124	168	368	567	0	0	0	0
CV DS6	FV	0	0	0	0	0	0	0.123	0.123	0.123	0.294	0.294	0.294	0.000	0.000	0.921	1.184
	Ft	0	0	0	0	0	0	522	522	522	918	918	918	0	0	7218	7223
CV DS7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.408	0.525
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	83

Table 42, Table 43 and Table 44 provide flammable volume ("FV" in m^3) and flammable time ("Ft" in s) for the rooftop unit for the 0.1 mm^2, 1 mm^2 and 5 mm^2 leak hole sizes, respectively.

Table 42: Flammable quantities for 0.1 mm^2 leaks in rooftop unit

CV		Stage 1															
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	C1	C2	C3	C4
CV RT1	FV	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0	0	0	0	0
	Ft	3690	3690	3690	21690	21690	21690	9150	9150	9150	9150	9150	9150	0	0	0	0
CV RT2	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	2315	2565	953	953
CV RT3	FV	0.940	0.940	0.940	0.940	0.940	0.940	0	0	0	0	0	0	0	0	0	0
	Ft	3660	3660	3660	21660	21660	21660	9150	9150	9150	9150	9150	9150	0	0	0	0
CV RT4	FV	0.376	0.376	0.376	0.376	0.376	0.376	0	0	0	0	0	0	0	0	0	0
	Ft	3660	3660	3660	21660	21660	21660	9150	9150	9150	9150	9150	9150	0	0	0	0
CV RT5	FV	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0	0	0	0	0
	Ft	3660	3660	3660	21660	21660	21660	9150	9150	9150	9150	9150	9150	0	0	0	0
CV RT6	FV	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ft	3600	3600	3600	21600	21600	21600	9150	9150	9150	9150	9150	9150	0	0	0	0
CV RT7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.000
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	2285	2535	953	953
		Stage 2															
CV RT1	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
	Ft	0	0	0	0	0	0	3690	3690	3690	7290	7290	7290	0	0	0	0
CV RT2	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	965	1215
CV RT3	FV	0	0	0	0	0	0	0.940	0.940	0.940	0.940	0.940	0.940	0	0	0	0
	Ft	0	0	0	0	0	0	3660	3660	3660	7260	7260	7260	0	0	0	0
CV RT4	FV	0	0	0	0	0	0	0.376	0.376	0.376	0.376	0.376	0.376	0	0	0	0
	Ft	0	0	0	0	0	0	3660	3660	3660	7260	7260	7260	0	0	0	0
CV RT5	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
	Ft	0	0	0	0	0	0	3660	3660	3660	7260	7260	7260	0	0	0	0
CV RT6	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

CV		Stage 1															
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	C1	C2	C3	C4
	Ft	0	0	0	0	0	0	3600	3600	3600	7200	7200	7200	0	0	0	0
CV RT7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.055	0.071
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	935	1185

Table 43: Flammable quantities for 1 mm^2 leaks in rooftop unit

CV		Stage 1															
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	C1	C2	C3	C4
CV RT1	FV	0.000	0.010	0.010	0.000	0.100	0.100	0	0	0	0	0	0	0	0	0	0
	Ft	450	450	450	2250	2250	2250	915	915	915	915	915	915	0	0	0	0
CV RT2	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.015	0.015	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	313	338	95	95
CV RT3	FV	1.672	1.672	1.672	1.672	1.672	1.672	0	0	0	0	0	0	0	0	0	0
	Ft	420	420	420	2220	2220	2220	915	915	915	915	915	915	0	0	0	0
CV RT4	FV	0.669	0.669	0.669	0.669	0.669	0.669	0	0	0	0	0	0	0	0	0	0
	Ft	420	420	420	2220	2220	2220	915	915	915	915	915	915	0	0	0	0
CV RT5	FV	0.000	0.000	0.000	0.000	0.003	0.003	0	0	0	0	0	0	0	0	0	0
	Ft	420	420	420	2220	2220	2220	915	915	915	915	915	915	0	0	0	0
CV RT6	FV	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ft	360	360	360	2160	2165	2160	915	915	915	915	915	915	0	0	0	0
CV RT7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.028	0.031	0.000	0.000
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	283	308	95	95
		Stage 2															
CV RT1	FV	0	0	0	0	0	0	0.000	0.005	0.006	0.000	0.011	0.011	0	0	0	0
	Ft	0	0	0	0	0	0	450	450	450	810	810	810	0	0	0	0
CV RT2	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.021
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	178	203
CV RT3	FV	0	0	0	0	0	0	1.672	1.672	1.672	1.672	1.672	1.672	0	0	0	0
	Ft	0	0	0	0	0	0	420	420	420	780	780	780	0	0	0	0
CV RT4	FV	0	0	0	0	0	0	0.669	0.669	0.669	0.669	0.669	0.669	0	0	0	0
	Ft	0	0	0	0	0	0	420	420	420	780	780	780	0	0	0	0
CV RT5	FV	0	0	0	0	0	0	0.000	0.000	0.001	0.000	0.001	0.001	0	0	0	0
	Ft	0	0	0	0	0	0	420	420	420	780	780	780	0	0	0	0
CV RT6	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000
	Ft	0	0	0	0	0	0	360	360	360	720	722	720	0	0	0	0
CV RT7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.120	0.154
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	148	173

Table 44: Flammable quantities for 5 mm^2 leaks in rooftop unit

CV	Value	Stage 1															
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	C1	C2	C3	C4
CV RT1	FV	0.000	0.160	0.160	0.000	0.460	0.460	0	0	0	0	0	0	0	0	0	0
	Ft	162	162	162	522	522	522	183	183	183	183	183	183	0	0	0	0
CV RT2	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.094	0.097	0	0
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	135	140	19	19

CV	Value	Stage 1															
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	C1	C2	C3	C4
CV RT3	FV	2.500	2.500	2.500	2.500	2.500	2.500	0	0	0	0	0	0	0	0	0	0
	Ft	132	132	132	492	492	492	183	183	183	183	183	183	0	0	0	0
CV RT4	FV	1.000	1.000	1.000	1.000	1.000	1.000	0	0	0	0	0	0	0	0	0	0
	Ft	132	132	132	492	492	492	183	183	183	183	183	183	0	0	0	0
CV RT5	FV	0.000	0.000	0.000	0.000	0.021	0.021	0	0	0	0	0	0	0	0	0	0
	Ft	132	132	132	492	492	492	183	183	183	183	183	183	0	0	0	0
CV RT6	FV	0.000	0.000	0.000	0.000	0.070	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ft	72	72	72	432	476	1082	183	183	183	183	183	183	0	0	0	0
CV RT7	FV	0	0	0	0	0	0	0	0	0	0	0	0	1.006	1.119	0.000	0.000
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	105	110	19	19
		Stage 2															
CV RT1	FV	0	0	0	0	0	0	0.000	0.016	0.036	0.000	0.054	0.054	0	0	0	0
	Ft	0	0	0	0	0	0	162	162	162	234	234	234	0	0	0	0
CV RT2	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.061	0.070
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108	113
CV RT3	FV	0	0	0	0	0	0	2.500	2.500	2.500	2.500	2.500	2.500	0	0	0	0
	Ft	0	0	0	0	0	0	132	132	132	204	204	204	0	0	0	0
CV RT4	FV	0	0	0	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	0	0	0	0
	Ft	0	0	0	0	0	0	132	132	132	204	204	204	0	0	0	0
CV RT5	FV	0	0	0	0	0	0	0.000	0.000	0.008	0.000	0.017	0.017	0	0	0	0
	Ft	0	0	0	0	0	0	132	132	132	204	204	204	0	0	0	0
CV RT6	FV	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.020	0.017	0.000	0.000	0.000	0.000
	Ft	0	0	0	0	0	0	72	72	72	144	156	154	0	0	0	0
CV RT7	FV	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0.408	0.525
	Ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	83

Appendix H: Context of risk and acceptability criteria

It is important to establish the context of the risk of a hazard. In order to clarify this, reference is made to the approach of the UK Health and Safety Executive (HSE, 2001) who address this issue.

Establishing the context

It is stated that an individual risk of death of one in a million per annum for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and tolerable regions. Reference is made to the data in Table 46 which demonstrates that there exist various kinds of risk that worker and members of the public are subjected to all of the time; these may be considered as a background level of risk. The sum of all of the background risks leads to a risk of death of 1×10^{-2} per year (averaged over a lifetime). Therefore a residual risk of 1×10^{-6} per year is considered extremely small. It is suggested that an individual risk of death of 1×10^{-3} per year should on its own represent the dividing line between what could be just tolerable for any substantial category of workers for any large part of a working life, and what is unacceptable for any but fairly exceptional groups. For members of the public who have a risk imposed on them 'in the wider interest of society' this limit is judged to be an order of magnitude lower – at 1×10^{-4} per year. It should also be noted that the acceptability of a given risk should be considered and balanced against the benefit that a particular activity or equipment offers to society; an increase in risk over the background level that results in a better environment and standard of living for the present and future populations is more acceptable than an increase in risk that offer no or a negative benefit.

Table 45: Average annual risk of injury as a consequence of an activity (HSE, 2001)

Activity	Number of injuries	Frequency of injury
Fairground accidents (per ride)	1 in 2,326,000	4.3×10^{-7}
Road accidents (per km travelled)	1 in 1,432,000	7.0×10^{-7}
Rail travel accidents (per passenger journey)	1 in 1,533,000	6.5×10^{-7}
Burn or scald in the home (per year)	1 in 610	1.6×10^{-3}

In order to help put the results of the QRA into context, Table 45 and Table 46, which provides a list of frequencies for injury and fatality for a variety of different activities and industries, may be reviewed. It should be recognised that many of these may not be directly comparable to the case of a LCC using flammable refrigerant since the use profile is not the same.

Table 46: Annual risk of death for various causes (HSE, 2001)

Type	Causes, activity or industry	Number of fatalities	Frequency of fatality
General cause (entire population)	Cancer	1 in 387	2.6E-03
	Injury and poisoning	1 in 3,137	3.2E-04
	All types of accidents and all other external causes	1 in 4,064	2.5E-04
	All forms of road accident	1 in 16,800	6.0E-05
	Lung cancer caused by radon in dwellings	1 in 29,000	3.4E-05
	Gas incident (fire, explosion, carbon monoxide poisoning)	1 in 1,510,000	6.6E-07
	Lightning	1 in 18,700,000	5.3E-08
Activity	Maternal death in pregnancy (per maternity)	1 in 8,200	1.2E-04
	Surgical anaesthesia (per operation)	1 in 185,000	5.4E-06
	Scuba diving (per dive)	1 in 200,000	5.0E-06
	Fairground rides (per ride)	1 in 834,000,000	1.2E-09
	Rock climbing (per climb)	1 in 320,000	3.1E-06
	Canoeing (per outing)	1 in 750,000	1.3E-06
	Hang-gliding (per flight)	1 in 116,000	8.6E-06
	Rail travel accidents (per passenger journey)	1 in 43,000,000	2.3E-08
	Aircraft accidents (per passenger journey)	1 in 125,000,000	8.0E-09

Context in relation to R290 refrigeration systems

It is useful to put the calculated ignition frequency and risks into context to assist with the decision as to whether the activity can be considered “safe” or “unsafe”. This may be achieved by comparing the results against a set of limits, indicating an acceptable or unacceptable risk considering the risk measures generated by the risk assessment. Based on previous research, there are no clearly defined tolerable risk limits for situations involving the use of flammable refrigerants or general flammable materials. However, some limits may be developed based on broader limits.

Ignition risk can be equated to fire risk, since ignition may lead to a secondary fire; addressing the likelihood of a secondary fire from ignition is complex, so for simplicity frequency of fire is equated directly to ignition frequency as described in Appendix D. It is useful to compare the risk of RAC equipment against risks from other household and small commercial appliances. Based on statistics of fires in the UK (DCLG, 2014) and product population data (Watson, 2003; Faberi, 2008; historical data extrapolated up to 2012), the following frequencies of building fires originating from an appliance were obtained (Table 47).

Table 47: Risk of household fires due to different appliances

Appliance type	Number of fires (per appliance)	Frequency of fire per appliance
Refrigerators (non-HC)	1 in 88,500	1.13×10^{-5} /y
Gas cookers	1 in 1,150	8.71×10^{-4} /y
Gas central heating	1 in 24,800	4.03×10^{-5} /y
Televisions	1 in 37,700	2.65×10^{-5} /y
Other audio/visual	1 in 123,800	8.08×10^{-6} /y

The data for refrigerators is given for a yearly basis in Figure 174. As a side remark, it is interesting to observe that there is a downward trend in the frequency of fires over the period from 2000 (the time that R600a was introduced into domestic refrigerators in the UK); it is difficult to determine whether this reduction is related to the increased application of R600a, but at least it is evident that the use of R600a did not result in an increase in the occurrence of fires.

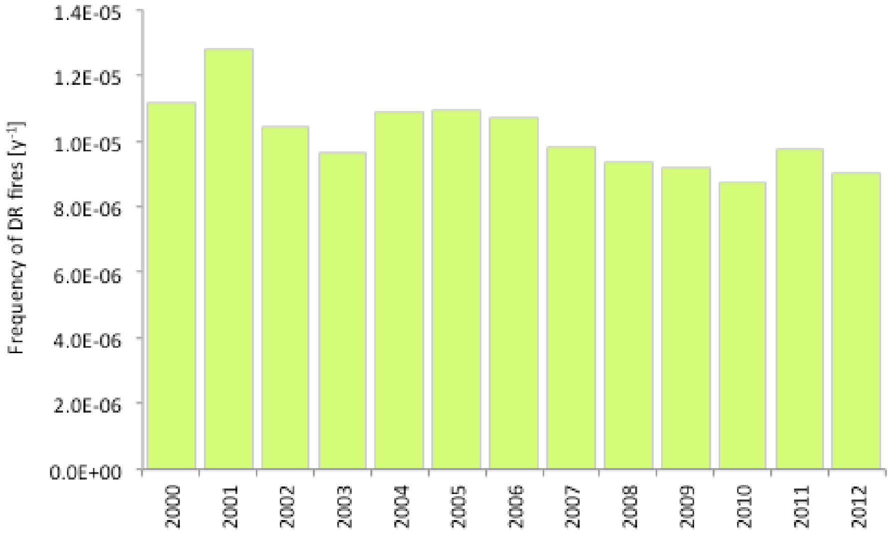


Figure 174: Frequency of fires caused by domestic refrigerators in the UK by year (ratio of number of fires for the installed population of refrigerators)

For all appliances, causes were electrical faults or a release of flammable gas depending on the type of equipment. Figure 175 provides a breakdown of the cause of the fires for refrigerators; whilst some are rather vague explanations, it can be seen that the majority are due to faulty electrical parts.

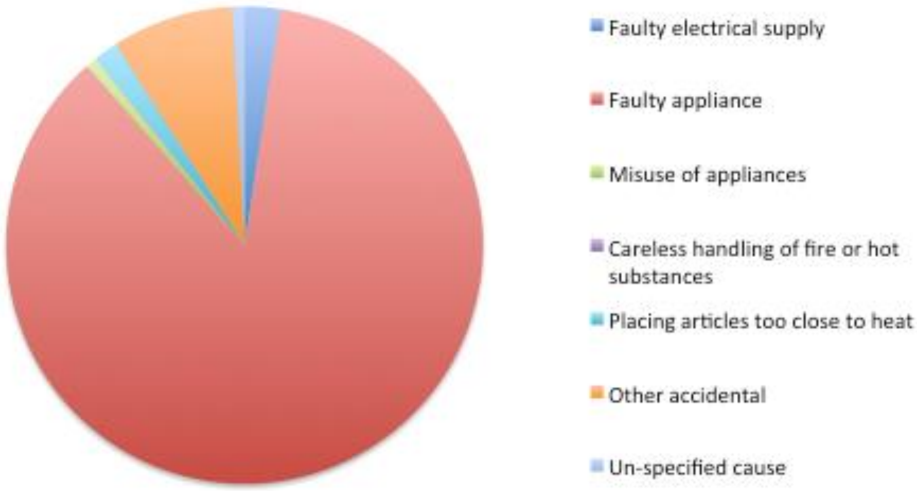


Figure 175: Average proportions of causes of fires from domestic refrigerators

The frequency of fires arising from typical domestic appliances is evidently considered “acceptable” by society, and therefore may be used as a reference point for acceptability of the ignition risk of flammable refrigerants. The lowest (rounded) value for all the refrigeration appliances listed in the data ($1×10^{-5}$ /y) was used as the acceptance limit (Table 48), so it is favourable for ignition frequency to be lower than these appliance fire frequencies.

As discussed elsewhere the likelihood of secondary fire is approximately 1/100 less than a flash fire event and assuming that a secondary fire could cause fatality, then the tolerable risk of ignition may be set as high as $1×10^{-3}$/y per cabinet.

Another source is the UK Health and Safety Executive (HSE, 2001) which recommends a value for "negligible" risk of fatality of members of the public, being 1×10^{-6} y^{-1}. Given that the HSE use fatality of a member of the public as a criterion for "acceptability", then the corresponding value of primary consequence that could cause fatality may also be used as a limiting criterion. Alternatively, a lower value based on some degree of injury or physical damage could be adopted, although it is not evident from the literature what this could be.

Another approach is to estimate the risk of fatality as a function of the likelihood of fire. If the data for risk of fire from a gas appliance (Table 47) is considered with respect to the risk of fatality due to a gas incident (Table 46; assuming half of this value in order to separate the flammability component from carbon monoxide), the likelihood of fatality is approximately 7,000 times less than that of a fire occurring. Thus, within the QRA, although the consequence modelling indicates overpressures and thermal intensity lower than that necessary to cause fatality, exceptional circumstances or secondary consequences may occur, which could lead to fatality. So using this approach, it may be proposed that the risk is approximately 1,000 to 10,000 times less than the risk of ignition (or the risk of fire).

Evaluation of tolerability

Based on the value specified by the HSE, acceptance limits for risk of OP and risk of TI can also be derived from the lowest acceptable frequency and the probability of fatality associated with each primary consequence. For thermal intensity, the lowest value that can cause fatality is 1050 s $(kW\ m^{-2})^{4/3}$ and the lowest overpressure is 250 kPa, so integrating these with the tolerable limit for worker fatality yields a tolerable risk of OP and a tolerable risk of TI.

Consideration the various criteria in the sections above, the calculated risk indicators should be lower than those listed in Table 48. Comparing the values provided within the table against the tolerability criteria indicate that in all respects, the risk posed by the LCC is well within the tolerable limits.

From Table 48 it can be seen that the frequency of ignition is lower than the tolerable risk level by at least four orders of magnitude and the risk of a secondary fire is also extremely low. In terms of the thermal intensity and overpressure it is well within the tolerable values. Similarly, the risk of TI and risk of OP are also well within the tolerable limits. The frequency of fatality (due to indirect effects) is also extremely low and many orders of magnitude below the tolerable limit. In general, it can be said that the estimated frequencies are so low they have no practical significance.

Table 48: "Tolerable" risk criteria

Criteria	"Tolerable" to members of public
Frequency of ignition (y^{-1})	$< 1\times10^{-5}$
Frequency of secondary fire (/yr)	$< 1\times10^{-6}$
Overpressure (kPa)	< 17
Thermal intensity (s $(kW\ m^{-2})^{4/3}$)	< 1050
Frequency of fatality (direct) (y^{-1})	$< 1\times10^{-6}$
Frequency of fatality (indirect) (y^{-1})	$< 1\times10^{-6}$ y^{-1}
Risk of thermal intensity (s $(kW\ m^{-2})^{4/3}$ y^{-1})	$< 6\times10^{-3}$
Risk of overpressure (kPa y^{-1})	$< 4\times10^{-4}$

Appendix I: Calculation of risk measures

Ignition probability calculations[28]

An ignition event is coincidence of three fundamental events:

- Occurrence of a leak,
- Development of a flammable-refrigerant/air mixture at a specific location, and
- Co-existence of a SOI being “active” within the flammable mixture.

These events have their individual probabilities or frequencies, and the frequency of ignition (f^*) is essentially the product of these. The ignition frequency of a single leak size (i) under a particular set of conditions (f_i^*) is calculated from equation (2).

$$f_i^* = f_{leak,i} P_i^{F*} \quad (2)$$

where $f_{leak,i}$ and P_i^{F*} are leak frequency and probability of ignition of a flammable mixture by an active SOI, respectively.

Under a specific set of conditions (j) the ignition frequency for all leak sizes (f_j^*) is the sum of the ignition frequency for each of the individual leaks (equation 3).

$$f_J^* = \sum_{i=1} f_i^* \quad (3)$$

The probability of ignition (P^{F*}) for an active SOI surrounded by a mixture at a flammable concentration. P_i^{F*} is determined from equation (4).

$$P_i^{F*} = \sum_{N=1}^{N_{soi}} \left\{ 1 - \left[(1 - P_{V,i}^F) + P_{V,i}^F (1 - P_{soi,i}^F) \right]^{N_E} \right\}_{N_{soi}}, \qquad P_i^{F*} \leq 1 \quad (4)$$

where P_V^F is the probability of a flammable volume, P_{soi}^F is the probability of an active SOI, N_{soi} is the number of SOI, and N_E is the number of active events of each SOI. P_V^F, and therefore P^F, is a function of the size and duration of a flammable mixture, influenced by many parameters, including reason and source of the release, rate of release, airflow conditions and other parameters.

The probability of the SOI event being present at the same time as the flammable concentration can be written as equation (5), showing the probability of an active SOI within a flammable volume within a given reference volume under a given set of conditions resulting from a certain leak size (in terms of duration).

$$P_{soi,i}^F = P_{avail} \frac{(t_{soi} + t_i^F)}{t'}, \qquad P_{soi}^F \leq 1 \quad (5)$$

where P_{avail} is included to account for the availability of the SOI (e.g., if electrics are protected against ingress of refrigerant, P_{avail} = 0, or the integrity of protection may fail, 0 < P_{avail} < 1; otherwise, for

[28] The derivation of most of these formulas is summarised within: Colbourne, D., Suen, K. O., 2008, Risk analysis of flammable refrigerants, Part 2: Methodology for calculation of risk frequencies and flammable quantities, Proc. 8th IIR Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen, Denmark

permanent SOI, P_{avail} = 1.) The reference time t' is taken as a 24 hour period since this may be considered to represent the natural cycle of the operation of the unit and the surroundings.

The probability of having a flammable volume (P_V^F) is based on the coincidence of the active SOI being present in the same spatial location as the flammable concentration (equation 6).

$$P_{V,i}^F = \frac{\bar{V}_h^F}{V_h'} P_{sys} P_{perc}, \qquad P_{V,i}^F \leq 1 \tag{6}$$

where V' is the reference volume. For the "room" control volume this corresponds to the bottom third of the room volume within which corresponding room SOI are present ($V_h' = A_{Rm} h_{Rm} / 3$) or the entire internal volume for the condensing unit compartment. $\bar{V}_h^F$ is the mean flammable volume existing within that reference volume. P_{sys} is the probability of a system to release its charge, also interpreted as "annual leak rate" or the ratio of total mass leaked from a given population of systems to the refrigerant bank. P_{perc} is percolation probability which is failure to ignite a flammable concentration due to small pockets of unmixed gas or air within a cloud (typically, P_{perc} = 0.6).

Quantification of the input parameters is discussed in later sections.

Operating mode ignition frequencies

As described in the following section, the normal operation is broken down into operating modes. To account for the dynamic nature of equipment operation and/or associated environment, f_j^* is evaluated for each operating mode (k) and the corresponding local conditions. Consequently, the overall ignition frequency for each specific operating mode (f_{op}^*) is the sum of the individual ignition frequencies for all leaks and all the different sets of local conditions, weighted with the corresponding time fraction for each combination of conditions that are present (equation 7).

$$f_{op,k}^* = \sum_{j=1} f_j^* \varphi_j \tag{7}$$

with each φ_j referring to the probability of each different set of conditions, such as compressor mode, infiltration rate, presence of thermal currents, mechanical ventilation, and so on, that leads to the corresponding leak frequency, probability of flammable volume and probability of active SOI.

The ignition frequency of the entire normal operation is simply the sum of the ignition frequencies for the separate sets of conditions (equation 8).

$$f_{no}^* = \sum_{k=1} f_{op,k}^* \tag{8}$$

where k refers to the individual sets of operating modes.

Calculation of consequences

Thermal radiation model

When a flammable substance burns, the heat energy is partially given off as thermal radiation. A "dose" of thermal radiation may be sufficient to cause burns to individuals nearby. The severity of burns is a function of heat flux and its duration, and this dose is termed thermal intensity (equation 9).

$$I_{occ,i} = q_{occ,i}^{4/3} t_{flam} \tag{9}$$

where t_{flam} is the time taken for complete combustion. The heat flux radiated onto an occupant (q_{occ}, in kW m^{-2}) was calculated with a correlation for a "fireball" from Hymes et al (1996)[29] (equation 10).

$$q_{occ,i} = \Gamma\left(\frac{\Delta H(\bar{C}^F)\bar{m}_r^F}{t_{flam}}\right)\frac{\vartheta}{4\pi z_{occ}^2} \tag{10}$$

where the incidence ratio ϑ is influenced by the size and shape of the flammable volume; ϑ = 0.2 for flames from a plume, and ϑ = 0.3 for fireballs. Γ is the radiative fraction of the fuel, or the proportion of energy from the burning material that translates to thermal radiation; the data presented by Beyler (2002)[30], gives $\Gamma \approx 0.3$. $\Delta H(\bar{C}^F)$ is the HOC at the corresponding mean concentration based on the average flammable mass over the flammable time, $\bar{m}_r^F$ is the average mass of refrigerant within the flammable mixture and z_{occ} is the distance between the fire and the occupant which is impractical to estimate, but assuming occupants are evenly distributed, $z_{occ} = 0.5\sqrt{A_{occ}/\pi}$, where A_{occ} is the average area occupied per person.

Overpressure model

Modelling an explosion from ignition of a flammable mixture is complex, and the most accurate methods typically employ CFD codes. As with estimation of flammable quantities, use of CFD was not considered suitable so a more simplistic lumped approach was used.

When a flammable mixture is ignited, the exothermic reaction raises the temperature of the combustion products, translating to an increase in pressure and/or volume. Under ideal conditions, where ignition is at the centre of a spherical stoichiometric mixture, the maximum pressure or volume can be reliably determined from the gas law (Harris, 1983[31]). Transposing the gas law, a non-dimensional expansion ratio (E) is obtained (equation 13).

$$E = \frac{N_{flam}^{mol}}{N_{VF}^{mol}}\frac{273+T_{flam}}{273+T_a} \tag{11}$$

where T_a is the initial (ambient) temperature of the flammable volume, and T_{flam} is the maximum adiabatic flame temperature. N_{flam}^{mol} and N_{VF}^{mol} are the number of moles in the burned and unburned mixture, respectively. Assuming a confined (fixed) volume that is completely filled with the mixture, the maximum rise in pressure is the product of initial (atmospheric) pressure (p_{atm}) and E. The pressure developed within the space (Δp^o) is the difference between the initial and maximum pressure (equation 14).

$$\Delta p^o = p_{atm}(1+E[1-\Gamma]) - p_{atm} \tag{12}$$

Conversely, if the flammable mixture were in an unconfined volume (i.e., constant pressure) its volume after combustion would be equation (15).

$$E = \frac{N_{flam}^{mol}}{N_{VF}^{mol}}\frac{273+T_{flam}}{273+T_a} \tag{13}$$

[29] Hymes, I., Boydell, W., Prescott, B. Thermal radiation: Physiological and pathological effects. Inst. Chem. Eng., Rugby. UK (1996)
[30] Beyler, C. L. Fire hazard calculations for large, open hydrocarbon fires. In SFPE Handbook of Fire Protection Engineering, NFPA, USA (2002)
[31] Harris, R. J. Gas explosions in buildings and heating plant. British Gas Corp., EF & N Spon Ltd., UK (1983)

where T_a is the initial (ambient) temperature of the flammable volume, and T_{flam} is the maximum adiabatic flame temperature. N_{flam}^{mol} and N_{VF}^{mol} are the number of moles in the burned and unburned mixture, respectively. Assuming a confined (fixed) volume that is completely filled with the mixture, the maximum rise in pressure is the product of initial (atmospheric) pressure (p_{atm}) and E . The pressure developed within the space (Δp^o) is the difference between the initial and maximum pressure (equation 14).

$$\Delta p^o = p_{atm}(1+E[1-\Gamma]) - p_{atm} \tag{14}$$

Conversely, if the flammable mixture were in an unconfined volume (i.e., constant pressure) its volume after combustion would be equation (15).

$$V_{flam} = \bar{V}^F E(1-\Gamma) \tag{15}$$

Although for the situation under consideration, the flammable material is within a confined space, that $\bar{V}^F < V_{Rm}$ implies both a pressure rise, and a volumetric change of the burning mixture within the room. As a result the overpressure within the room (Δp_{Rm}^o) will be less than equation (14) in proportion to the flammable mass and the total mass of gas within the room.

Harris (1983) and others show that the pressure and/or volume of a flammable mixture increase exponentially following ignition until a maximum pressure (p_{max}) is reached, and that development of Δp_{Rm}^o at time (t) after ignition follows the "cube-law" (equation 16).

$$\Delta p^o(t) = \frac{K p_{atm} u_{flam}^3 t^3}{\bar{V}_i^F} \tag{16}$$

where the constant K is dependent upon the gas under consideration and characteristics of the explosion and u_{flam} is the burning velocity.

Since most occupied spaces have flow paths in the room envelope through which developed pressure will escape, as Δp_{Rm}^o rises, material may be vented from the room, and this occurs in two stages. Initially, any openings such as gaps in the room fabric, ventilation ducts, etc., allows the higher pressure gas to escape from the room. Secondly, certain barriers that comprise the room construction may eventually give way at a given Δp_{Rm}^o, thereby enlarging the venting area. In both cases, the exhausted material results in a lower rate of pressure rise. Using the steady flow equation, the mass of material vented through an opening of a given area is estimated.

The overpressure required to blow out vulnerable barriers within the room fabric was determined using a method for explosion vent panels. An approach was developed by Molkov et al (2003, 2004)[32] was used to model the effect of such venting.

Where ignition occurred within the a partially confined enclosure within the main room (i.e., the condensing unit compartment) there would be an exponential decay of the strength of the pressure wave away from the position on the enclosure that enables the venting. Thus, the average overpressure within the room would be considerably less than the pressure at the point of venting. However, for the purpose of

[32] Molkov, V. V., Grigorash, A. V., Eber, R. M., Tamanini, F., Dobashi, R. Vented gaseous deflagrations with inertial vent covers: state of the art and progress. Process Safety Progress, Vol. 23, No. 1. AIChemE, (2004) and Molkov, V. V., Grigorash, A. V., Eber, R. M., Tamanini, F., Dobashi, R. Vented gaseous deflagrations: modelling of translating inertial vent covers. J. Loss Prevention in the Process Industries. Vol. 16, pp. 395 – 402, (2003).

this study (due to the possibility of an occupant standing directly adjacent to the condensing unit compartment) the maximum overpressure is used.

Flashover and secondary fire

The necessary thermal dose for flashover varies considerably with construction and furniture materials. Data collated by Babrauskas et al (2003)[33] showed flashover to occur between 125 to 4100 s $(kW/m^2)^{4/3}$, including different foam insulation, wood and other construction materials. Other easily combustible materials such as loose paper or hair may ignite at even lower value. Since the types of materials are not known and may vary widely, it is difficult to estimate the likely situation. ADL[34] indicates that the likelihood of flashover occurring as 1/100 to 1/1,000 less than the ignition frequency. The approach taken in the present study is to use a combination of the proportion of a leak event that could result in a sustained flame and the proportion of the cases where the thermal intensity may exceed a value of 125 s $(kW/m^2)^{4/3}$ (equation 17).

$$f_{SF} = \max\left\{\left(0.5 \times \frac{t_{leak}}{t_{flam}} \times f_i^*\right), \left[0.5 \times f_i^*\right]_{I_{occ} > 125}\right\} \quad (17)$$

It is noted that this approach is considerably more conservative that that implied by the literature cited.

Nomenclature

a	a constant
A_f	room floor area (m^2)
A_v	vent opening area (m^2)
b	a constant
C	concentration (kg/m^3)
c_d	discharge coefficient (-)
d	leak hole diameter (mm)
D	pipe diameter (mm)
E	Expansion ratio (-)
f^*	ignition frequency (/y)
f_{leak}	leak frequency (/y)
$f_{leak}(d)$	leak frequency (for a specific leak size) (/y)
f_{no}^*	frequency of ignition during normal operation (/y)
f_{op}^*	frequency of ignition for a given operating mode (/y)
f_{rep}^*	frequency of ignition for repair activities (-)
$f_{rep}^{*\prime}$	frequency of ignition for technicians starting and completing a repair activity (-)
f_{SA}^*	frequency of ignition of those technicians that (intend to) begin the servicing activity (-)
$f_{SA}^{*\prime}$	frequency of ignition of average number of technicians starting and completing an activity (-)
$f_{SA}^{*\prime\prime}$	frequency of ignition for technicians starting an activity (-)
$f_{SA}^{*\prime\prime\prime}$	frequency of ignition for technicians starting and completing an activity (-)

[33] Babrauskas, V., Peacock, R. D., Reneke, P. A., 2003, Defining flashover for fire hazard calculations: Part II. Fire Safety Journal, Vol. 38, pp. 613 – 622.
[34] ADL. Risk assessments of flammable refrigerants. Report for Calor Gas Ltd. Arthur D. Little, Cambridge, UK. 1998

f_{SF}	frequency of secondary fire (/y)
f_T^*	frequency of ignition for all of the technicians that begin an individual task (-)
$f_T^{*\prime}$	frequency of ignition for only the technicians that (intend to) complete the task (-)
g	gravitational acceleration (9.807 m/s^2)
$\Delta H(\bar{C}^F)$	heat of combustion of the mean concentration of flammable mixture (kJ/kg)
h_v	height for static pressure (m)
i	refers to leak size
I_{occ}	thermal intensity (s(kW/m^2)$^{4/3}$)
j	refers to specific air flow/environmental condition
k	refers to specific operating condition
K	explosion constant (kPa s)
m	mass of refrigerant (kg)
$\dot{m}_r$	mass flow rate of the release (g/min, kg/s)
M_r	mass of refrigerant released (kg)
$M_{r,cc}$	mass of refrigerant within condensing unit compartment (kg)
$\bar{m}_r^F$	the average mass of refrigerant within the flammable mixture (kg)
n_1, n_2	indices
N_E	number of source of ignition events (-)
N_{flam}^{mol}	Number of moles of combustion products (-)
N_{soi}	number of sources of ignition (-)
N_{VF}^{mol}	Number of moles of flammable mixture (-)
Δp^o	overpressure (kPa)
P^{F*}	probability of ignition of a flammable mixture (-)
P_{act}	probability of a technician action (-)
p_{atm}	atmospheric pressure (Pa, kPa)
P_{avail}	probability of availability of a source of ignition (-)
P_{ev}	probability of a specific event (-)
P_{perc}	percolation probability (-)
p_{sat}	saturation pressure (Pa)
P_{soi}^F	probability of a source of ignition within a flammable mixture (-)
P_{sta}	probability of starting a task (-)
P_{sys}	probability of system leaking (-)
P_V^F	probability of a flammable volume (-)
q_{occ}	heat flux radiated onto an occupant (kW/m^2)
t'	reference time period (s)
t^F	duration of flammable mixture (s)
T_a	air temperature (°C)
t_{soi}	duration of active source of ignition (s)
t_{flam}	flame/burn time (s)
T_{flam}	adiabatic flame temperature (°C)

u_{flam} laminar flame speed (m/s)
V' reference volume (m^3)
$\bar{V}^F$ average flammable volume (m^3)
$\dot{V}_{ba}$ airflow due to buoyancy effects (m^3/s)
V_{cc} volume of condensing unit compartment (m^3)
V_{flam} volume of combustion products (m^3)
$\bar{V}_h^F$ average volume of flammable mixture within a specific region (m^3)
$\dot{V}_{ma}$ airflow due to mechanical ventilation (m^3/s)
z_{occ} average distance between flame and occupant (m)
α homogenous void fraction (-)
χ_I integrated risk of thermal intensity ($s(kW/m2)^{4/3}/y$)
$\chi_{\Delta p}$ integrated risk of overpressure (kPa/y)
φ time fraction for a specific set of conditions (-)
Γ radiative fraction of fuel mixture (-)
ϑ incidence ratio (-)
$\bar{\rho}_{sat}$ homogenous/average two-phase density (kg/m^3)
ρ_{vap} vapour density (kg/m^3)
ρ_{liq} liquid density (kg/m^3)
$\bar{\rho}$ homogenous/average density (kg/m^3)

Appendix J: Additional text for inclusion within instructions

The following text should be included within the DACS product instructions, primarily for use by installation and service companies and technicians. The material is based on IEC 60335-2-40, but modified to suit the equipment under consideration.

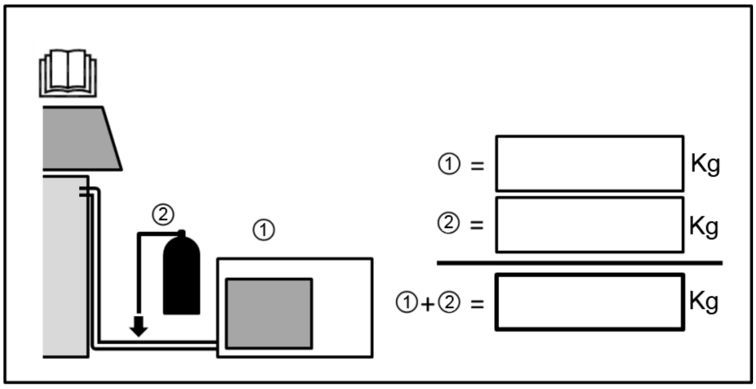
General

The following information shall be specified in the manual where the information is needed for the function of the manual and as applicable to the appliance:

– information for spaces where refrigerant pipes are allowed, including statements
  - that the installation of pipe-work shall be kept to a minimum;
  - that pipe-work shall be protected from physical damage and, in the case of flammable refrigerants, shall not be installed in an unventilated space, if that space is smaller than *the stated minimum room area. T*he effect on refrigerant charge caused by the different pipe length has to be quantified;
  - that compliance with national gas regulations shall be observed;
  - that mechanical connections shall be accessible for maintenance purposes;
  - that, for appliances containing flammable refrigerants, the minimum floor area of the room shall be mentioned in the form of a table or a single figure without reference to a formula;

– the maximum refrigerant charge (m_{max});

– instructions how to determine the additional refrigerant charge and how to complete the refrigerant charge on the label provided by the manufacturer, for example::



Key

Example 1 refrigerant charge of the pre-charged part of the appliance

Example 2 refrigerant charge added during installation

– the minimum rated airflow;

– information for handling, installation, cleaning, servicing and disposal of refrigerant;

– for appliances using flammable refrigerants, instructions shall include the minimum installed height h_{inst} (when required to calculate A_{min}), refrigerant charge m_c and minimum room area of the space A_{min} or a minimum room area of conditioned space TA_{min} where applicable. Additional minimum room area data may be provided based on other installed heights and/or charge levels.

– a warning to keep any required ventilation openings clear of obstruction;

– a notice that servicing shall be performed only as recommended by the manufacturer;

– a warning that ducts connected to an appliance shall not contain a potential ignition source;

– for appliances connected via an air duct system to one or more rooms the supply and return air shall be directly ducted to the space. Open areas such as false ceilings shall not be used as a return air duct;
– following information requirements apply:
  - Equipment piping in the occupied space shall be installed in such a way to protect against accidental damage in operation and service.
  - Precautions shall be taken to avoid excessive vibration or pulsation to refrigerating piping.
  - Protection devices, piping, and fittings shall be protected as far as possible against adverse environmental effects, for example, the danger of water collecting and freezing in relief pipes or the accumulation of dirt and debris.
  - Provision shall be made for expansion and contraction of long runs of piping.
  - Piping in refrigerating systems shall be so designed and installed to minimize the likelihood hydraulic shock damaging the system.
  - Solenoid valves shall be correctly positioned in the piping to avoid hydraulic shock.
  - Solenoid valves shall not block in liquid refrigerant unless adequate relief is provided to the refrigerant system low pressure side.
  - Steel pipes and components shall be protected against corrosion with a rustproof coating before applying any insulation.
  - Flexible pipe elements shall be protected against mechanical damage, excessive stress by torsion, or other forces. They should be checked for mechanical damage annually.
  - The indoor equipment and pipes shall be securely mounted and guarded such that accidental rupture of equipment cannot occur from such events as moving furniture or reconstruction activities.
  - Where safety shut off valves are specified, the minimum room area may be determined based on the maximum amount of refrigerant that can be leaked.
  - Field-made refrigerant joints indoors shall be tightness tested. The test method shall have a sensitivity of 5 grams per year of refrigerant or better under a pressure of at least 0,25 times the maximum allowable pressure. No leak shall be detected.
– For appliances using flammable refrigerants using a refrigerant detection system, safety shut-off valves shall not be reset until the refrigerating system has been serviced, because resetting may result in additional refrigerant released into the space.

Unventilated areas

For appliances containing more than *150 g* for any refrigerating circuit the manual shall include a statement advising that an unventilated area where the appliance using flammable refrigerants is installed shall be so constructed that should any refrigerant leak, it will not stagnate so as to create a fire or explosion hazard. This shall include:

– a warning that if appliances connected via an air duct system to one or more rooms with flammable refrigerants are installed in a room with an area less than A_{min}, that room shall be without continuously operating open flames (for example an operating gas appliance) or other potential ignition sources (for example an operating electric heater, hot surfaces);
– for appliances using flammable refrigerants connected via an air duct system to one or more rooms, a warning that only auxiliary devices approved by the appliance manufacturer or declared suitable with the refrigerant shall be installed in connecting ductwork. The manufacturer can list in the instructions all approved auxiliary devices by manufacturer and

model number for use with the specific appliance, if those devices have a potential to become an ignition source.

The manufacturer should specify other potential continuously operating sources known to cause ignition of the refrigerant used.

The appliance shall be stored so as to prevent mechanical damage from occurring.

Qualification of workers
The manual shall contain specific information about the required qualification of the working personnel for maintenance, service and repair operations. Every working procedure that affects safety means shall only be carried out by competent persons.
Examples for such working procedures are:

- breaking into the refrigerating circuit;
- opening of sealed components;
- opening of ventilated enclosures.

Information on servicing
The manual shall contain specific information for service personnel.

Checks to the area
Prior to beginning work on systems containing flammable refrigerants, safety checks are necessary to ensure that the risk of ignition is minimised.

Work procedure
Work shall be undertaken under a controlled procedure so as to minimise the risk of a flammable gas or vapour being present while the work is being performed.

General work area
All maintenance staff and others working in the local area shall be instructed on the nature of work being carried out. Work in confined spaces shall be avoided.

Checking for presence of refrigerant
The area shall be checked with an appropriate refrigerant detector prior to and during work, to ensure the technician is aware of potentially toxic or flammable atmospheres. Ensure that the leak detection equipment being used is suitable for use with all applicable refrigerants, i.e. non-sparking, adequately sealed or intrinsically safe.

Presence of fire extinguisher
If any hot work is to be conducted on the refrigerating equipment or any associated parts, appropriate fire extinguishing equipment shall be available to hand. Have a dry powder or CO_2 fire extinguisher adjacent to the charging area.

No ignition sources
No person carrying out work in relation to a refrigerating system which involves exposing any pipe work shall use any sources of ignition in such a manner that it may lead to the risk of fire or explosion. All possible ignition sources, including cigarette smoking, should be kept sufficiently far away from the site of installation, repairing, removing and disposal, during which refrigerant can possibly be released to the surrounding space. Prior to work taking place, the area around the equipment is to be surveyed to make sure that there are no flammable hazards or ignition risks. "No Smoking" signs shall be displayed.

Ventilated area
Ensure that the area is in the open or that it is adequately ventilated before breaking into the system or conducting any hot work. A degree of ventilation shall continue during the period that the work is carried out. The ventilation should safely disperse any released refrigerant and preferably expel it externally into the atmosphere.

Checks to the refrigerating equipment
Where electrical components are being changed, they shall be fit for the purpose and to the correct specification. At all times the manufacturer's maintenance and service guidelines shall be followed. If in doubt, consult the manufacturer's technical department for assistance.
The following checks shall be applied to installations using flammable refrigerants:

– the actual refrigerant charge is in accordance with the room size within which the refrigerant containing parts are installed;
– the ventilation machinery and outlets are operating adequately and are not obstructed;
– if an indirect refrigerating circuit is being used, the secondary circuit shall be checked for the presence of refrigerant;
– marking to the equipment continues to be visible and legible. Markings and signs that are illegible shall be corrected;
– refrigerating pipe or components are installed in a position where they are unlikely to be exposed to any substance which may corrode refrigerant containing components, unless the components are constructed of materials which are inherently resistant to being corroded or are suitably protected against being so corroded.

Checks to electrical devices
Repair and maintenance to electrical components shall include initial safety checks and component inspection procedures. If a fault exists that could compromise safety, then no electrical supply shall be connected to the circuit until it is satisfactorily dealt with. If the fault cannot be corrected immediately but it is necessary to continue operation, an adequate temporary solution shall be used. This shall be reported to the owner of the equipment so all parties are advised.
Initial safety checks shall include:

- that capacitors are discharged: this shall be done in a safe manner to avoid possibility of sparking;
- that no live electrical components and wiring are exposed while charging, recovering or purging the system;
- that there is continuity of earth bonding.

Repairs to sealed components

During repairs to sealed components, all electrical supplies shall be disconnected from the equipment being worked upon prior to any removal of sealed covers, etc. If it is absolutely necessary to have an electrical supply to equipment during servicing, then a permanently operating form of leak detection shall be located at the most critical point to warn of a potentially hazardous situation.

Particular attention shall be paid to the following to ensure that by working on electrical components, the casing is not altered in such a way that the level of protection is affected. This shall include damage to cables, excessive number of connections, terminals not made to original specification, damage to seals, incorrect fitting of glands, etc.
Ensure that the apparatus is mounted securely.

Ensure that seals or sealing materials have not degraded to the point that they no longer serve the purpose of preventing the ingress of flammable atmospheres. Replacement parts shall be in accordance with the manufacturer’s specifications.

Repair to intrinsically safe components

Do not apply any permanent inductive or capacitance loads to the circuit without ensuring that this will not exceed the permissible voltage and current permitted for the equipment in use. Intrinsically safe components are the only types that can be worked on while live in the presence of a flammable atmosphere. The test apparatus shall be at the correct rating.
Replace components only with parts specified by the manufacturer. Other parts may result in the ignition of refrigerant in the atmosphere from a leak.

NOTE The use of silicon sealant can inhibit the effectiveness of some types of leak detection equipment. Intrinsically safe components do not have to be isolated prior to working on them.

Cabling

Check that cabling will not be subject to wear, corrosion, excessive pressure, vibration, sharp edges or any other adverse environmental effects. The check shall also take into account the effects of aging or continual vibration from sources such as compressors or fans.

Detection of flammable refrigerants

Under no circumstances shall potential sources of ignition be used in the searching for or detection of refrigerant leaks. A halide torch (or any other detector using a naked flame) shall not be used.

The following leak detection methods are deemed acceptable for all refrigerant systems. Electronic leak detectors may be used to detect refrigerant leaks but, in the case of flammable refrigerants, the sensitivity may not be adequate, or may need re-calibration. (Detection equipment shall be calibrated in a refrigerant-free area.) Ensure that the detector is not a potential source of ignition and is suitable for the refrigerant used. Leak detection equipment shall be set at a percentage of the *LFL* of the refrigerant and shall be calibrated to the refrigerant employed, and the appropriate percentage of gas (25 % maximum) is confirmed.

Leak detection fluids are also suitable for use with most refrigerants but the use of detergents containing chlorine shall be avoided as the chlorine may react with the refrigerant and corrode the copper pipe-work.

NOTE Examples of leak detection fluids are
- bubble method,
- fluorescent method agents.

If a leak is suspected, all naked flames shall be removed/extinguished.
If a leakage of refrigerant is found which requires brazing, all of the refrigerant shall be recovered from the system, or isolated (by means of shut off valves) in a part of the system remote from the leak.

Removal and evacuation
When breaking into the refrigerant circuit to make repairs – or for any other purpose – conventional procedures shall be used. However, for flammable refrigerants it is important that best practice is followed since flammability is a consideration. The following procedure shall be adhered to:
- remove refrigerant;
- purge the circuit with inert gas;
- evacuate;
- purge with inert gas;
- open the circuit by cutting or brazing.

The refrigerant charge shall be recovered into the correct recovery cylinders. For appliances containing flammable refrigerants, the system shall be purged with oxygen free nitrogen to render the appliance safe for flammable refrigerants This process may need to be repeated several times. Compressed air or oxygen shall not be used for purging refrigerant systems.
For appliances containing flammable refrigerants, refrigerants purging shall be achieved by breaking the vacuum in the system with oxygen free nitrogen and continuing to fill until the working pressure is achieved, then venting to atmosphere, and finally pulling down to a vacuum. This process shall be repeated until no refrigerant is within the system. When the final oxygen free nitrogen charge is used, the system shall be vented down to atmospheric pressure to enable work to take place. This operation is absolutely vital if brazing operations on the pipe-work are to take place.

Ensure that the outlet for the vacuum pump is not close to any potential ignition sources and that ventilation is available.

Charging procedures
In addition to conventional charging procedures, the following requirements shall be followed.
- Ensure that contamination of different refrigerants does not occur when using charging equipment. Hoses or lines shall be as short as possible to minimise the amount of refrigerant contained in them.
- Cylinders shall be kept in an appropriate position according to the instructions.
- Ensure that the refrigerating system is earthed prior to charging the system with refrigerant.

- Label the system when charging is complete (if not already).
- Extreme care shall be taken not to overfill the refrigerating system.

Prior to recharging the system, it shall be pressure-tested with the appropriate purging gas. The system shall be leak-tested on completion of charging but prior to commissioning. A follow up leak test shall be carried out prior to leaving the site.

Decommissioning

Before carrying out this procedure, it is essential that the technician is completely familiar with the equipment and all its detail. It is recommended good practice that all refrigerants are recovered safely. Prior to the task being carried out, an oil and refrigerant sample shall be taken in case analysis is required prior to re-use of recovered refrigerant. It is essential that electrical power is available before the task is commenced.

a) Become familiar with the equipment and its operation.
b) Isolate system electrically.
c) Before attempting the procedure, ensure that:
   - mechanical handling equipment is available, if required, for handling refrigerant cylinders;
   - all personal protective equipment is available and being used correctly;
   - the recovery process is supervised at all times by a competent person;
   - recovery equipment and cylinders conform to the appropriate standards.
d) Pump down refrigerant system, if possible.
e) If a vacuum is not possible, make a manifold so that refrigerant can be removed from various parts of the system.
f) Make sure that cylinder is situated on the scales before recovery takes place.
g) Start the recovery machine and operate in accordance with instructions.
h) Do not overfill cylinders (No more than 80 % volume liquid charge).
i) Do not exceed the maximum working pressure of the cylinder, even temporarily.
j) When the cylinders have been filled correctly and the process completed, make sure that the cylinders and the equipment are removed from site promptly and all isolation valves on the equipment are closed off.
k) Recovered refrigerant shall not be charged into another refrigerating system unless it has been cleaned and checked.

Labelling

Equipment shall be labelled stating that it has been de-commissioned and emptied of refrigerant. The label shall be dated and signed. For appliances containing flammable refrigerants, ensure that there are labels on the equipment stating the equipment contains flammable refrigerant.

Recovery

When removing refrigerant from a system, either for servicing or decommissioning, it is recommended good practice that all refrigerants are removed safely.

When transferring refrigerant into cylinders, ensure that only appropriate refrigerant recovery cylinders are employed. Ensure that the correct number of cylinders for holding the total system charge is available. All cylinders to be used are designated for the recovered refrigerant and labelled for that refrigerant (i.e. special cylinders for the recovery of refrigerant). Cylinders shall be complete with pressure-relief valve and associated shut-off valves in good working order.

Empty recovery cylinders are evacuated and, if possible, cooled before recovery occurs.

The recovery equipment shall be in good working order with a set of instructions concerning the equipment that is at hand and shall be suitable for the recovery of all appropriate refrigerants including, when applicable, flammable refrigerants. In addition, a set of calibrated weighing scales shall be available and in good working order. Hoses shall be complete with leak-free disconnect couplings and in good condition. Before using the recovery machine, check that it is in satisfactory working order, has been properly maintained and that any associated electrical components are sealed to prevent ignition in the event of a refrigerant release. Consult manufacturer if in doubt. The recovered refrigerant shall be returned to the refrigerant supplier in the correct recovery cylinder, and the relevant waste transfer note arranged. Do not mix refrigerants in recovery units and especially not in cylinders.

If compressors or compressor oils are to be removed, ensure that they have been evacuated to an acceptable level to make certain that flammable refrigerant does not remain within the lubricant. The evacuation process shall be carried out prior to returning the compressor to the suppliers. Only electric heating to the compressor body shall be employed to accelerate this process. When oil is drained from a system, it shall be carried out safely

Competence of service personnel

General

Information of procedures additional to usual information for refrigerating appliance installation, repair, maintenance and decommission procedures is required when an appliance with flammable refrigerants is affected.

The training of these procedures is carried out by national training organisations or manufacturers that are accredited to teach the relevant national competency standards that may be set in legislation.

The achieved competence should be documented by a certificate.

Information and training

The training should include the substance of the following:

Information about the explosion potential of flammable refrigerants to show that flammables may be dangerous when handled without care.

Information about potential ignition sources, especially those that are not obvious, such as lighters, light switches, vacuum cleaners, electric heaters.

Information about the different safety concepts:

Unventilated – Safety of the appliance does not depend on ventilation of the housing. Switching off the appliance or opening of the housing has no significant effect on the safety. Nevertheless, it is possible that leaking refrigerant may accumulate inside the enclosure and flammable atmosphere will be released when the enclosure is opened.

Ventilated enclosure – Safety of the appliance depends on ventilation of the housing. Switching off the appliance or opening of the enclosure has a significant effect on the safety. Care should be taken to ensure a sufficient ventilation before.

Ventilated room – Safety of the appliance depends on the ventilation of the room. Switching off the appliance or opening of the housing has no significant effect on the safety. The ventilation of the room shall not be switched off during repair procedures.

Information about refrigerant detectors:

- Principle of function, including influences on the operation.
- Procedures, how to repair, check or replace a refrigerant detector or parts of it in a safe way.
- Procedures, how to disable a refrigerant detector in case of repair work on the refrigerant carrying parts.

Information about the concept of sealed components and sealed enclosures according to IEC 60079-15:2010.

Information about the correct working procedures:

Commissioning

- Ensure that the floor area is sufficient for the refrigerant charge or that the ventilation duct is assembled in a correct manner.
- Connect the pipes and carry out a leak test before charging with refrigerant.
- Check safety equipment before putting into service.

Maintenance

- Portable equipment shall be repaired outside or in a workshop specially equipped for servicing units with flammable refrigerants.
- Ensure sufficient ventilation at the repair place.
- Be aware that malfunction of the equipment may be caused by refrigerant loss and a refrigerant leak is possible.
- Discharge capacitors in a way that won't cause any spark. The standard procedure to short circuit the capacitor terminals usually creates sparks.
- Reassemble sealed enclosures accurately. If seals are worn, replace them.
- Check safety equipment before putting into service.

Repair

- Portable equipment shall be repaired outside or in a workshop specially equipped for servicing units with flammable refrigerants.
- Ensure sufficient ventilation at the repair place.
- Be aware that malfunction of the equipment may be caused by refrigerant loss and a refrigerant leak is possible.
- Discharge capacitors in a way that won't cause any spark.
- When brazing is required, the following procedures shall be carried out in the right order:
  - Remove the refrigerant. If the recovery is not required by national regulations, drain the refrigerant to the outside. Take care that the drained refrigerant will not cause any danger. In doubt, one person should guard the outlet. Take special care that drained refrigerant will not float back into the building.
  - Evacuate the refrigerant circuit.
  - Purge the refrigerant circuit with nitrogen for 5 min.
  - Evacuate again.
  - Remove parts to be replaced by cutting, not by flame.
  - Purge the braze point with nitrogen during the brazing procedure.
  - Carry out a leak test before charging with refrigerant.
- Reassemble sealed enclosures accurately. If seals are worn, replace them.
- Check safety equipment before putting into service.

Decommissioning

- If the safety is affected when the equipment is putted out of service, the refrigerant charge shall be removed before decommissioning.
- Ensure sufficient ventilation at the equipment location.

- Be aware that malfunction of the equipment may be caused by refrigerant loss and a refrigerant leak is possible.
- Discharge capacitors in a way that won't cause any spark.
- Remove the refrigerant. If the recovery is not required by national regulations, drain the refrigerant to the outside. Take care that the drained refrigerant will not cause any danger. In doubt, one person should guard the outlet. Take special care that drained refrigerant will not float back into the building.
- When flammable refrigerants are used,
  - Evacuate the refrigerant circuit.
  - Purge the refrigerant circuit with nitrogen for 5 min.
  - Evacuate again.
  - Fill with nitrogen up to atmospheric pressure.
  - Put a label on the equipment that the refrigerant is removed.

Disposal

- Ensure sufficient ventilation at the working place.
- Remove the refrigerant. If the recovery is not required by national regulations, drain the refrigerant to the outside. Take care that the drained refrigerant will not cause any danger. In doubt, one person should guard the outlet. Take special care that drained refrigerant will not float back into the building.
- When flammable refrigerants, are used,
  - Evacuate the refrigerant circuit.
  - Purge the refrigerant circuit with nitrogen for 5 min.
  - Evacuate again.
  - Cut out the compressor and drain the oil.
- Evacuate the refrigerant circuit.
- Purge the refrigerant circuit with nitrogen for 5 min.
- Evacuate again.
- Cut out the compressor and drain the oil.

Risk Analysis Report to Implement LPG R290 in Industrias Thermotar LTDA

Facilities:	**Industrias Thermotar LTDA**
Address:	**Carrera 65B No. 48 – 03**
Visit date:	**22/12/2017**
Reporting date:	**25/01/2018**
Requested by:	**Seguros Generales Suramericana SA**
Performed by:	**Eduardo Canedo Santos**

Engrin de Colombia SAS — Engineering applied to Risks and Insurance

SEGUROS, TENDENCIAS Y RIESGOS

Contents

I. Introduction

Upon request of Industrias Thermotar Ltda Company, hereinafter "Thermotar", through engineer Álvaro Javier Arango Guete, Project Engineer, in charge of the R290 Refrigerant Charge Implementation Project for the cooling equipment produced at the Thermotar plant visited. The following is a report on our December 2017 Risk Analysis study about R290 gas as a refrigerant agent for commercial and industrial cooling units of the 290 production line, which will be commissioned next April 2018.

This document is divided in different sections. The first section focuses on identifying the main risks and basic knowledge about gas behavior, followed by a risk quantification and categorization exercise, a section with recommendations, and a final section with the emergency plan overview and general comments on maintenance.

The document division aims at achieving the objectives initially set in our proposal. The objectives are: to identify risks and impact levels in case risks take place. We also refer to the minimum controls required in the industry where a substance with the physicochemical characteristics of R290 "propane" gas is used. This methodology has been applied to each area where R290 is handled, including its production process, which is simply the refrigerant charging operation.

The productive line in our analysis has been divided as follows:

- Reception and storage of R290 cylinders.

- Installation of cylinders in the Agramkow machine manifold and R290 recharge.

We have attached a separate chapter on the analysis of human safety and response plans, addressing the structuring requirements for an emergency plan under the NFPA standard.

The requirements of fire protection systems and alarms will be included in our section of recommendations for improvement.

The final section shows our additional comments on maintenance for equipment in direct contact with R290 gas, knowing that priority is given to the recommendations and parameters of equipment manufacturers, in this case the Agramkow firm.

II. Purpose and Scope

This study mainly focuses on risk analysis of the implementation of R290 Liquefied Petroleum Gas - LPG as a cooling agent for refrigeration units produced by Industrias Thermotar LTDA. The analysis carried out is based on the information provided by Industrias Thermotar LTDA. Consequently, Seguros Generales Suramericana S.A. holds no liability for the accuracy of data, calculations or opinions presented in this report based on such information or any losses or damages caused by or in relation to such data, calculations or opinions. This report does not aim at identifying all the existing risks or cover all the possible events related to R290.

This risk analysis was specifically and only applied to Industrias Thermotar LTDA located at Carrera 65B No. 48 – 03 in Barranquilla, Colombia.

III. Risk Identification

Overview and characteristics of Flammable Gases.

Definition and classification of gases under the NFPA 55

The LPG R290 (Propane) refrigerant is a petroleum gas deemed to be a substitute for other products with harmful environmental impacts, mainly against the ozone layer, in compliance with the commitments made by Colombia in Montreal Protocol and the Ozone Technical Unit (Unidad Técnica Ozono — UTO) of the Ministry of Environment, Housing and Territorial Development. The National Phaseout Plan is being implemented in Colombia to facilitate the phasing-out of ozone depleting substances currently imported by the country.

The use of R290 is a suitable alternative solution to environmental problems, especially in small hermetic systems such as domestic and commercial refrigerant equipment. The R290 refrigerant has a low ozone depletion potential and very low global warming potential as a petroleum gas; it is therefore considered to be a natural refrigerant. Since it is available worldwide, it is a suitable alternative to replace CFC, HCFC and HFC refrigerants. R290 propane is a refrigerant useful for several applications with good performance due to its thermodynamic properties and/or Joule Thomson coefficient; however, it must be treated with caution as it is flammable. Such flammability is the main reason and goal of this risk analysis study for this particular customer and application.

Let us first check the definition of a gas in the NFPA and FM. The term gas refers to a physical state with no form or volume that will take the form or fill the volume of any container of any geometric shape or enclosed space contained. This feature differentiates gas from liquids, which have no shape but have volume, and solids, which have their own form and volume. Since all substances can exist as gases, depending on the temperature and pressure applied, the term ‘gas’ usually applies to substances in gas state under conditions of Standard Temperature and Pressure (STP). Approximately 21°C and 14.7 PSIA. However, many substances can exist as liquids or gases even under normal STP conditions.

The scope of this risk analysis study includes defining the physicochemical characteristics that identify a gas as flammable and/or combustible. Flammable gas is any gas that comes into contact with air/oxygen in uncontrolled proportions and can cause explosive reactions, explosion or fire hazard when

it reaches an excessive concentration in an oxidizing agent, which may be air and/or oxygen. According to the NFPA, flammable gas is defined as a gas at atmospheric temperature and pressure that is ignitable when in a mixture of 13% or less by volume in air, or a gas that has a flammable range with air of at least 12% regardless of the lower flammable limit. The NFPA defines a liquefied gas as a gas that is not in a solution and, when bottled at charging pressure, can exist as both a liquid and gas at 20°C temperature.

In accordance with the NFPA 55 standard, gases are classified as: flammable gas, non-flammable gas, pyrophoric gas, oxidizing gas and toxic and/or poisonous gas. The definition of flammable gas is provided in the paragraph above. Each flammable gas has a lower and upper limit for ideal concentrations of combustion and/or explosion. The mixes of flammable gas and air only ignite within this flammable range, provided that the minimum ignition energy is present. In few cases much reduced flammable ranges or a very high lower flammable limit, or both, make it possible to classify a gas that can burn in the air as non-flammable, since the ignition properties of gas in the air are low in most cases. Anhydrous ammonia is an example of flammable gas within the context of the paragraph above.

Although the vapors of flammable liquid and flammable gases have similar combustion characteristics, the term 'flash point' describes a common and useful property of combustion of flammable liquids which has no impact on flammable gases. The temporary ignition point or flash point is a temperature measure at which a flammable liquid produces enough vapors for combustion. This temperature is always under the normal boiling point. A flammable gas exists normally at a higher temperature than its normal boiling point, even when the gas is in liquid state (as it is usually the case in storage and transport.) Therefore, flammable gas exists at a temperature which is not only higher than its temporary flammable point, but generally surpasses such point by far. In other words, a flammable liquid must be over a specific temperature to produce sufficient vapors for combustion, while flammable gases can always ignite.

Non-combustible gases are gases that do not burn at any concentration in air; although oxidizing gases are not flammable, they are classified separately by the NFPA 55. The most common include nitrogen, helium, argon and other rare gases from the atmosphere. Pyrophoric gases are gases that ignite spontaneously when coming in contact with air; their storage demands special care since they require no ignition source to burn. Oxidizing gases are those required for combustion; they are usually mixtures of oxygen and helium, and oxygen and nitrogen.

These mixtures contain more oxygen than that found in mixtures of oxygen and nitrogen present in the air.

Toxic gases represent a high risk for human health if released into the atmosphere. These gases are poisonous, cause irritation on contact or when inhaled; for example, chlorine, sulfur dioxide, ammonia, carbon monoxide and arsine. Fires with the presence of this type of gases are difficult for firefighters to extinguish due to the high risk of toxicity.

Classification of gases by physical properties

Physical properties demand special care in fire protection because they affect the physical behavior of gases while they are in their containers and after any accidental release. The gases must be completely confined until required; this includes transport, transfer and storage. Gases are packaged in containers filled as much as possible for economic reasons and ease of use. These requirements have provided good results in transport and storage in both liquid and gas state. It is important to define and differentiate gases in liquid state and gas state to apply safe fire prevention and protection practices.

The classification of gases by physical properties includes compressed gases, liquefied gases and cryogenic gases. Considering the subject-matter and scope of our study, we will briefly describe each classification.

A compressed gas is defined by the NFPA 55 as a gas that is not in a solution and, when bottled at charging pressure, is totally gaseous, at a 20 °C temperature, meaning that a compressed gas is only a gas that exists in a gaseous state, at any normal atmospheric temperatures. Pressure depends on the initial pressure used to charge the container, the remaining amount of gas in the container and the gas temperature.

There are no universally defined lower or upper limits for container pressure. In many countries the minimum limit is 25psi at normal temperatures, that is 20 °C; the upper limit is defined by the construction characteristics of the container, where pressures from 1800 to 3600 psig can be reached. Compressed gas containers depend on the gas weight they can hold, for example, the largest and most common oxygen cylinder contains only 9kg of oxygen, which is approximately 9.3m3 under STP.

A liquified gas exists in liquid state and gas state at 20 °C under pressure, if there is some liquid remaining in the container. Pressure depends on the liquid temperature, although the amount of liquid may affect pressure under specific conditions. Liquified gas is more concentrated than compressed gas, for example, the oxygen cylinder mentioned in the example above may contain 53 liquified kilograms, approximately 39.6m3. That is, about 6 times lower than the STP.

A cryogenic gas is a liquified gas that exists in a container at temperatures under -90 °C, one of its main distinctive features compared to a liquified gas is that cryogenic gas cannot be held indefinitely in a container. Heat in the atmosphere may be delayed but it is impossible to prevent the heat transfer into the container, which progressively increases the container pressure. If the gas is confined, the feasible resistance of the container may be widely extended.

In accordance with this NFPA classification, in our case, the gas analyzed in this study is a liquified gas in metal containers with a capacity of 12.1 lbs. 5.5 kg at 140 psi.

Classification of gases by use

Most gases have been historically classified based on their main use. This is evidenced in some codes such as the NFPA 54, National Fuel Gas Code, where this classification is not as accurate as the classification by physical properties and the uses of gases constantly overlap.

Combustible gases include flammable gases traditionally used with air in devices to produce heat, thermal energy; the most commonly used combustible gases are natural gas and liquified petroleum, butane and propane gases.

Industrial gases include the complete set of gases classified by physical properties, which are traditionally used in industrial processes for welding and cutting, thermal treatment, chemical processes, cooling and water treatment.

In this case, R290 is a combustible gas and an industrial gas according to the NFPA 54, since it will be used as a refrigerant gas.

Finally, the NFPA 54 classification wraps up the categorization with medicinal gases. This is the most specialized classification by use, as they are employed for medical purposes such as anesthesia and respiratory therapies. Oxygen and nitrous oxide are the most common medicinal gases.

Associated risks of containers

Risk by increase of pressure and fire risk

In our case, R290 refrigerant gas is in the plant in liquified gas form in 12.1 lb. containers at 140 psi. Although the amount of gas in a container is relatively low, the sum of all possible containers in the inventory forms a high fuel charge; the inventory reports 150 cylinders which represent 750kg.

R290 containers, as observed in the plant, represent a moderate/high risk in the event of a fire as gases expand when heated, causing an increase in the container pressure; this can generate the release of gas or the failure of a container. Additionally, the containers may lose their resistance and fail during a fire.

Any compressed gas attempts to expand when heated, following the classical physics laws of gas behavior; it should be noted that no gas follows these laws exactly, but the laws of Boyle and Charles are accurate enough to predict gas behavior.

To calculate the pressures and temperature of gases, there are several formulas in which temperature and pressure are absolute values, namely, the temperature expressed in degrees Rankine or Kelvin, i.e. (° F + 459 = ° R) or (° C) + 273 = ° K) and absolute pressure P = Man Pressure + 14.7 psi or kPa + 101kPa.

According to Charles' law and Boyle's Law, for purposes within practical ranges, Boyle's law states that PV = Cte, and Charles's law states that V/T = Cte.

Therefore, we have the following relation for ideal gases.

= + 14.7

° + 459 = ° ° + 273 = °

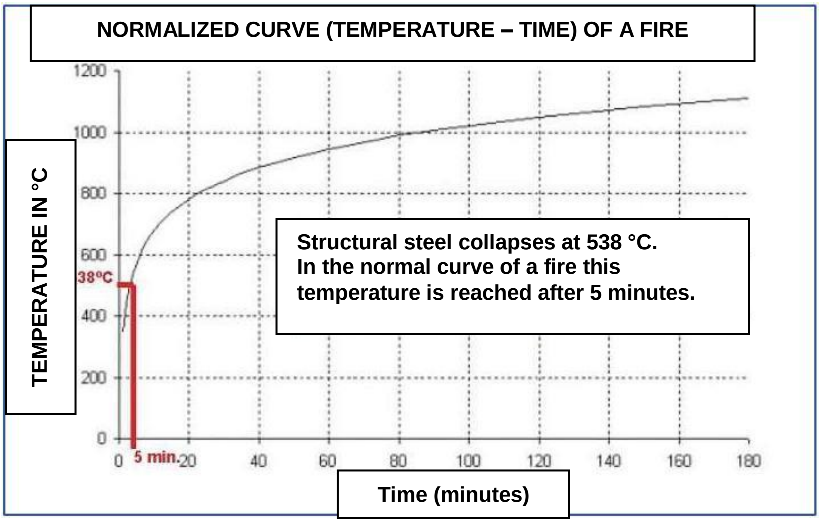
— =——

By using this ideal gas equation, we can determine the internal pressures of the cylinders studying the temperatures that could be reached during a fire, since the gas always remains in a gaseous state. In our case we have a liquefied gas, which shows deviant behaviors compared to those of the ideal gas equation. The real gas equation is more suitable for this situation. In our calculation we will use the Van Der Waals equation of state with the following structure.

+ — (−) =

For thermodynamic calculations, a and b are correction constants of the equation of state of ideal gas in the behavior of a liquified gas.

The liquefied gas and cryogenic gas show a complex behavior because heating results produce three effects: first, the gas column behaves like the ideal gas, attempts to expand and increases the pressure, the liquid region attempts to expand by compressing the gas phase, the vapor pressure of the liquid increases as the liquid temperature increases. These effects cause an increase in pressure when the container is heated, if 500 °C temperatures are reached during a fire (as in the following graph).



As an exercise, we are going to determine the internal pressure of a R290 propane cylinder. Applying the Van Der Waals equation of state at a 500 °C temperature and observing that the container has a 0.10m3 volume, the values of the a and b Van Der Waals constants for Propane are:

= 9.315 = 0.0900

For the specific volume calculation we have:

= $\frac{0.10}{5.5}$ ( ) = 0.01818 44.09 = 0.8015

Solving the pressure in the Van Der Waals equation of state, we have:

= – – / (+)

Considering that the temperature is 500 °C, we have absolute values of 500 + 273 = 773°K

Replacing the equation values, we have

$$= \frac{0.08314(773)}{0.8015 - 0.0900} - \frac{9.315}{773\underline{3}\ (0.8015)(0.8015 + 0.0900)}$$

$$= \frac{64.26}{0.7115} - \frac{9.315}{19.8661}$$

$$= 90.31 - 0.4668 = 89.84$$

this is approximately 1300 psi; according to data from the cylinder manufacturers there is a relief valve that triggers when the tank pressure increases over a pressure percentage of cylinder charge. Some manufacturers provide this safety seal near 300/400 PSI.

Risks of R290 cylinders exposed to fire

The cases in which LPG R290 or liquefied gas cylinders are exposed to fire and break in two or three parts are a failure called BLEVE — Boiling Liquid Expanding Vapor Explosion. All liquefied gases, such as R290, are stored at temperatures above their boiling point, under standard temperature and pressure conditions, and remain under pressure only while the cylinder remains closed to the atmosphere.

This pressure can be lower than 6.9kpa (0.069 bar), in liquefied gas containers. If the pressure is reduced to atmospheric pressure as in the case of a container failure, the amount of heat stored in the container generates a very quick vaporization of part of the liquid.

This vaporization occurs at a point directly proportional to the temperature difference between the temperature of the liquid at the time of container failure and the normal boiling point of the liquid. In many flammable liquefied gases, this temperature differential at standard atmospheric pressures can cause the vaporization of a third of the liquid in the container. Since the pressure relief devices are calibrated to discharge at pressures higher than the operating pressure of the pressurized container, the liquid temperature will be well above the normal atmospheric boiling point. For example, propane R290 at 275PSIG, which is the maximum pressure of the relief calibration valve, has a boiling point of 57 °C, well above the atmospheric boiling point which is -40 ° C. Therefore, the liquid temperature at the time of failure is higher than the boiling temperature, which is why more liquid is vaporized —more than half of the liquid in the container. The remaining liquid cools down to its boiling point. The

vaporization of the liquid is accompanied by a large expansion of liquid vapor; this process of expansion produces the violent tank rupture and the ejection of fragments, the quick mixture of vapor/air produces the characteristic fireball of the ignition of fire that caused the BLEVE, and the atomization of the remaining cold liquid. Many of the atomized droplets burn in the air; however, it is not uncommon for the cold liquid to be propelled very quickly from the fire area, not reaching ignition temperature and falling down to earth in liquid form. The reduction of internal pressure to atmospheric level in a container reduces its capacity to maintain the pressure it was designed for. This failure is often caused by the weakening of the metal material of the container by contact with flames, but it can also be caused by a mechanical failure of the container due to loss of wall thickness as a result of corrosion in its walls. It is important to be clear and remember that the BLEVE occurs after the container failure and is not a container failure itself.

Transfer risks

An abrupt increase in pressure may occur, if the liquid expansion causes the container to be filled with liquid. If this occurs, a small additional amount of heat causes an excessive increase in pressure. Consequently, it is not advisable to transfer more liquefied gas in liquid phase than the amount the container can hold, leaving a space for the vapor or gas phase if the temperature of the liquid rises to a level proportional to the expected ambient temperatures. The appropriate amount varies with the liquefied gas and factors that affect the expected temperature increases such as the temperature of the liquid at the time of transfer into the container, whether the container is insulated, or whether it is installed at ground level or underground.

In our case, this type of risk does not exist in the plant as we are no longer performing cylinder charge operations; however, we have analyzed the R290 gas supply process for line 290 and concluded that it is a closed process consisting of a manifold system for 4 cylinders and a pump that injects gas into the R290 charger. No abrupt changes in pressure are observed, several nipples and coupling systems are identified as susceptible to leaks, no gaps or pipes exposed to being hit are observed. Transfer from the charging machine to the refrigeration units is controlled electronically with an internal PLC incorporated to the charging machine.

Permitted quantities are generally expressed as "charge densities" or "filling densities" and are stipulated for each gas; however, filling densities expressed in units of volume must be always qualified, specifying the temperature of the liquid. There are

general charts for charge densities based on temperature.

Liquefied compressed gas vessels such R290 containers have a high degree of potential energy release due to the concentration of matter by compression or liquefaction. A failure in this type of containers releases all this energy in a simultaneous release of gas into the surrounding areas and propels the container. Failures in compressed gas containers as those observed in the plant are more characterized by the risk of projectiles thrown into the air than by the consequences of the release of gas itself, since they contain relatively smaller amounts than other storage systems such as horizontal tanks on saddles or buried tanks. This does not rule out that the gas release represents a risk of explosion and fire.

Risks by accidental release in occupancies

Uncontrolled mixes of flammable gases greatly increase the risk of explosion and subsequent fire, as well as, the threat of asphyxiation in confined or scarcely ventilated spaces. In our case we already know that R290 is a gas with flammable characteristics and a hydrocarbon gas derived from crude oil that requires special care inside and outside a containment system (refrigerant units). The danger of flammable liquids and flammable gases lies in the flash points and mixing with oxidizing agents, producing a flammable gas/air mixture. The flammable mixture is the flammability range of the gas. Flammable mixtures occur when the concentrations of vapors or gases in the air are in a defined percentage limit, generally known as the flammable (explosive) range. The lower limit of the range is known as the Lower Flammable Limit (LFL). The upper limit of the range is known as the Upper Flammable Limit (UFL). For example, the proportions (flammable range) for carbon disulphide in the air range from 1% to 44%, ethyl alcohol ranges from 4% to 19% percent, gasoline ranges from 1.4% to 7.6%. The R290 subject-matter of our study reports a flammable range when concentrations from 2.1% to 9.5% are reached in the air, the former value is the LFL and the latter value the UFL. The reported autoignition temperature is 450 °C.

The NFPA 70 suggests having "explosion proof" equipment available in areas susceptible to the occurrence of leaks, the R290 storage area and charging chamber should be considered as an area classified under the NFPA 70, that is, it should be a special area with electrical connections different from those in unclassified areas, it must also have excellent ventilation, and a non-combustible construction is more suitable to the occupancy or construction, with fire resistant doors and walls at least 1.5H. For

fire protections, it is advisable to have the site equipped with automatic fog sprinklers or water fog systems; fire can also be extinguished using dry chemical powder and/or CO2. Water can be applied manually with hose cabinets in order to cool the tanks that have been exposed to intense heat. The gas that escapes from broken cylinders can ignite the fire or expand to the surrounding areas and reach other sources of ignition causing simultaneous explosions. It is advisable to have available proximity suits and self-contained suits in the emergency brigade.

Explosion prevention measures are based on one or more of the following techniques or principles: (1) exclusion of ignition sources, (2) exclusion of air, oxygen, (3) storage in closed tanks, (4) ventilation to avoid steam and/or gas accumulation, (5) use of an inert gas atmosphere instead of air.

The accumulation of fuel-air gas mixtures can occur in closed spaces such as vessels or containers, tanks, rooms or buildings. The violence of an explosion depends on the type of gas, the enclosure containing the mixture, the amount of mixture and concentration of gas in the mixture with air. Fuel-air gas mixtures with concentrations near the lower and upper limits are less strong than those occurring in a "stoichiometric" concentration or mixture. The stoichiometric mixture is deemed to be the ideal mixture to deliver the greatest amount of energy during combustion.

In R290 applications, it is vital to control and detect timely any leak that occurs in the two potential areas of accidental leaks. The first region is considered as the storage area and the second area is considered as the loading area or R290 line; this process is carried out in the Agramkow machine.

Operation of R290 reception and storage

The supply of the R290 gas is carried out by an external supplier named Amuco. It is a cargo handling operation in wooden pallets with packs of cardboard boxes; LPG metal cylinders at 140 PSI, with a 0.10m3 volume, containing 12.1 kg Pounds/5.5kg are received.

Fig. 1. External Storage of R290

The packaging of refrigerants is made of wooden pallets to make cylinder plies that can reach a 2.5-meter height.

Although R290 will be stored outside the plant area, a successful storage operation requires taking into account the special considerations to be fulfilled by the occupancy. In addition to the considerations on fire protection, namely, having smoke detection systems, air analyzers, automatic water mist sprinklers for the application of water spray and CO2 injection, it is very important that they meet special characteristics in the occupancy such as keeping the area clear at all times, very good ventilation, the construction should preferably have non-combustible and fire-resistant characteristics and be equipped with fire doors.

All staff in charge of the R290 cylinders must know their physicochemical characteristics and how to respond to an emergency event. Unlike storage systems in large-volume cylinders in bulk, these cylinders are filled with 12.1 lb. of Propane and are not reusable; this condition does not exempt the plant from having the resources and equipment necessary for the brigade members to control an uncontrolled leak of propane at a given time.

The most frequent failures in the handling and storage of cylinders usually are:

Cylinders are stored in the corridors or circulation areas and common areas. Cylinders are not anchored and missing the corresponding safety caps. Some outputs or connections to equipment have faults or bends in their path. Cylinders are transported unsafely by dragging or

rolling them on the ground; safety trolleys are not used for this purpose. (See recommendations).

Piping and transfer systems.

Basically, there is no internal transfer system for the R290, which substantially reduces the risk of leakage by hitting a pipe system. Gas arrives in cylinders in the form of liquefied gas and they are manually moved to the cargo area; there is a tandem system or 4-cylinder cabinet. The internal equipment of the refrigerant loading machine has a flexible duct system that feeds a pneumatic pump and finally arrives at the refrigerant charger. The transport of refrigerant gas cylinders must be performed with wheelbarrows equipped with chains and locks, only to be handled by qualified personnel trained by Thermotar (see recommendations). There is a cabinet where 4 cylinders are installed simultaneously at the recharge site or R290 production line; the observed cylinders with a metal body of approximately 12.1lb of R290 gas were properly fastened.

Fig. 2. R290 Cylinder Manifold

At present and during our visit we were informed that the storage of these cylinders will be moved or relocated to another area of the plant located in a mezzanine nearer the 290 production line in order to shorten the path and reduce the risks of cylinder transport to the production line.

Under the NFPA standards, it is advisable for storage operations that the cylinders be stored in well ventilated spaces, protected from the sun, water, humidity and corrosive environments.

The cylinder storage area must remain free from flammable, volatile substances and highly combustible materials. It must be located in a special place, signposted and far from areas of flammable product storage. Mark cylinder deposits with appropriate diamond warnings of the NFPA DOT such as: “R290 Propane Gas", "R290", "Empty Cylinders", "Full Cylinders", "Compressed Gases" (see recommendations).

During the storage, transport and use of the cylinders, they must remain in vertical position and be secured with chains or other suitable means to prevent them from falling. Empty cylinders must be stored separately from filled cylinders to avoid damage such as the damage caused when an empty cylinder is connected to a pressurized system. Use the first in, first out inventory system to avoid storing cylinders for long periods of time. Check that every cylinder which is not in use has the cap or lid on. The confined areas for cylinder storage must be covered and have good ventilation. Store product batches vertically. Do not store in heavy traffic areas (corridors) to prevent them from being hit or damaged. The cylinders of other oxidizing gases must be in areas separated from R290 storage areas.

Whenever possible, oxygen cylinders at the plant (if any) should be stored separately from those containing R290 or at a minimum distance of 7.5 meters. Gas cylinders must be kept away from any danger of spark, molten metal, open flames or any source of excessive heat. It is dangerous to smoke or use open flames in cylinder deposits. Visible notices must be posted prohibiting such practices. To store large quantities of cylinders of flammable gases, the storage place must be insulated by walls made of non-combustible and fire-resistant materials, with emergency exits. (See recommendations).

R290 Charge 10

R290 gas handling inside the plant occurs during the gas charging process performed in the 290 production line; this is a charging operation on the refrigeration units manufactured there. It is an operation based on the Agramkow charging machine. This system connects 4 simultaneous cylinders where the filling process is controlled through an automatic system. The cylinders are connected manually; there is a manifold where the cylinders are connected and the refrigerant gas goes to a pump that transports the gas through hoses to the charging machine, which controls -automatically by weight control- the amount of refrigerant to be used to charge each produced unit. The R290 charging

site is a confined space, with a metal structure and other acrylic materials.

Fig. 3. R290 Pump

The R290 production line has a series of special protections to determine the presence of R290 in the air, as well as a two-speed air movement system to be able to renew the air inside the cargo area. During our visit we observed that the R290 charging room has a single air analyzer sensor, which constantly monitors the gas PPM surrounding the place; this sensor depends on the activation of the ventilation system for air renewal.

We suggest having a backup system with at least one additional sensor to be able to compare signals in order to avoid false triggering either caused by decalibration or sensor failure. Under the current conditions, in case the only sensor of the system decalibrates or breaks down completely, it would not be possible to detect the presence of gas in the enclosure, a compelling reason for the implementation of these sensors (see recommendations).

Cabin and surrounding risks

The R290 recharging site observed in this process is an enclosed space where the Agramkow machine is located. As we mentioned previously, any enclosure with space or natural ventilation limitations will require forced draft ventilation systems. In our case, the enclosure of the R290 line has an automatic filling system equipped

with an air analyzer sensor for constant analysis of the gas PPM that may be in the air, this system is interlocked to a forced ventilation system that operates with two speed levels set by the air analyzer sensor. The potential places for a leak are the filling tandem the R290 line, in which there may be a leakage in the nipples and hoses. A malfunction may also occur in the gas filling system causing an accidental leak in a cylinder or the 4 cylinders simultaneously. According to the NFPA 55 standard, the risks associated to R290 release in gaseous form are fire and explosion; in case of a gas leak in liquid state caused by the low temperatures reached, they may weaken significantly and produce weakening when coming into contact with carbon steel materials.

In our case, the R290 refrigerant gas charging enclosure must be thoroughly evaluated. Under the NFPA 70 Electrical Installations Standard, the areas exposed to explosion risk must have electrical explosion-proof connections and this area must be classified as a high-risk area, consequently electrical outlets, cables, lighting systems, and other electrical devices must be explosion proof. This must be validated with a specialist electrical installation firm if the R290 equipment or filling machine manufacturer does not guarantee or specify that its components and other peripheral equipment powered by electric supply are explosion proof.

Fig. 4. R290 Cabin

Another risk that must be mitigated or considered is the risk of accidental release of R290 in either state, liquid or gaseous; we have mentioned that the greatest exposure in liquid state is direct contact with carbon steel materials due to the low

temperatures that may be reached. It is already known that the gaseous state represents a high risk of fire and explosion.

The filling machine has a gas analyzer detection system consisting of a single sensor. In our view, we consider that this device alone has no backup, leaving the area unprotected in case of failure or decalibration. For this reason, we suggest having a backup air analyzer system consisting of at least two additional sensors, which may be the same type supplied by the manufacturer or any other type of sensors providing the same service. Smoke and/or heat sensors are convenient for this area, as well as the cylinder storage area and any area used for cargo storage. These recommendations will be specified in the recommendations chapter. In the other form of exposure, which is accidental spill in liquid state, direct contact with metal structures should be avoided; this must be analyzed at the new storage location since the filling cabin of the R290 line is located on concrete floors.

By observing the surrounding exposures, we noticed that there are storage operations in cardboard boxes and piles of wooden pallets around this filling cabin, which pose a high risk of fire propagation to the refrigerant cargo cabin. In addition to this risk, which is deemed to be very serious, the welding operations performed a few meters from the cabin should also be considered; we have prepared a recommendation on the minimum distance between hot works and the closest structure.

Fig. 5. Inside view of the R290 Cabin

Fig. 6. Hot works site

IV. Impact and frequency analysis

Our risk matrices are presented below in order to quantify and prioritize risks. The essential goals of risk management companies include determining the most significant risks that occur or can be identified, regardless of their characteristics; a second goal is to assess those risks, that is, identifying how likely they are to occur and their level of impact in case they actually occur; and a third and final goal is to determine the treatment for those specific risks, that is to say, the path to be followed through a loss control program or risk reduction program. A second path to be taken as risk treatment is to transfer it or generate sufficient funds for a recovery in case of an accident.

We present a risk map of the process below in order to address the risk identification stage for the implementation of this new technology, and we also present the corresponding probability of occurrence scales and impact level applied to each risk —and therefore to each stage of the R290 charging process— to assess such risks.

Risk Analysis and Methodology

The risk assessment of the R290-line production process was initially developed with the information provided by Industrias Thermotar; this stage was carried out in meetings with key personnel with extensive knowledge of the R290 project, followed by a field inspection to identify the risk conditions in this new implementation. This analysis was developed by dividing the production process of the R290 charge from the receipt of cylinders as raw material to the charging process. Next, we show the process partitions used in our analysis.

- **Operation of R290 Receipt and Storage**
- **R290 recharge process and transfer systems**
- **Risks due to environmental conditions or surrounding risks**

Risk Classification

The Frequency and Severity (or Probability and Impact) scores were used to classify the identified risks. A 4x4 matrix was designed based on these scales.

Risk severity was classified based on 5 types of impacts: People, Property, Operation, Environment and Image. The Severity (Impact) score was defined as follows:

IMPACT ON PEOPLE		
SEVERITY	DEFINITION	POINTS
NEGLIGIBLE	No injuries or injuries not requiring hospital care	1
MARGINAL	Minor injuries that require medical care or a health care professional.	2
CRITICAL	Serious injuries requiring a heath care center Hospital care and/or temporary leave.	3
CATASTROPHIC	Disability and/or Death	4

IMPACTS ON PROPERTY (material); M = millions of Colombian pesos.		
SEVERITY	DEFINITION	POINTS
NEGLIGIBLE	Low Cost (0 – 5 M)	1
MARGINAL	Moderate cost (5 - 25M)	2
CRITICAL	High cost (30 - 100M)	3
CATASTROPHIC	Several high-cost losses simultaneously (P > 100M)	4

IMPACTS ON THE OPERATION		
SEVERITY	DEFINITION	POINTS
NEGLIGIBLE	The operation is not suspended for more than 4 hours	1
MARGINAL	The operation is not suspended for more than 12 hours	2
CRITICAL	The operation is suspended up to 7 days	3
CATASTROPHIC	The operation is suspended for more than a week	4

IMPACTS ON THE ENVIRONMENT		
SEVERITY	DEFINITION	POINTS
NEGLIGIBLE	By using easy-application or low-cost elements and/or treatments, it is possible to exercise control over the impact; the consequences are mild and resources recover quickly.	1
MARGINAL	It is necessary to apply primary treatment, the recovery of resources is slow and gradual.	2
CRITICAL	Secondary treatments are required; these are expensive and their technology is hard to apply. The impacts on resources are devastating and lasting	3
CATASTROPHIC	The impact generated makes recovery difficult and long lasting, it is necessary to apply tertiary treatments. In some cases, the recovery of resources is not possible.	4

IMPACTS ON THE IMAGE		
SEVERITY	**DEFINITION**	**POINTS**
NEGLIGIBLE	- Internal dissemination (process, work team), meaning it does not leave the company. - Concerns from co-workers/partner companies	1
MARGINAL	- Adverse coverage widely spread in local, regional or national media - Concerns from stakeholders - Requirements or investigation open by the regulatory body	2
CRITICAL	- Adverse coverage widely spread in local, regional or national media - Serious or clear reduction of support or credibility from some stakeholders - Suspension of licenses and/or permits that slows down the operation, but does not stop it.	3
CATASTROPHIC	- Serious or clear reduction of support or credibility from all stakeholders - Suspension of licenses and/or permits that temporarily block (less than 30 days) the performance of operations	4

The frequency score was defined as follows:

FREQUENCY		
POINTS	**DESCRIPTOR**	**DEFINITION**
4	Frequent	An event that repeats somehow regularly
3	Moderately Likely	The event may occur under certain circumstances or occurs sporadically
2	Unlikely	The event is not regular, but may occur at some point
1	Rare	The event can only occur under exceptional circumstances

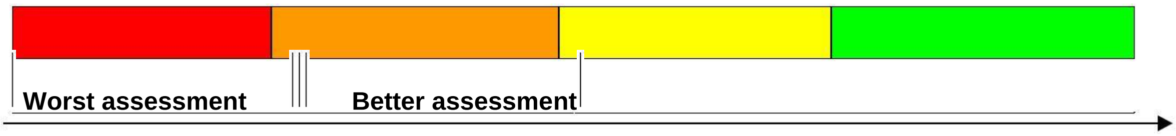
Risk Matrix

Once a Frequency and Severity risk score has been assigned, it is graphed in the Risk Assessment Matrix. This indicates the risk severity and thus allows classifying the such risk.

It should be noted that although the impact of some risks is high they are not necessarily the most significant risks, since the probability is low and, therefore, the actual level of risk is not as high as it might be expected.

The opposite situation also occurs. A high frequency of incidents with slightly moderate impacts such as persistent accidents that cause disability will turn these risks into significant risks.

	IMPACT			
PROBABILITY	Negligible 1	Marginal 2	Critical 3	Catastrophic 4
Frequent 4	HR	ER	ER	ER
Moderately Likely 3	MR	HR	ER	ER
Unlikely 2	LR	MR	HR	ER
Rare 1	LR	LR	MR	HR



The color scale is classified as follows:

ER	EXTREME RISK
HR	HIGH RISK
MR	MODERATE RISK
LR	LOW RISK

Extreme Risk: It must be reported to the directors and constantly monitored.

High Risk: The attention of the CEO/executive director and general manager is required.

Moderate Risk: requires proper monitoring by the medium levels of direction.

Low Risk: Requires monitoring by the supervision level.

1. Operation of R290 reception and storage.

The supply of R290 gas is performed by an external supplier. It is a cylinder reception operation in wooden pallets with packs of cardboard boxes; 12.1 kg LPG metal cylinders are received. All the cargo is handled with wooden pallets and forklifts. This storage operation is performed at a site outside the plant.

Severity analysis

Operation of R290 refrigerant reception and storage.							
No.	**IDENTIFIED RISKS**	**Person**	**Property**	**Operation**	**Environment**	**Image**	**AVERAGE SEVERITY**
1	Warehouse fire/BLEVE	3	2	1	2	2	2
2	Fire at adjacent R290 line	3	3	3	2	2	3
3	Gas release (no explosion)	2	2	1	0	0	1
4	Explosion by accumulation of gases	3	3	2	2	2	3
5	LPG spillage	1	2	1	0	0	1
6	Hitting, accidents caused by forklifts at the warehouse	3	2	1	0	0	2

Frequency Analysis

In our frequency analysis we considered a fire event in the warehouse as an unlikely event, that is, an unusual event that may occur at some point with a probability of occurrence 2; a gas release is considered a more likely event than the former and may occur under certain circumstances or sporadically with a probability of occurrence 3. An explosion is an event that is not usual, but could occur at a given time; we classify it as an event of probability 2. The event of an accidental spillage of LPG is an event we consider may rarely occur; we classify it with frequency of occurrence 1. Finally, we consider the cylinders hit by forklifts as an event that happens sporadically and is not usual, we have classified it as frequency 2.

Operation of R290 Refrigerant Reception and Storage.			
No.	**IDENTIFIED RISKS**	**FREQUENCY**	**AVERAGE SEVERITY**
1	Fire in an external warehouse/BLEVE	2	2

2	Minor storage fire adjacent to the line R290	2	3
3	Gas release in the plant area/externally (no explosion)	3	1
4	Explosion by gas accumulation in the plant area	2	3
5	LPG spillage	1	1
6	Hitting, accidents caused by warehouse forklifts	3	2

Risk Classification

	IMPACT			
PROBABILITY	Negligible 1	Marginal 2	Critical 3	Catastrophic 4
Frequent 4				
Moderately Likely 3	3	6		
Unlikely 2		1	2, 4	
Rare 1	5			

Since the R290 storage operation takes place outside the property, we consider that the impact of a fire event risk (1) is substantially reduced for both the property and the operation. A fire in the external warehouse could cause damages to third parties at a certain point and the company may face civil responsibility claims, but it does impact the property whatsoever, it may harm the company reputation. Under Risk (2), which is a fire in secondary storage caused by the low fuel charge of this secondary operation, an outbreak of fire may be controlled, discarding a possible propagation; if a fire is not controlled within its incipient stage, a BLEVE may occur with severe impacts on the operation, people and property.

In addition to this risk, two risks form the high-risk area are observed, namely risks 4 and 6, which are explosion by accumulation of gases and accidents by forklift hits; analyzing the risk by explosion, this risk can lead to serious injuries and loss of human lives, it may cause a sequential fire with some degree of uncertainty depending on the magnitude of the explosion and environmental conditions. The environmental damage of an explosion is minimal, but causes severe harm to the company's reputation and a potential partial stoppage of processes.

In risk (6) which is the risk of accidental hits of cylinders, it is observed that this type of event could result in severe damage for people, even leading to death; it has no significant impacts on property damage.

Unless a blow causes a tank to crack and triggers an explosion or sends a projectile that could seriously damage some expensive equipment, no impact on productive equipment is considered, assuming that this occurs in the storage area. No potential environmental damages are observed for this risk, nor any impacts to the reputation of the company.

We wrap up with the risks (3 and 5), which are accidental gas leaks and spill of R290 in liquid state. The impacts of accidental gas leaks on people are severe due to possible asphyxiation depending on the place of the plant where this event occurs. The operation of the protections in place at the R290 charging line are also involved. The event of an accidental gas leakage causes severe damage on property if an explosion with consequential fire occurs. No damage to the reputation of property and damage to the environment are observed; no severe damage to the integrity of the operation is observed, unless this event triggers in a fire. The risk of accidental R290 spillages is a risk with very low probability of occurrence; it poses severe risks to property and no serious injuries to people considering that it is not consumed and there is no contact with the liquid; it does not cause any damages to property unless it starts a fire; neither impacts on the company's reputation nor severe environmental damages are observed.

2. R290 recharge and transfer systems

Gas arrives in cylinders that are manually transferred to the recharging area. There is a tandem system with a 4-cylinder manifold. The internal equipment of the refrigerant charging machine has a hose system with flexible ducts that feeds a pneumatic pump and finally reaches the refrigerant charger.

Severity analysis

R290 recharge and transfer systems							
No.	**IDENTIFIED RISKS**	**Person**	**Property**	**Operation**	**Environment**	**Image**	**AVERAGE SEVERITY**
1	Fire in a R290 cabin	3	3	3	2	2	3
2	Gas release in the R290 cabin	3	1	3	0	0	2
3	Explosion in the R290 cabin	4	2	4	2	2	3
4	LPG spillage in the R290 Cabin	1	1	1	0	0	1

Frequency Analysis

In our frequency analysis we considered a fire event in the R290 charging cabin as an unlikely event, that is, an unusual event that may occur at some point with a probability of occurrence 2; a gas release is considered a more likely event than the former and may occur under certain circumstances or sporadically with a probability of occurrence 3. An explosion by gas accumulation inside the R290 line is an unusual event, but it may occur at a given time; we classify it as an event of probability 2. The accidental LPG spillage is considered as an event with rare probability of occurrence; it is rated under frequency of occurrence 1.

R290 recharge and transfer systems			
No.	IDENTIFIED RISKS	FREQUENCY	AVERAGE SEVERITY
1	Fire in the R290 cabin	2	3
2	Gas release in the R290 cabin	3	2
3	Explosion by gas accumulation in the R290 cabin	2	3
4	LPG spillage the R290 cabin	1	1

Risk Classification

	IMPACT			
PROBABILITY	Negligible 1	Marginal 2	Critical 3	Catastrophic 4
Frequent 4				
Moderately Likely 3		2		
Unlikely 2			1.3	
Rare 1	4			

We can observe in our risk matrix that risks (1, 2 and 3) are in the high-risk zone. The event with greatest impact on the refrigerant charging process is a fire risk (Risk 1) inside the

R290 cabin, considering that the fuel load is well below the fuel load stored in the storage warehouse. The impacts on property have a lower rating. This type of event would partially impact the continuity of the business and/or operation, mostly on the R290 line; if the fire is not controlled, the fire could spread to other structures. However, a fire event exclusively confined to the line R290 would have severe impact on the occupants, even causing death. If the fire does not reach other structures, there is minimal risk for the company's reputation and environmental impacts.

The most severe impact observed in the risk of gas release (risk 2) in the R290 line would be a subsequent explosion and sequential fire. It would be highly critical for the operation of the R290 line, since the process would stop indefinitely. If there is no explosion, neither severe damage to the occupants nor severe damage to the environment or the company's image are expected.

The risk of explosion (risk 3) corresponds to one of the most severe events for line R290; an explosion in the R290 cabin would mean the total loss of equipment and would harm the occupants considerably, causing serious injuries and even death. If an explosion occurs without a sequential fire, damage would not impact the entire property, as expected from an uncontrolled fire event. An explosion event in the R290 line would not cause serious damage to the environment, but there are moderate impacts on the company's image and/or reputation.

No severe impacts on property are expected under the risk of accidental spillage of LPG (risk 4), as there are relatively low tanks or leaks; severe impacts to the recharging operation are not expected either, unless there is a violent leak or behavior of the gas cylinders. If this occurs, the equipment of the R290 line may suffer partial damage, ruling out the total loss. The impacts on the occupants are discarded considering that the cylinders are housed inside a cabinet and the event of release of dangerous projectiles is discarded. Neither environmental damages nor company image damages are observed.

3. Risks around the R290 chamber

During our visit to the facilities, we observed that the surrounding risks are impacts caused by fire, water damages and structural damages caused by the collapse of the structural roofing.

Severity analysis

Surrounding Risks							
No.	IDENTIFIED RISKS	Person	Property	Operation	Environment	Image	AVERAGE SEVERITY
1	Fire	4	4	3	2	2	3
2	Damages caused by water and/or structural damages	4	2	3	1	1	2

Frequency Analysis

In our frequency analysis, we consider a fire event adjacent to the R290 recharging line as an unlikely event, that is, it is an unusual event, but it could occur at some point causing severe damage to the entire property; it was rated with a probability of occurrence 2. Damage caused by water or collapsing structural roofing is more likely than the former event. It may occur under some circumstances or sporadically; it was rated with a probability of occurrence 3.

Surrounding Risks			
No.	IDENTIFIED RISKS	FREQUENCY	AVERAGE SEVERITY
1	Fire	2	3
2	Damages caused by water or collapse of the main roofing	3	2

Risk Classification

	IMPACT			
PROBABILITY	Negligible 1	Marginal 2	Critical 3	Catastrophic 4
Frequent 4				
Moderately Likely 3		2		
Unlikely 2			1	
Rare 1				

This analysis shows that risks focus on the high-risk area with different probabilities of occurrence, as well as, different levels of impact.

The risk of fire (risk 1) has a high level of impact on property and the production process of the entire R290 line; an adjacent fire is likely to cause the total loss of this production line; considering the impact on people, a fire adjacent to the R290 line can have serious impacts on the occupants, with a highly negative impact on the company's reputation and environmental damages due to the high release of combustion gases. The risk of water damage or structural damage is an event we rated as an average severity level 2, since a structural collapse is likely to be less harmful than a fire, not ignoring that a partial interruption of the productive process may occur; the impacts or injuries suffered by people can be severe as heavy elements fall from the roof. No reputation or environmental damage is observed in this event.

Under the risk matrices of our study, the results show that there are several risks with the same degree of severity and the same level of impact. From any perspective, the risk of fire in the process area -as a risk adjacent to the R290 recharging chamber- has the greatest severity due to the possible consequences not only affecting the R290 line but the entire productive process of the company. It must be taken into account that the risk of fire as an adjacent risk to the R290 line is simply a fire in any area of the plant that must be treated as a risk inherent to the type of process and materials in the productive process, that is, the risk of fire will always exist if there is no R290 line.

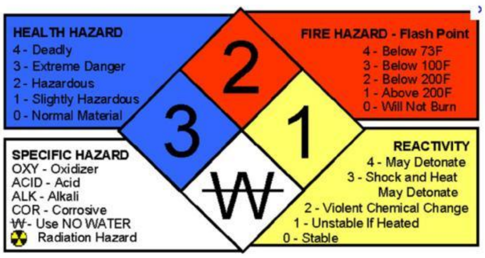
V. Recommendations for Improvement

The following are our recommendations to improve LPG R290 operations.

[2018-001]			[Fire Protection Systems in the Storage Warehouse]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	High investment
Description	During our tour in the storage warehouse for Refrigerant Gases and equipment parts located at the basement of the spare part warehouse, we observed that this company area has a single extinguisher as the only resource to respond to fire emergencies. Under the current conditions there is no way to control or detect a fire in its incipient stage. Although the electrical connections observed inside the warehouse were in good condition, the occurrence of short circuits or failure of other elements powered by electrical energy such as lights and/or outlets is not ruled out. Considering the high fuel load in this site, we recommend hiring a specialist firm for the correct selection and assembly of an automatic extinguishing system, a smoke detection system. 		
Customer response	Pending		

[2018-002]			[NFPA diamond signs in the storage area]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure
Description	Considering that one of the steps to be taken into account in the occupancy emergency plans for hazardous material storage areas, in this case R290 LPG, is to identify substances involved in emergency situations, this identification is achieved by means of labeling at the facilities. NFPA recommends placing DOT or NFPA labels near the storage area. The DOT labels are mandatory for mobile devices and NFPA labels are mandatory for stationary devices or storage areas. In our case, this label may be on the internal walls of the basement or in a visible area. The following are two examples of these labels: first DOT and second NFPA 704.		
customer response	Pending		

DOT Square



NFPA Square

[2018-003]			[Good Storage Practices]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure
Description	During our visit to the warehouse basement we observed some loose R290 refrigerant cylinders without retaining chain; we also noticed that the storage areas and corridors for forklifts and occupants inside the basement were not observed. We recommend marking the storage areas and avoiding blocking traffic areas with merchandize in order to improve this situation. Under the current conditions, the exit of occupants would be difficult, as well as, using the only extinguisher, which is blocked. Additionally, this would obstruct the access of brigades and the fire department to fight a fire. Considering that order and cleanliness is the main strategy to be followed as a preventive measure, we recommend improving the conditions within the storage warehouse. The following is a		

[2018-003]		[Good Storage Practices]
	photo showing the current condition of the warehouse and a sample of correct marking and traffic areas for occupants.  	
Customer response	Pending	

[2018-004]			[Anti-shock protection for R290 gas storage]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Moderate investment
Description	During our visit we observed that the different piles of refrigerant gases have no anti-shock protection from hitting that may be caused by forklifts. Since		

[2018-004]	[Anti-Shock Protection for R290 Gas Storage]
	hitting is undesirable in this type of operations, we recommend installing protection barriers at the site where R290 cylinders are piled up. The following photo shows the current situation and an example of anti-shock protection barriers.  
Customer response	**Pending**

[2018-005]			[Construction Features of Storage]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	High investment
Description	We were told that the company has a future project of a new storage area exclusively for R290 compressed gas cylinders. The matters to be considered to implement such project successfully are: first, the site must have a ventilation system to prevent gas concentration, explosive atmospheres and asphyxiation risk for occupants; second, as the R290 is a flammable substance being stored, this area must be considered a classified area, electrical devices such as connections, lamps and outlets must be explosion proof; third, it is advisable for the area to be isolated from fire, in order to mitigate the risk of fire propagation, it is advisable to build fire walls and doors; finally, this site must have automatic smoke detection systems, air analyzers and automatic extinguishing systems.		
Customer response			

[2018-006]			[Classification of NFPA 70 Areas]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure
Description	During our visit to the facilities we observed that the storage areas and the R290 recharging cabin are areas exposed to the formation of explosive atmospheres as they are potential sites for gas leaks. The NFPA 70 establishes that high-risk areas must be special classified areas, which must have explosion-proof connections, lamps, outlets. Consequently, we recommend hiring a specialist electrical installations firm to perform a study of area classification to implement the relevant modifications and have available explosion-proof equipment in these areas.		
Customer response	Pending		

[2018-007]			[Lights of the R290 Recharging Cabin]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure

[2018-007]		[Lights of the R290 Recharging Cabin]
Description	During our visit we evidenced that two of the three lamps inside the R290 refrigerant cabin are not explosion proof. To mitigate the risk of explosion we recommend hiring a specialist Electrical installations firm to install the explosion-proof lamps. This procedure complies with the requirements of the NFPA 70, electrical code related to areas classified as high-risk areas. The following is an example of a lamp listed by UL to be implemented in areas under high-risk of explosion. 	
Customer Response	Pending	

[2018-008]			[Detection System]
Status	Open	**Status date**	21/01/2018
Priority	N/A	**Type**	High investment
Description	During our tour in the facilities we observed that there is no system for early fire detection in the storage warehouse and the R290 recharging cabin. According to the NFPA, The fire detection system is required to start the response actions, automatic or manual extinction. Considering the location and present elements such as electrical energy and R290, it is necessary to implement early detection systems for potential fires that may break out. Regardless of the type of detection system selected (smoke detectors, heat detectors, etc.), it is important to perform a practical assessment of the response time consequences after a fire has been detected and before lethal or high-risk conditions develop in this area. Therefore, we recommend hiring a specialist fire protection firm to install a detection system appropriately under the NFPA 72 recommendations for these two occupancies.		
Customer response	Pending		

[2018-009]			[Fastening Cylinders]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure
Description	During our visit to the R290 recharging chamber, we observed a Helium cylinder, which is used to test refrigeration units. This cylinder had no safety chains. Under these conditions the cylinder may be hit and fall, its valve may be damaged and the cylinder may become a very dangerous projectile against occupants and the plant integrity. We recommend fastening this cylinder and every other plant cylinder with safety chains to mitigate this risk. 		
Customer response	Pending		

[2018-010]			[Backup Sensors]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Moderate investment
Description	During our visit we evidenced that the R290 recharging chamber has only one gas detector. This cabin has no backup Sensor, leaving the area unprotected in case the only available		

[2018-010]		[Backup Sensors]
	sensor decalibrates or is damaged by hitting or electrical problems. Many factors may cause a failure in the only available sensor, in which case it would not be possible to detect the formation of explosive atmospheres. We recommend hiring a specialist firm or contacting the same supplier to have a second air-analyzer sensor installed as backup. 	
Customer response	Pending	

Matters to be addressed

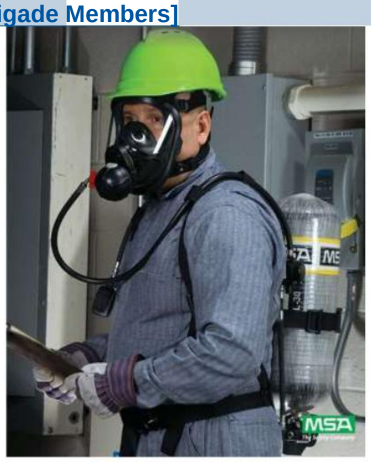
The following are recommendations on matters to be addressed and matters related to proper equipment for R290 emergency responses.

[2018-012]			[Lighting and Exits]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure
Description	The storage warehouse where the R290 gas is located requires Emergency lights and additional exit points to ensure that the occupants can evacuate quickly. It is advisable to have Lighting with wall-mounted lights with enough light intensity not to be dimmed by smoke that may be generated during a fire. NFPA 101 requires an additional emergency source using power independently from the normal plant power service. This is how the necessary lighting can be provided in case of a power outage during an emergency. Thus, we recommend hiring a specialist electrical installations firm for an appropriate		

[2018-012]	[Lighting and Exits]
	installation of emergent lights in the warehouse basement and the exit corridors with capacity no less than 11 lux per square meter.

Customer response	Pending

[2018-013]			[PPE for Brigade Members]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure
Description	In occupancies that store substances such as R290 gas, emergency situations may occur at some point and the environmental conditions will require the use of special self-contained equipment. Resources and personal protection equipment are one of the most important aspects for proper response to emergencies in a fire-fighting organization. Considering the size of the exposed occupancy, the lack of internal fire division walls that prevent fire from expanding, and the variety of toxic combustible products that may be generated in a fire, we recommend acquiring specialized personal protection equipment for fire-fighting such as self-contained equipment.		

[2018-013]	[PPE for Brigade Members]
	 
Customer response	Pending

[2018-014]			[Risks Surrounding The R290 Line]
Status	Open	Status date	21/01/2018
Priority	N/A	Type	Important procedure
Description	We observed during our visit that finished products are stored around the R290 recharging chamber not keeping the minimum distances required by good manufacturing practices. We recommend not to store finished products near the R290 recharging line and keep a minimum distance of 5 meters in order to mitigate the risk of fire propagation. 		
Customer response	Pending		

[2018-015]			[Minimum Distances under NFPA 51B]
Status	**Open**	**Status date**	**21/01/2018**
Priority	**N/A**	**Type**	**Important procedure**
Description	**We noticed during our visit that welding operations are performed near the recharging cabin using blowtorches on the refrigeration units; this represents a high risk of fire. We recommend verifying the minimum distance established by the NFPA 51B standard, which is the minimum distance a structure must keep from hot works. For information purposes only, we attached this standard as an annex to this report.**		

Safety measures required by the hot work permit
11m (35ft) rule.

- All combustible and flammable material within an 11m (35ft) range from the hot work area must be removed.
- If combustible or flammable products cannot be moved within an 11m (35ft) radius, they must be covered with fire-resistant blankets and a fire supervisor must be appointed during the task (fire watch).
- Floors and all surfaces within the 11m (35ft) radius must be swept to remove dust and other combustibles from the ground.
- All orifices and cracks on the walls, floors or ducts such as drains or similar paths that may transport incandescent material (sparkles) vertically must be covered and protected.

Fire detection and suppression

- There must be portable extinguishers available in the hot work area.
- The alarm and detection systems of the facilities must not be disabled. However, detectors in the hot work area can be TEMPORARILY covered to prevent false alarms and uncovered after the job is completed.
- If automatic sprinklers are installed, they cannot be disabled for hot work. However, the sprinkler heads at the hot work area can be covered using wet cloths to prevent accidental triggering and uncovered after the authorized job is completed.

The following figures show the 11m (35ft) rule and some of the recommendations presented above.

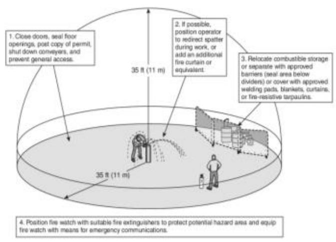


FIGURE A.5.5.1(1)(a) The 35 Foot Rule Illustrated.

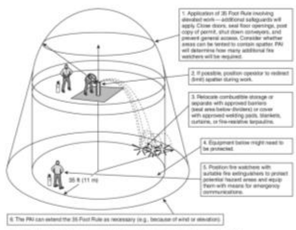


FIGURE A.5.5.1(1)(b) Example of Where Multiple Fire Watches Are Needed.

Customer response	**Pending**

IV. Emergency Plan 44

Emergency response plan

The control measures for emergency response will depend on the type of substance involved in each event or emergency. In our case, R290 has two main types of impacts: impacts on people and impacts on property. Flammable gases such as R290 pose a risk of igniting and possibly exploding. Gas fires create thermal hazards for people or property (emergencies with fire), and if gas containers are exposed to these fires, they may fail and suffer a BLEVE; this type of risk is clearly identified in the cylinder storage area.

Security Measures against Explosions by Combustion

The safety measures to prevent explosions by combustion are designed to delimit the accumulation of gas and air mixtures inside the buildings. The basic measures to mitigate this risk are the use of equipment or control volumes to minimize as much as possible the possibility of leaks, the release of minimum quantities of gas from gas charging devices, or other control volumes existing within a productive process; in our case, the control volumes are the LPG cylinders, recharge unit, Agramkow accessories and refrigerators.

One of the measures for detecting gas leaks is to add odors to facilitate the leak detection; in general, these odors are sometimes unpleasant. In our case, the R290 used at the Thermotar plant is an odorless gas, which makes it more difficult to detect a leak at any given time. It is not convenient to limit yourself to this type of detection because the added odors are to be detected by the smell sense of the occupants, which may lose their acuity at any given time due to several reasons such as their health condition, prolonged exposure to this odor, and sometimes insufficient odor concentration to be detected.

Although this is an effective control measure, the addition of odors has limitations; the functional detector, in this case the human sense, is not always present, for example, when there are no personnel in the facilities or the gas is odorless due to functionality requirements. The ventilation systems of buildings are another limitation to identify gas leaks; they do not allow the odor concentrations to form for identification, it is therefore necessary to implement detectors and/or ppm analyzers for a correct analysis of the presence of combustible flammable gas in the air.

To control ignition sources, it is essential to implement the restriction of ignition sources such as no smoking in the facilities and ensuring that electrical connections are in good condition, according to the classification of areas by level of criticality established by the NFPA 70. In our case, we have suggested the implementation of air-analyzer detectors equipped with smoke detectors in the R290 cylinder storage areas. We have also suggested the installation of a PPM gas detection device or air analyzer inside the R290 recharging cabin.

It is essential for Industrias Thermotar staff to establish and implement an emergency response program to face and mitigate all the risks associated with the presence of R290 in the facilities.

Effective handling of a hazardous substance such as R290 LPG requires prevention, training, response and recovery activities.

The purpose of any emergency plan is to change the sequence of events that lead to the emergency before it follows its natural course and minimize the damage that might otherwise occur. Although there is no single structure to develop an emergency plan, this time we have relied on the structure recommended by the NFPA and included additional comments about the information provided.

The following four steps must be performed to achieve the main purpose of an emergency plan.

1. To analyze the problem
2. To plan a response
3. To implement the planned response
4. To evaluate it as required

To Analyze the Problem

The following phases must be completed to achieve an adequate process of substance analysis such as R290:

- Detecting the presence of flammable materials: This task is going to be skipped, since Industrias Thermotar is aware of the presence of R290 LPG inside the facilities. This task includes the search for marks and colors in the facilities and forms of interaction with the R290 gas. The type of process has helped to define the presence of R290 in the storage area, R290 charging line and refrigeration equipment where the quantities are relatively small. All boxes and R290 package forms have

flammable substance diamond signs. The greatest risk posed by the presence of flammable materials is the risk of fire and subsequent explosion. This risk can be considered as an explosion by combustion, where an explosive quantity of flammable gas and air mixture does not accumulate because the mixture burns very quickly, and there is no enclosing structure. As it might be expected, when a flammable gas escapes to the outside, there is a greater chance of a fire than an explosion. If a massive leak occurs, the air or surrounding buildings may form a sufficient containment to produce a type of explosion by combustion known as free-air explosion or space explosion. Liquefied gases such as R290, Hydrogen, Ethylene, etc., which have a high flame speed, are exposed to this phenomenon.

- Starting Command and Control Activities: Although these activities are not part of the analysis, they must start automatically when an incident is reported. The specific command and control procedures must be included in the local Thermotar response plan or the standard operating procedures of the organization. The main command and control functions are to notify about the resources required to handle the situation, place the personnel at a safe distance from the problem and control access to the incident site. This task is a vital part of the company's emergency brigade.

- Controlling emergencies without a fire: In this form of control the gas must be considered, directed, diluted and/or dispensed to avoid contact with people, preventing gas infiltration into the facilities. In our case, the recharging chamber has a 2-speed ventilation system depending on the gas concentration observed inside the cabin; however, there is no ventilation or detection system for the storage process. Liquefied gases such as R290 have a visible indicator for location; the cooling effect of their vaporization condenses the water vapor of the refrigerant producing a visible fog.

- Controlling emergencies with a fire: the control of emergencies with a fire is based on fire control by applying water, while the gas flow is interrupted, if possible. Many gas fires can be extinguished with CO2, dry chemical powder and halogen agents. Water can be applied through hose stream, automatic water mist sprinklers. The combination of water application systems requires a special study in the design of the fire protection system. In our case, there is a clear risk of BLEVE.

- Inspecting the incident: After detecting the presence of a flammable substance during and emergency and while command and control activities

are initiated, the next task is to evaluate the incident. This is achieved through an inspection that must be performed from a safe position, using visual equipment to avoid exposure to the materials involved as much as possible. This inspection will determine how serious (impact level) the incident is. When incidents with hazardous materials are evaluated, the surrounding conditions must be observed. These conditions include topography, land use, access roads, weather conditions, bodies of water, the potential for exposure to the public and nature. In our case, if the incident happens inside the process plant, we must look for information about floor drains, ventilation systems, return air systems, etc. This task will be in charge of the OSHA department and Brigade Members.

- Gathering and Interpreting Information on Risk and Response. Once the flammable substance has been identified, information is gathered about its risks (already known), behavioral characteristics and suggested options for the response. This information is divided into six groups: identification of the material (name), physical properties, chemical properties, physical risks, health risks and information on the response.

- Evaluating the extent of damage to the R290 containment system. To enter into this analysis, let's first define our containment systems. The identified containment systems are: Cylinders and R290 Charging Machine. The information on the types of extent of damage in a primary and secondary containment system is used to predict the likely behavior of the containment system and mainly its contents, which in our case will be R290 Gas. The following steps are necessary to determine the extent of damage to a containment system.

Identification of damaged equipment and systems: Indications about a damage in a machine or process system.

Determining the type and location of any damage to the system and its closures: It is the recording of the presence of dents, cracks, notches, incisions, corrosion, and perforations.

- Predicting possible behavior: After gathering information about the characteristics of R290 and related equipment, the next task is to predict the possible behavior of R290 gas in the event of an accidental failure or escape. The identification and analysis of risks carried out in advance is very useful in the development of this stage. The prediction, loss scenarios or "mental movie" are used as reference points during the entire response activity. A "mental movie" must be made for each system of the process involved; it must be based on the worst-case scenario. In our case, the worst-case scenario would be a fire event in the cylinder R290 storage area

with a high spread rate. The following steps must be followed to develop this mental movie.

Identifying the causes of emergency: These causes may be, for example, the application of a strength, or a system of strengths that tend to stress a component as critical as the R290 containment equipment. Other causes that can generate mechanical stress that lead to breakage are thermal-chemical shocks, cracks, irradiation and etiological stresses. Potential mechanical and chemical stresses can be identified visually, while irradiation and etiological stresses are more difficult to identify. In our case, there is a very low probability of generating a system with sufficient mechanical stress to break a R290 cylinder, but it is not ruled out; this event is listed in the possible events and is called forklift impact or crash. Another cause of emergency is a fire event caused by short circuit or an explosion by release and accumulation of gases. All these causes of emergency are presented in our risk matrix section.

Predicting how events will occur: Idealization of the sequential order in which events will occur. Events will take place as follows in our loss scenario: Application of strength, breakage, (failure of some valve) gas leak, short circuit, explosion, fire and spread. This mental movie could have different outcomes as it depends on how quickly we respond to the emergency.

Predicting the risks to be caused by damages: The subject-matter of this study, damages are the injuries or losses caused when we are exposed to risks in a given industrial process. The types of risks are fire, explosion, BLEVE, etc. which were categorized in our study and risk matrices.

- Evaluating the event and estimating results: This is the final task in the analysis process; the aim is to indicate the magnitude of the problem in terms of results within the impacted area. The impacted area or the actual or potential area of exposure generated by the presence of R290 gas. We have concluded that possibly 100% of the property will be impacted as a result of a fire. In our case, it would be the entire manufacturing area, but the greatest exposure is in the R290 recharging chamber. The following steps must be followed to evaluate the results of the impacted area.

Estimating the number of exposures within the impacted area: Exposures include people, property, the environment, and critical systems.

Predicting the extent of physical risks: Predicting the risks for health requires knowledge about the different exposure limits, which include: immediately dangerous value for life and health, lethal concentrations,

permissible explosion limits and combustion gas limits. (See recommendations.)

The purpose of analyzing the problem related to R290 gas is to determine the probable dimension of the problem. Although this process is time consuming, it is an essential part of emergency management. When decisions are made before beginning the analysis process on actions, protection and control measures, risk for the response groups is higher.

Response Planning

The emergency response should include information about evacuation routes, meeting point, instructions for employees whether they are members the emergency brigade, descriptions of the response methodology and mitigation of risks in the process plant.

The plan should indicate the procedures to be established for testing, maintenance and use of response equipment. In this case, Thermotar is responsible for staff training on response and emergency procedures and documenting all the training activities, as well as, the creation and update of the emergency plan.

Preventive measures and appropriate control actions are identified based on the magnitude of the problem. Control actions must include the containment, confinement and extinction actions. The potential impact of each action on people, property and the environment must be considered.

The outcome of the planning process is the direction that the response effort will take to influence the sequence of events during the emergency and turn to a favorable outcome. Response planning is a process to identify and evaluate the response objectives (strategy) and response options (tactics). This process considers the available resources. The planned response must be consistent with the local emergency response plan and the standard operating procedures of the operation. The planning process begins before the incident, as part of the pre-planning stage of the response before the emergency and/or before the accident and continues at the incident site from a safe location.

The response planning process is based on the following tasks.

Setting the response objectives: Control of gas leaks and fire extinction.

Determining the possible response options that can favorably change the outcomes: Detection, alarm, communication and action control and fire-fighting.

Identifying the personal protection equipment options for the response: Fire equipment and self-contained equipment (see recommendations.) For all occupancies with potential to produce very high levels of heat, NFPA recommends having specialized PPE for proximity firefighting and PPE for respiratory protection; we have recommended the acquisition of self-contained equipment.

Selecting the response options focused on community that will change the outcomes in the most favorable way. The response plan must get the community involved through outreach sessions and provide the community with knowledge on what to do if an alarm triggers. It is advisable for part of the brigade members to include in their command and control plan a communication strategy with the neighbors in case it is necessary.

Developing an action plan that includes security considerations: The action plan must be in accordance with the requirements expressed in the R290 safety sheets.

Determining the response objectives (Strategy).

The first task to plan the response is to determine the response objectives. The response objectives based on the incident scenario are the strategic goals to stop the event in progress or prevent future events from happening. The response objectives are based on the incident scenario; they are the strategic goals to stop the event in progress or prevent future events from happening. Decisions should focus on changing the actions of factors that trigger the incident. If an accidental spillage or uncontrolled gas leak occurs, it is most likely that no immediate corrective actions can be taken, and we will let the event occur safely.

Determining the response options (Tactics).

Two types of response options are available: corrective actions taken to solve an immediate problem, or preventive actions taken to prevent the immediate problem from escalating. These actions are intended to keep losses to a minimum.

Determining the possible options for the potential response through the response objective. The response options are tactical activities to stop the event in progress or maintain a prediction for an event to occur. The response options are associated with the specific events of the emergency. Knowledge of procedures, equipment and safety precautions is critical to make this decision. Response options include one of the following types: defensive, offensive, and non-intervention. Control options include extinction,

containment or confinement options. The response staff must determine the appropriate response for the incident, taking into account the analysis of the problem. The plant only has portable fire extinguishers (see recommendations.)

Estimating how each response option will impact the outcomes. Before choosing a response option, we must review the impact of such response option or combination of response options on the sequence of events and finally on the outcomes. For example, if we choose to use an extinguisher as a means of response and the fire is not extinguished, the plan should consider this possible outcome of such response. Thus, each of the response options should be reviewed and analyzed with their possible outcomes.

Identifying the appropriate personal protection equipment.

It is imperative to consider the types of fire and combustion products that can potentially lead to a fire event. There are response options to identify properly the suitable personal protection equipment; these options will indicate the equipment required to implement the different response options that have been identified. Although there is not a single combination of personal protection equipment that can protect people against all risks (chemical, biological, physical and thermal), personal protection equipment must be used together with other protection methods such as medical monitoring and environmental surveillance. Personal protection equipment that provides the appropriate level of protection must be selected for any situation that occurs. At present Thermotar does not have any special equipment for the plant's brigade members. Protection against inhalation of hazardous combustion products must be available for firefighting. The availability of at least 1 self-contained breathing equipment device of positive pressure and 3 suits for structural firefighting should be considered.

Selecting the response options.

The selection of response options to change the outcome favorably should be consistent with the response plan, Thermotar's operating procedures, staff capacity and suitable personal protection equipment. The steps to select the response options include the following.

Determining the resources required to implement each response option: The resources required include the time to implement the option (therefore the automatic detection and alarm systems are essential), sufficient staff availability (emergency brigade and personal

protection equipment), and control means (extinction means, fire-fighting networks.)

Inventory of available resources: The available quick-access resources such as alarm, detection and extinction systems, special suits for emergencies, fire support network.

Determining how to obtain the necessary resources: A review based on engineering studies, loss controls and planning exercises should provide a response to determine the necessary resources.

Developing an action plan.

After selecting the response options, an action plan that includes safety and health must be developed. This action plan describes the response objectives, options, personnel and equipment required to achieve the objectives.

The emergency response staff (brigade members and employees) must recognize and understand the potential risks associated with R290. They should also be familiar with the procedures of the action plan. Therefore, all personnel must participate in an informational meeting about safety before working on the emergency scene. This informational meeting will describe the assigned tasks and their potential risks, coordination of the activities, identification of methods, cautions to avoid injuries, and the emergency plan.

Plans prior to the incident.

The Thermotar emergency organization should describe the plans prior to the incident to all the plant areas. The plans must be designed to limit large fires, minimize the threat to employees, and reduce damage from fires. Although the plans prior to the incident must be detailed, they must be flexible enough to allow for including different problems generated by the fires to be fought. It is important for the brigade members to participate in the plan development prior to the incident as the training is valuable. The brigade members will also become familiar with the plant from a fire protection perspective. A pre-incident emergency plan should be developed for each area, (storage area and R290 recharging chamber) and it must be useful to the brigade. This plan must contain at least the following information:

Review of the plant distribution: The Thermotar plant has several segmented areas depending on the stage of the manufacturing process, but there are no separate fire areas, fire walls or fire doors.

Discussing the construction characteristics of the facility and its probable reaction during a fire and explosion incident: the type of construction of the warehouse where the R290 cylinder operation is located is made of reinforced concrete and floors of concrete-casting deck sheet. No combustible elements were observed in the construction. Unlike the recharging chamber, it is a structure with metal profiles and divisions in acrylic materials, with a high possibility of damage during a fire in both directions.

Overview of the facility operations, equipment and associated fire risks: The risks of the manufacturing process are many; the presence of electrical energy, heat sources and the required process substances indicate that the two biggest risks are fire and explosion.

Review of the available water supplies, fire pumps, control valves, fire department connections, alarm detection equipment and special suppression equipment: There is no water pumping system in the plant, only portable fire extinguishers were observed. In accordance with the NFPA recommendations, it is necessary to have water mist, foam or dry chemical systems as extinction means for this occupancy.

Description of available communications and pre-established plans with the fire department responding to the incident: This format must contain the cell phone numbers and landlines of plant managers, firefighters, hospitals, etc.

Requirements for manual firefighting efforts, including the most suitable tactics. This section discusses the manual means of firefighting and the results of their implementation the manual firefighting techniques are using portable extinguishers and network of hose stations. This means of combat can be ineffective in many scenarios such as fires of flammable liquids and oils.

Information on ventilation systems that can cause the spread of smoke or be used to prevent the spread of smoke. Smoke pollution is a concern, as there are no interior partitions. The air ducts of the recharging chamber must have smoke detection systems.

Evaluation of chemical risks and methods to manage spills: This is a very low risk due to the potential quantities of LPG that can escape in liquid form. Additionally, they contain considerable heat for vaporization as R290 is a liquefied gas; they often vaporize very quickly when coming in contact with air or the ground; once they escape, there is no liquid phase. They will not even form a puddle. The

Liquefied gases with lower vapor pressure such as butane and chlorine are exceptions to the puddle example, but in our case, R290 can form puddles when the ambient temperature is below the freezing point.

Location of flammable liquid and cut-off valves of the R290 supply system: The R290 dosing system is an automatic filling and automatic locking system. When the air-analyzer sensor is activated, the R290 circuit is cut off. The highest concentration of R290 is observed in the basement warehouse, where they report about 150 cylinders of 5.5kg.

Implementing the planned response.

Once the action plan is determined, the response staff must implement the response options of such plan. The following tasks must be carried out for proper implementation.

Implementing the selected protection actions: protection measures are measures taken to preserve the health and safety of the response and emergency staff and the public, during an incident with flammable substances (Propane LPG).

The protective actions are: isolating the area of risk and forbidding entry; evacuating people from the threatened area and protecting people who cannot be evacuated from the emergency site.

Performance of Control Functions: The response staff (brigade members) is expected to perform the control functions set forth in the action plan. This staff will have to select the tools, equipment, resources and materials for the assigned task. They must also understand the precautions to control emergencies related to R290.

Evaluating the progress and implementation of the corresponding adjustments.

The fourth and final task for an emergency plan related to flammable substances is to evaluate the progress of the planned response, whether it is stabilized, intensified or other changes occur. This task evaluates the effectiveness of the following items.

Participating staff: Brigade members and plant staff

Personal protection equipment: Protection elements needed to respond to emergencies.

Setting the established control zones: Unloading area and Plant.

Control and extinction process: Protection systems, fire protection network and portable extinguishers.

Selected options of action: Designed by Thermotar and discussed at the organization level.

In summary, as in any emergency, favorable changes in the results require a logical sequential process, including four activities.

1) Analysis

2) Planning

3) Implementation

4) Evaluation

Each activity is made up of a series of tasks that need to be carried out in full to complete the activity.

VII. Comments on Maintenance

Maintenance Program.

The main equipment to be subject to scheduled maintenance is the R290 Agramkow charging machine; this is a European equipment that has been supplied with a maintenance routine based on technical specifications and datasheets for each component. From our perspective, all maintenance parameters must be observed; therefore, there is no further advice we can offer on the structuring of a strategic maintenance plan. It is the company's responsibility to follow the recommendations and technical data provided in the machine manuals carefully. The manufacturer's manuals are documents that contain the necessary and relevant information the maintenance staff should know about this highly-specialized system and all its components. The purpose of these manuals is to provide sufficiently technical information with an approach as didactic as possible: they are a primary source of data and the main guide to detailed procedures to extend the useful life of the equipment and preserve its operating characteristics.

The manufacturer's manuals may contain one or more of the following documents: technical service manual, maintenance manual, operating manual, safety manual, electrical drawings, hydraulic circuits (if any), manufacturer's drawings, among others.

The maintenance department is in charge of performing maintenance tasks safely and efficiently considering within its structure the operating principles of the machine or equipment, its location in the process, tasks or procedures associated with preventive, predictive and corrective maintenance, including the analysis of risks and environmental impact, as well as, the investigation of breakdowns, list of parts and spare parts.

Maintenance Software

If the company does not have any maintenance software, they lack a key element for timely support of industrial equipment; they help to control and manage maintenance times and deliver performance indicators of the maintenance and production equipment. The software must be "programmed" to generate preventive and predictive maintenance tasks based on the useful life of the machine components assigned by the manufacturer or the equipment log book.

If this input information is not well supplied and accurate, the software will become a useless tool and

the rate of corrective interventions will probably increase because of the machine's poor condition, in parallel, a series of risks may arise that could threaten people and property.

Therefore, if not available, we recommend requesting the manufacturers for technical information about maintenance frequencies, limit service hours of components and determining when specialized technical support is necessary, in order to properly program the company's maintenance software. A well-synchronized maintenance software will allow the correct support of equipment and better outcomes regarding safety and production performance.

Agramkow Machine Maintenance

During our visit we observed that the charging machine is simply a R290 refrigerant dosing pump controlled by a series of sensors and other automatic instrumentation and control equipment. It has a series of protections and locks for correct operation created by the designer and manufacturer that are locked to a PLC. There is not much to say about electronic equipment because they have parameters for proper maintenance which, in our view, must be met rigorously; however, we advise giving special care to 290 LPG transport equipment such as hoses, flexible elements and nipples, especially those that work under pressure, since they are one of the main mechanical elements with high rate of failure.

It is very important to keep the R290 containment system under a strict maintenance program to mitigate the risk of accidental releases. In the equipment prone to leaks we observed that the hoses, joints, nipples and other couplings have mechanical seals inside. All these equipment devices have a useful life; the work cycles are parameterized by the manufacturer (we will not make recommendations to modify these maintenance routines). We recommend including all these service parameters in the maintenance software available; if not available, they should be included in the equipment log book to perform these tasks in a timely manner.

Conclusions

As part of our risk analysis, we can conclude that risks adjacent to the R290 recharging chamber should be paid special attention, since the event or risk of fire adjacent to said chamber could have catastrophic consequences according to our matrices.

Although this risk is not in the red area of the matrix, it could have serious consequences for the operation such as complicity to control a fire due to the high probability of container failures as a BLEVE; it may cause other serious detrimental effects such as injuries to people, damage to the company's image or reputation, possible environmental impacts and death of employees. Additionally, there is a high concentration of risk in the process area due to the existence of a great variety of equipment, input and parts for the productive process with a high material value. Special attention should be paid to the recommendations for improvement issued in this report to make available the minimum protections for this type of occupancy.

Following this risk, even though the risks of fire, gas leak and explosion are in the same area of matrix number 2, we consider that an explosion event with subsequent fire would be the most critical event for the R290 recharging cabin; the estimated consequences of this event are not as serious as those of a fire inside the warehouse, since the fuel load inside the R290 recharging cabin is assumed to be much lower than the fuel load in the storage warehouse. However, we would like to consider that if the following events are combined, namely, explosion, sequential fire and damage to the acrylic walls of the enclosure, the fire may rapidly spread to other plant areas, if the minimum distances of finished product are not kept, causing a major fire and making it difficult to control with the current resources available for fire control and the current plant configuration which comprises a single fire area.

Therefore, the implementation of these recommendations is very important, as well as, adopting the best manufacturing practices of order and observing the minimum storage distances from the R290 cargo cabin, a recommendation included in this report.

VIII. Reference Standards

Cited Standards.

NFPA 54 National Fuel Gas Code

NFPA 13 Standard for the Installation of Sprinkler

Systems NFPA 55 Compressed Gases and Cryogenic

Fluids NFPA 13 Standard for the Installation of

Sprinkler Systems NFPA 70 National Electrical Code

NFPA 51B Standard for Fire Prevention During Welding, Cutting and Other Hot Works.

IEC 60079-29-2 Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen

FM/ANSI Approvals 6325- 2007 Gas Detectors

FM/ANSI Approval Standard for Combustible Gas Detectors Class Number 6320

ANSI/ISA 92.00.01

ANSI/ISA 92.04.01

ANSI/ISA 60079-29-1

ASHRAE 34 Designation and Safety Classification of Refrigerants

Engrin de Colombia SAS — Engineering applied to Risks and Insurance

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Address: Cra 52 # 94 – 167
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Demonstration project to validate the use of Hydro-Fluoro-Olefins (HFO) for discontinuous panels in Article 5 Parties through the development of cost-effective formulations

UNDP REPORT
Submitted on behalf of the Government of Colombia

APRIL 2018

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DEMONSTRATION PROJECT TO VALIDATE THE USE OF HYDRO-FLUORO-OLEFINS (HFO) FOR DISCONTINUOUS PANELS IN ARTICLE 5 PARTIES THROUGH THE DEVELOPMENT OF COST- EFFECTIVE FORMULATIONS

UNDP REPORT

Submitted on behalf of the Government of Colombia

Executive Summary

This project was developed as response to the Decision 76/29 of the Multilateral Fund Executive Committee and is part of a limited group of projects with the objective to assess new technology options that use non-ODP and low GWP blowing agents.

In the context of Decision XIX/6 there is a concern on the availability in Article 5 parties of validated cost effective and environmental sound technologies to phase-out HCFC-141b. This is particularly critical for the applications of polyurethane (PU) rigid foam, discontinuous panels, small appliances, spray foam, etc., where most of the end users are small enterprises with a poor control of the operation and safety discipline. Several work orders are done in-doors with limited ventilation. Safety is the main barrier for the introduction of flammable technologies (hydrocarbons, methylal and methyl formate) in this market segment.

The proven non-flammable technical options to replace HCFC-141b as blowing agent for PU rigid foam are mainly limited to high GWP HFCs as HFC-245fa and the blend of HFC-365mfc/HFC-227ea, which have GWP values of 1030 and 964 respectively. Recent publications show promissory results with the new unsaturated HFC/HCFC blowing agents, commonly known as Hydro-Fluoro-Olefins (HFO), that exhibit GWP values lower than 10.

The project was designed to evaluate two HFO molecules as co-blowing agent in association with CO_2 derived from the water-isocyanate reaction: HFO-1336mzz(Z) and HFO-1233zd(E). The foam processing and physical properties obtained with these substances along with their respective formulating costs were compared to those of HCFC-141b based systems.

Espumlátex, the largest Colombian 100% owned PU system house, served as local technical host to coordinate the demonstration, foam application and testing activities. The experimental protocol included a statistical full factorial design with 2 factors for polyurethane foam (PUR). The factors (independent variables) were the type of HFO and the HFOs/CO_2 ratio in the foam cell. To determine the physical properties of the foam, the samples were prepared and analysed following ASTM standards in Espumlátex laboratories. In addition, three samples (one with each blowing agent) were sent for the E-84 fire performance testing at QAI laboratories in the United States.

The following conclusions can be pointed out:

1. The foam HFO based technology is not flammable. It does not deplete the ozone layer (0 ODP) and has a low GWP (< 2). Compared to HCFC-141b it does not present any incremental EH&S issue.
2. In the framework of this project supported by the Multilateral Fund, HFO based formulations with blowing agent reductions of 61 to 64 by weight were developed. This is equivalent to an HFO reduction in the gas cells of 60%.
3. Compared to HCFC-141b, the HFO reduced formulations showed:

  - Better foam flow reflected by a lower flow index (ratio between the free rise density and the minimum fill density).
  - An initial foam K factor higher by 7% in laboratory (Brett injections). This value was reproduced at industrial plant.
  - Similar values of foam K factor when measured one month after injected.
  - Similar laboratory and production plant values of compression strength, dimensional stability and adhesion to metal.
4. There was not observed -from a statistical point of view- a difference between the performance of foam based on the two types of HFO: 1233zd(E) and 1336mzz(Z).
5. The handling and processability at the production plant of the HFO reduced formulation was similar to HCFC-141b.
   - In hot weathers the PU systems based on HFO-1233zd(E) could require a storage conditioned at low/ medium temperatures.
6. Nowadays the HFO reduced systems have higher costs than HCFC-141b by 16.4 and 33.2%, but these figures could be lower in the future.
7. Thanks to the technology formulation it was possible to significantly reduce the cost of the HFO based formulations.

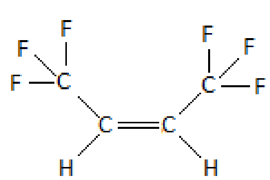
1. INTRODUCTION

In the context of Decision XIX/6 there is a concern on the availability in Article 5 parties of validated cost effective and environmental sound technologies to phase-out HCFC-141b in the different foam applications.

This project was developed as response to the Decision 76/29 of the Multilateral Fund Executive Committee and is part of a limited group of projects with the objective to assess new non-ODP and low GWP technology options to replace HCFC-141b as blowing agent. The present project was designed to evaluate the use of HFOs for discontinuous panels in Article 5 Parties through the development of cost-effective formulations.

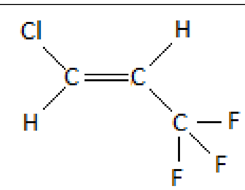
For developing countries, the proven technical options to replace HCFC-141b as blowing agent for PU rigid foam are mainly limited to high GWP HFCs as HFC-245fa or HFC-365mfc/HFC-227ea blend, which have GWP values of 1030 and 964 respectively (100yr ITH, IPCC 4th Assessment Report 2008). Recent publications show promissory results with the new unsaturated HFC/HCFC blowing agents, commonly known as HFOs, that exhibit GWP values lower than 10 (Bodgan, 2011; Costa, 2011). The barrier for the well-known hydrocarbon technology in this rigid foam application is safety during foaming because of flammability. This issue is particularly critical for this sector where most of the enterprises are small in size with a poor control of the operation and safety discipline. Several work orders are done in-doors with limited ventilation.

The project was designed to evaluate two HFO molecules as co-blowing agent in association with CO_2 derived from the water-isocyanate reaction: HFO-1336mzz(Z) and HFO-1233zd(E). Figures 1 and 2 show the chemical formulas of the blowing agents evaluated in this project and Table 1 summarizes their physical properties.



cis-1,1,1,4,4,4-hexafluoro-2-butene

Figure 1. HFO-1336mzz(Z)



(E) 1-chloro-3,3,3-trifluoropropene

Figure 2. HFO-1233zd(E)

Table 1. Physical properties of HCFC-141b and HFOs

Characteristics	HCFC-141b	HFO-1336mzz(Z)	HFO-1233zd(E)
Suppliers		Chemours	Honeywell/Arkema
Bowling point (°C)	32	33	19
Thermal conductivity of gas (Mw/m.K) to 25°C	9.5	10.7	10.0
ODP	0.11	0	0
GWP	782	2	1

2. PROJECT OBJECTIVES AND IMPLEMENTATION

In accordance to Decision 76/29 of the Executive Committee adopted in its 76th meeting held in Montreal in May 2016, the project objective is:

> *Validate the use of HFOs for discontinuous panels in Article 5 parties through the development of cost-effective formulations*

Espumlátex, the largest Colombian 100% owned PU system house, served as local technical host to coordinate the demonstration, foam application and testing activities.

The start-up of the project took place the week of November 30, 2016 after the administrative arrangements between the Government of Colombia, the UNDP local office and Espumlátex were agreed. The implementation was done in a team effort among the company Ingeniería de Refrigeración Industrial Rojas Hermanos S.A., Espumlátex, the Ministry of Environment and Sustainable Development of Colombia, through the National Ozone Unit (UTO), and UNDP. The activities that were carried out are shown in Table 2.

Table 2. Activities developed during the project

Activity	Date
Bibliographic review.	November 30, 2016 - January 2017
Raw materials acquisition.	November 30, 2016 - January, 2017
Definition of evaluation plan and experimental protocol.	November 30, 2016 - December, 2016
Development of HFO based formulations: laboratory tests at Espumlátex (hand-mix and Brett mould injections). Preparation of foam samples to test physical properties.	November 30, 2016 - March, 2018
Evaluation of foam physical properties (Espumlátex, QAI laboratories).	November 30, 2016 - April, 2018
Selection of the best cost/performance formulations for an industrial trial: Injection of discontinuous panels at Rojas Hermanos plant.	January, 2018
Presentation of the final results and conclusions in an international seminar.	February, 2018
Preparation of Final Report.	January – April, 2018

3. EXPERIMENTAL

3.1. Experimental Design

When a specific process or experiment is repeated under what are, as nearly as possible, the same conditions, the observed results are never identical (Box & Hunter & Hunter, 2005). This statement is particularly true in the field of PU foam. This fluctuation that occurs from one repetition to another is called *experimental error* and refers to variations that are unavoidable such as human errors of measurement, analysis and sampling. The no consideration of experimental error can lead to false conclusions about the *real* effect of a specific independent variable. In the line of these thoughts and having in mind that usually is most efficient to estimate the effects of several variables simultaneously, it was decided to apply for this project the technique of statistical design of experiments, commonly known as DOE.

One simple 2 x 5 full factorial design was planned. *Genuine* replicates were made in all points of the design to have the best estimate of the error variance across the experimental region.

3.1.1. Factors and levels

The factors (independent variables) and levels considered for the experimental design are described in Table 3.

Table 3. Experimental Design

Factors (independent variables)	Levels
Type of HFO	HFO-1336mzz(Z)
	HFO-1233zd(E)
Mole fraction of HFO into the gas cells (reduction percent of HFO compared to HCFC-141b formulation)	0.83 (0 %)
	0.66 (20 %)
	0.50 (40 %)
	0.33 (60 %)
	0.17 (80 %)

A commercial formulation blown with HCFC-141b, having a 0.83 mole fraction into the gas cells, was used as comparison standard. Three genuine replicates of this standard were done.

Figure 3 illustrates the HFO reduction into the gas cells. The mole fraction value of HCFC-141b into the gas cells of the standard formulation, that is 0.83, was taken as the starting point: it represents the 0% reduction of blowing agent. The 20% reduced gas will have a HFO mole fraction equals to 0.83 x 0.80 = 0.66, as it is shown in the figure. The 40% reduced gas will have a HFO mole fraction of 0.50, etc., etc.

The isocyanate/polyol index (equals to 1.20), the gel time (measured at machine) and the free rise density were kept constant throughout all the experiments.

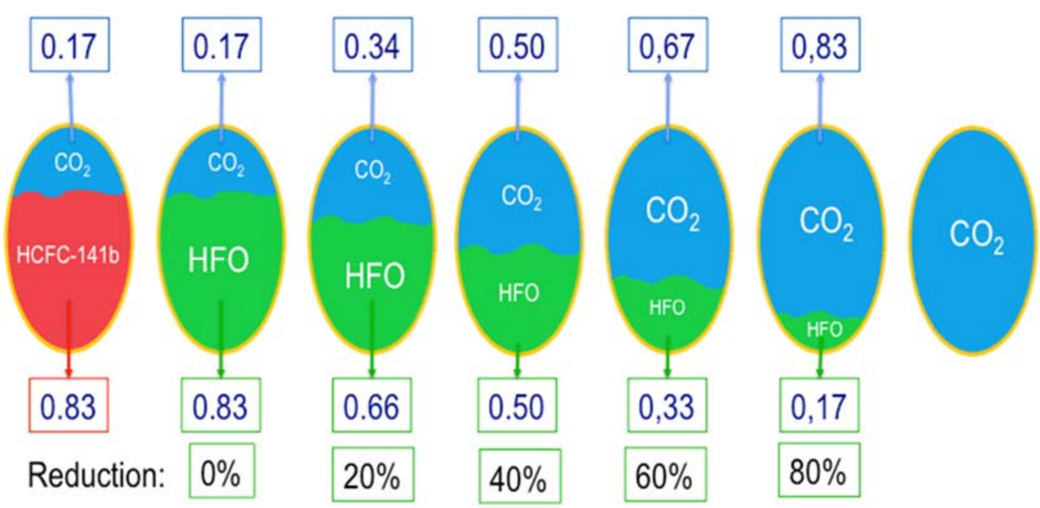


Figure 3. Mole fraction of HCFC-141b/CO_2 and HFO/CO_2 into the gas cells

3.1.2. Responses and test methods

Table 4 lists the responses (dependent variables) along with the test methods that were used for their determination.

<table>
<tr><th colspan="4">Table 4. Responses and Test Methods</th></tr>
<tr><th colspan="2">Property</th><th>Test</th><th>Testing Laboratory</th></tr>
<tr><td colspan="2">Reactivity at machine</td><td>Visual</td><td>In-situ during application</td></tr>
<tr><td colspan="2">Density</td><td>ASTM D-1622</td><td>Espumlátex</td></tr>
<tr><td colspan="2">K-Factor</td><td>ASTM C-518</td><td>Espumlátex</td></tr>
<tr><td colspan="2">Compressive strength</td><td>ASTM D-1621</td><td>Espumlátex</td></tr>
<tr><td colspan="2">Adhesion strength</td><td>ASTM D-1623</td><td>Espumlátex</td></tr>
<tr><td colspan="2">Dimensional stability</td><td>ASTM D-2126</td><td>Espumlátex</td></tr>
<tr><td rowspan="2">Aging (*)</td><td>K-Factor</td><td>ASTM C-518</td><td>Espumlátex</td></tr>
<tr><td>Compressive strength</td><td>ASTM D-1621</td><td>Espumlátex</td></tr>
<tr><td colspan="2">Fire Performance</td><td>ASTM E-84</td><td>QAI Laboratories</td></tr>
</table>

(*) For K-Factor: 2 weeks, 4 weeks, 2 months, 6 months, 1 year, 2 years
For Compressive strength: 1 month, 2 months

3.2. Laboratory Testing Procedures

3.2.1 Stability of polyol blend

It is known that some amine-based catalysts currently used in the industry may interact with HFO, particularly the unsaturated HCFCs, causing a deterioration of the system reactivity (longer gel times). The stability of the fully formulated polyol was evaluated by monitoring the hand-mix reactivity (cream, gel and tack free time) over time.

3.2.2 Preparation of foam samples

After blending the fully formulated polyol, composed of base polyols, catalysts, surfactant, additives, water and blowing agent, its mixture with isocyanate was injected using a high pressure machine Cannon AP at the conditions shown in Table 5.

Table 5. Conditions at Laboratory Foam Injection	
Injection pressure, bar	150
Isocyanate Temperature, ºC	21 +/- 0.5
Polyol Temperature, ºC	20 +/- 0.5
Output, g/s	200
Mould surface temperature, °C	45

A Brett mould (5 cm x 20 cm x 200 cm), made of aluminium and equipped with water heating, was used for the preparation of foam. With the mould in horizontal position the iso/polyol mixture was injected through a hole located 15 cm from the bottom; immediately after the mould was changed to the vertical position and remained so until reaching the de-mould time (6 or 8 minutes).

Once the machine reactivity (cream, gel, tack free time and free rise density) was verified the minimum fill density (MFD), corresponding to the minimum amount of foam material needed to fill the mould, was determined. Based on the MFD value, for each experimental point, six additional Brett panels were shot at six levels of over-packing: 6, 8, 10, 12, 14 and 16%. The pieces at 6, 10 and 14% were de-moulded at 6 minutes and the foam expansion was measured; the remaining were de-moulded at 8 minutes. This data on foam expansion is used to compare the de-mould characteristics among different PU systems.

Figure 4 illustrates the determination of minimum fill density (MFD) and Figure 5 the corresponding measurement of foam expansion at Brett mould.

Figure 4. Determination of Minimum Fill Density (MFD)

Figure 5. Measurement of foam expansion at Brett mould

After 24 hours of the injection, each Brett panel was cut to prepare the foam samples required to measure the physical properties listed in Table 4: one for K factor; fifteen for compressive strength at 24 hours, one and two months; six for dimensional stability at -30 and 70 °C. For the determination of the minimum freeze stable density, 10 cm thick bricks of the Brett panels at the six different over-packings were left overnight at -30°C.

4. RESULTS AT LABORATORY LEVEL

4.1. Polyol Aging

The reduced HFO formulations up to the 60% level were prepared with conventional amine catalysts: pentamethyl-diethylene triamine, N,N.dimethyl cyclohexylamine, 1,3,5-tris (3-(dimethyylamino) propyl) and N,N dimethylethanolamine., The variation of the gel time over time is shown in Figures 6, 7, 8 and 9 (testing at longer time intervals, 4 and 6 months, is planned). A slight catalyst deactivation with HFO based systems was observed. However the longer gel times did not have a particular effect on foam processability and properties when the 40 and 60% reduced systems were run at industrial level (section 6). For the formulation of 80% reduced systems special catalysts -recommended by one of the HFO suppliers- were used (section 7.3) and a better blend stability was observed (testing at longer times is also planned). This point deserves further investigation and monitoring during implementation of investment projects.

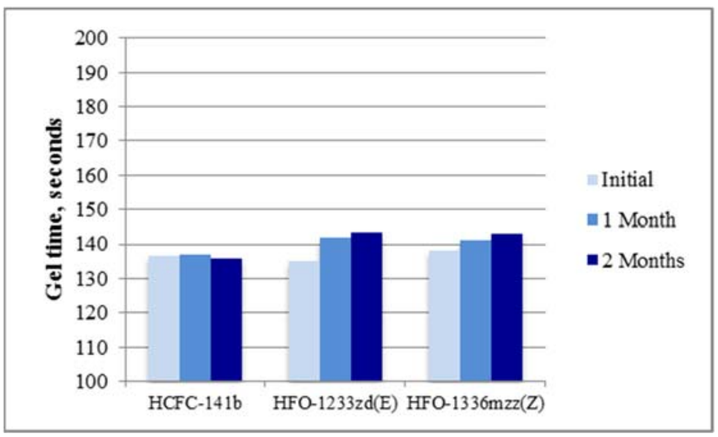


Figure 6. Gel time over time. 0% reduced systems

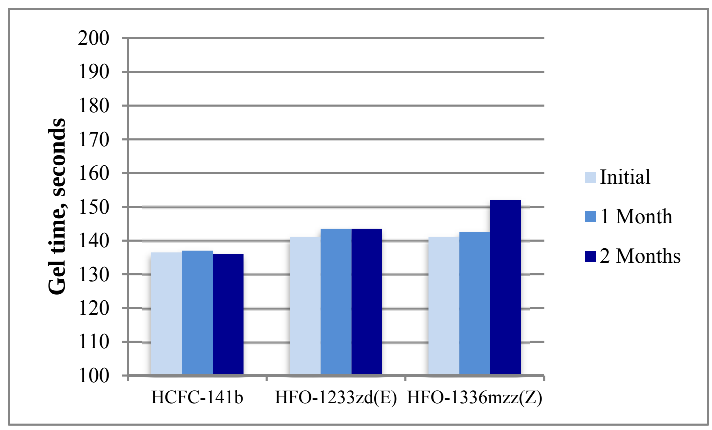


Figure 7. Gel time over time. 20% reduced systems

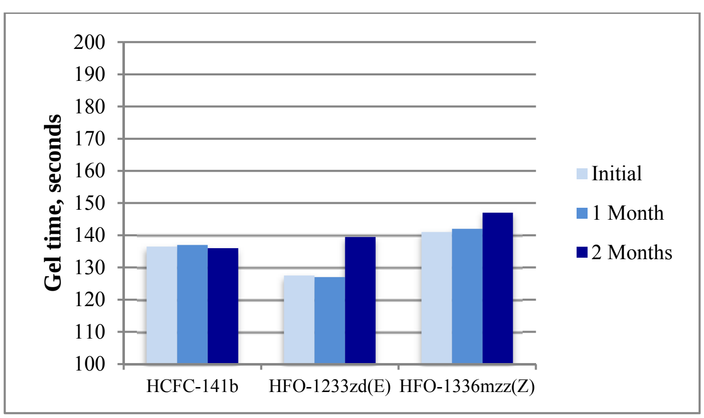


Figure 8. Gel time over time. 40% reduced systems

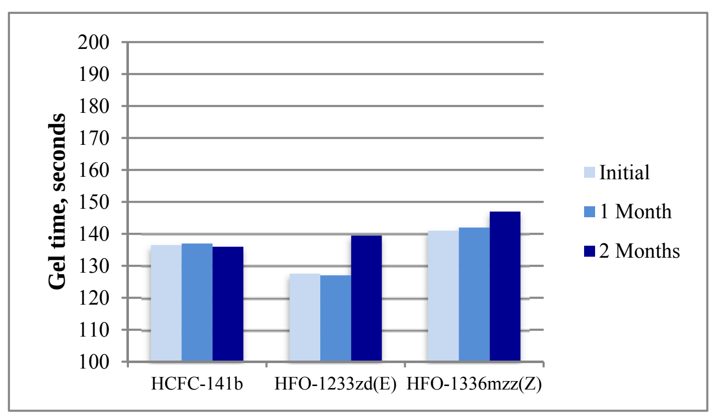


Figure 9. Reactivity polyols over time, reduced by 60% molar

4.2. Brett expansion

Figures 10, 11, 12 and 13 show the results for Brett expansion at the two demould times (6 and 8 minutes) and the different percentages of reduction.

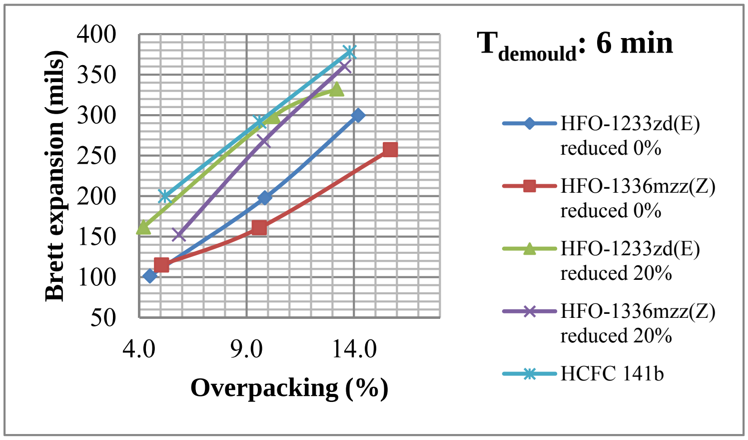


Figure 10. Brett expansion ($T_{demould}$: 6 min), 0% and 20% reduced

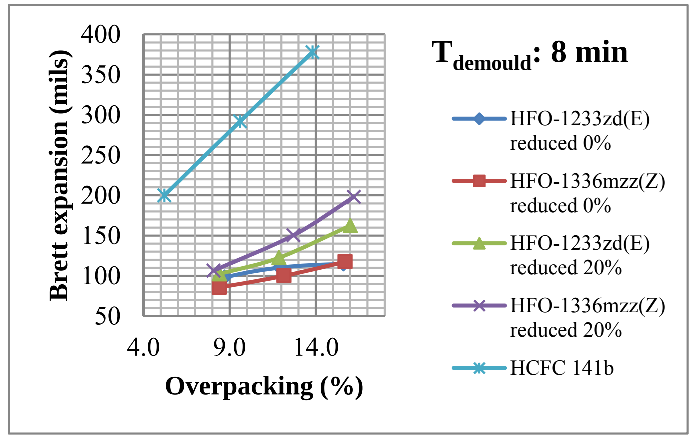


Figure 11. Brett expansion ($T_{demould}$: 8 min), 0% and 20% reduced

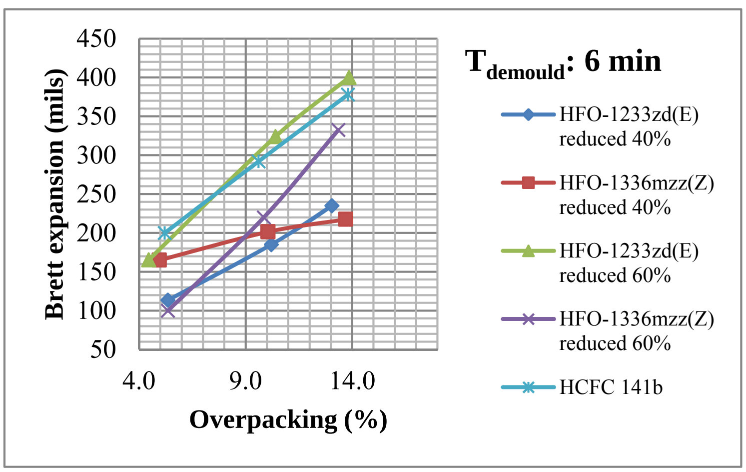


Figure 12. Brett expansion ($T_{demould}$: 6 min), 40% and 60% reduced reduced

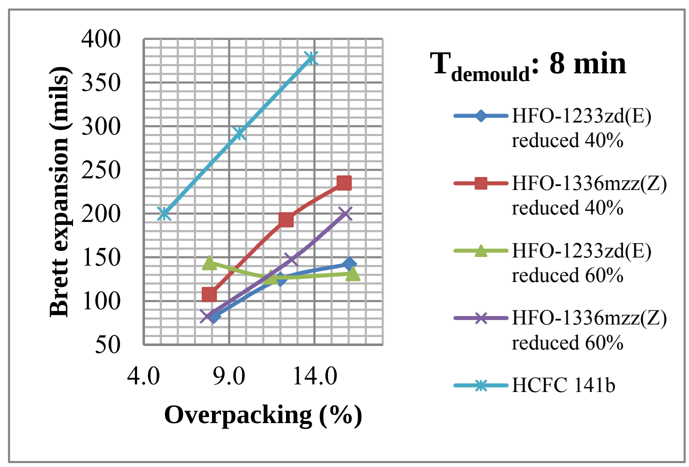


Figure 13. Brett expansion ($T_{demould}$: 8 min), 40% and 60%

4.3. Physical Properties

Table 6 summarizes the initial results for both mechanical and thermal properties of the injected panels.

Table 6. Initial results of mechanical and thermal properties of panels.
Reported data are an average of 2 genuine replicates

Blowing agent	HCFC- 141b	HFO-1233zd(E)				HFO-1336mzz(Z)			
Mole fraction in the gas cells	0.83	0.82	0.66	0.51	0.32	0.83	0.66	0.50	0. 33
Weight percent of Blowing Agent in formulation (%)	12.89	13.41	9.81	7.37	4.86	16.57	11.98	9.62	6.50
Reduction percent by weight (%)			26.85	45.04	63.76		27.70	41.94	60.77
Machine reactivity									
Cream/ Gel/ Tack Free times (s)	10/111/155	8/129/187	8/142/204	8/138/216	8/125/244	8/140/207	9/141/193	8/139/216	8/140/244
Free rise density (kg/m^3)	20.1	19.7	20.6	21.0	21.4	19.5	19.7	21.2	21.1
MFD (kg/m^3)	29.3	27.7	28.1	27.8	27.5	26.2	27.2	27.5	27.0
Foam moulded density (kg/m^3)	34.6	32.4	33.0	31.4	32.1	30.6	32.0	32.1	31.6
K factor (mW/m.K)									
Initial	21.51	22.31	23.05	23.43	23.65	22.70	22.50	23.00	23.60
2 weeks	22.94	23.06	23.53	23.63	23.85	23.40	23.10	23.50	23.90
1 month	23.76	23.98	24.35	23.47	24.82	24.20	24.10	24.10	24.20
Compressive strength (kPa) at 16% over-packing									
Compressive strength initial	107.6	102.7	108.5	85.9	86.9	95.1	113.2	102.8	105.2
Core density (kg/m^3) initial	25.4	25.1	26.2	26.0	27.9	24.6	25.9	26.4	25.8
Compressive strength initial adjusted at 32 kg/m^3	172.3	169.0	162.2	130.9	114.0	164.5	173.1	150.6	162.1
Compressive strength 2 months	105.8	98.1	106.6	74.5	85.4	88.6	111.2	106.0	111.8
Core density 2 months (kg/m^3)	25.4	24.7	25.7	25.9	27.2	24.5	25.7	26.4	25.8
Compressive strength 2 months adjusted at 32 kg/m^3	170.8	167.7	166.3	114.8	124.0	155.1	174.0	155.3	171.9
Dimensional stability 70°C (%ΔV)									
1 day	1.02	-0.19	-1.52	-2.41	-3.16	-0.64	-0.63	-2.94	-1.36
1 weeks	1.90	0.63	-0.35	-1.32	-2.12	1.79	1.18	-1.47	-0.78
2 weeks	2.47	1.05	0.38	-0.25	-1.01	2.79	1.70	0.69	0.22
Dimensional stability -30°C (%ΔV)									
1 day	0.38	0.32	-0.13	0.13	0.24	-1.23	-0.65	-0.58	-0.74
1 weeks	0.10	0.05	-0.19	-0.05	-0.07	-0.26	-0.03	-0.23	-0.10
2 weeks	0.11	-0.09	-0.23	-0.12	-0.50	-0.29	0.04	-0.34	-0.47
Adhesion strength to metal (kPa)	166.03	169.35	198.15	236.1	216.5	155.95	215.5	151.95	148.7

* All data points correspond to the average of two genuine duplicates with the only exception of those of "HCFC-141b" column that are the average of three genuine replicates.

5. ANALYSIS OF RESULTS (LABORATORY LEVEL)

To assess the statistical significance of the effect of the different factors on the foam properties, an analysis of variance (ANOVA) was developed for each property. In this section the ANOVA of few selected foam properties, critical for the thermal insulation performance, such as initial and aged K factor (lambda value), aged compressive strength, dimensional stability an adhesion to metal will be shown.

5.1. Initial K factor

The results of the initial K factor are summarized in Table 7 and Figure 14.

Table 7. K factor, 24 Hours, mW/m*K

Reduction Percentage	HFO-1233zd(E)		HFO-1336mzz(Z)		AVERAGE
0%	22.51	22.11	23.10	22.30	22.51
20%	22.85	23.25	22.60	22.40	22.78
40%	23.05	23.80	22.70	23.40	23.24
60%	23.60	23.69	23.40	23.80	23.62
AVERAGE	23.11		22.96		
HCFC-141b standard: 21.51					

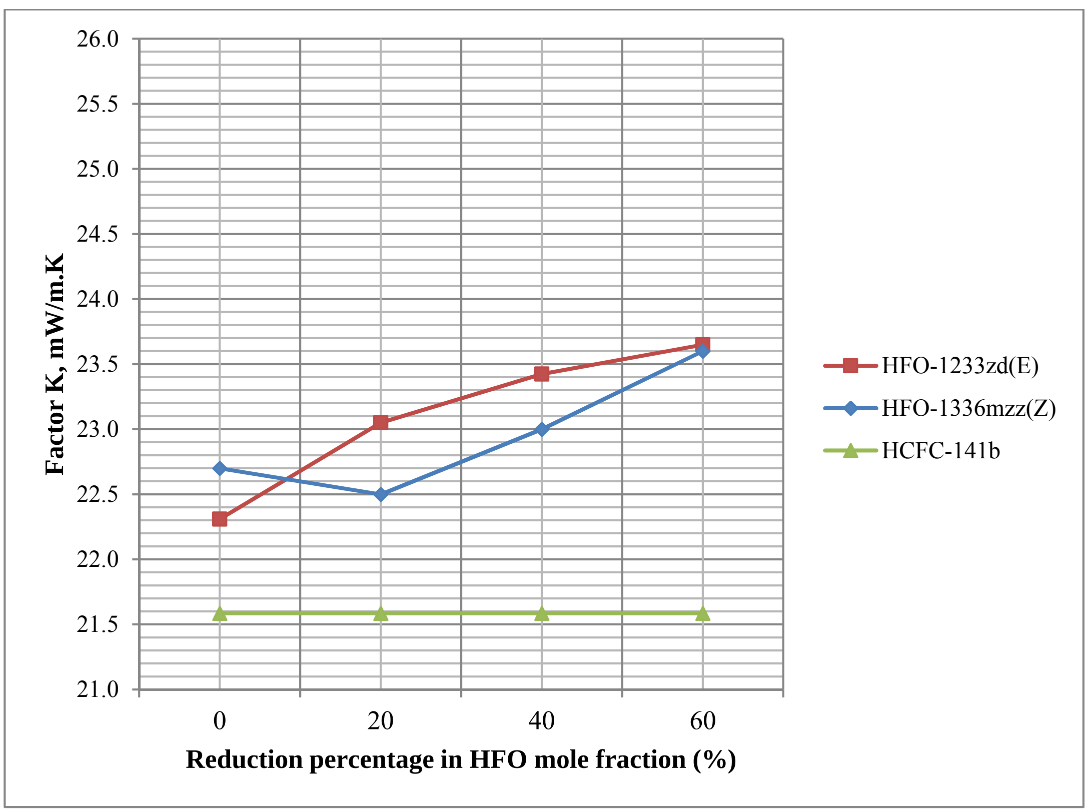


Figure 14. K factor (initial) vs. Reduction percentage in HFO mole fraction

Table 8 shows the ANOVA results of K factor for 24 hours. It is concluded that the molar HFO/CO_2 ratio has a statistically significant effect on the initial foam K factor. No significant difference between the two types of HFO, HFO-1233zd(E) and HFO-1336mzz(Z), was observed.

Table 8. ANOVA of K factor, 24 hours

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	P(1)	
Type of blowing agent (A)	1	0.084	0.084	0.606	0.459	
Mole fraction (B)	3	2.939	0.980	7.058	0.012	Significant
A*B	3	0.513	0.171	1.232	0.360	
Pure Error	8	1.110	0.139			

(1) Probability of Type I error (rejecting the null hypothesis when it is in fact true). If $P < 0.05$ it is considered that the effect of the factor is significant.

Tables 9 and 10 that statistically compare HCFC-141b with the HFO reduced systems (40 and 60%) led to the conclusion that there is a significant difference in initial K factor between the HCFC-141b and the two types of HFO.

Table 9. ANOVA of K factor, 24 Hours: HCFC-141b vs. HFO-1336mzz(Z) (40% reduced) vs. HFO-1336mzz(Z) (60% reduced)

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	P	
Type of blowing agent	2	4.340	2.170	11.010	0.042	Significant
Pure Error	3	0.591	0.197			

Table 10. ANOVA of K factor, 24 hours, HCFC-141b vs. HFO-1233zd(E) (40%) vs. HFO-1233zd(E) (60%)

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	P	
Type of blowing agent	2	5.120	2.560	13.910	0.030	Significant
Pure Error	3	0.552	0.184			

5.2. K factor measured 4 weeks after injection

Table 11 and Figure 15 show a summary of the results of the foam K factor measured 4 weeks after injection.

Table 11. K factor, 4 weeks, mW/m*K

Reduction Percentage	HFO-1233zd(E)		HFO-1336mzz(Z)		AVERAGE
0%	24.23	23.72	25.00	23.50	24.11
20%	24.29	24.40	23.80	24.40	24.22
40%	24.49	22.45	23.80	24.30	23.76

Table 11. K factor, 4 weeks, mW/m*K					
Reduction Percentage	**HFO-1233zd(E)**		**HFO-1336mzz(Z)**		**AVERAGE**
60%	24.57	25.07	24.10	24.30	24.51
AVERAGE	24.15		24.15		
HCFC-141b standard: 23.76					

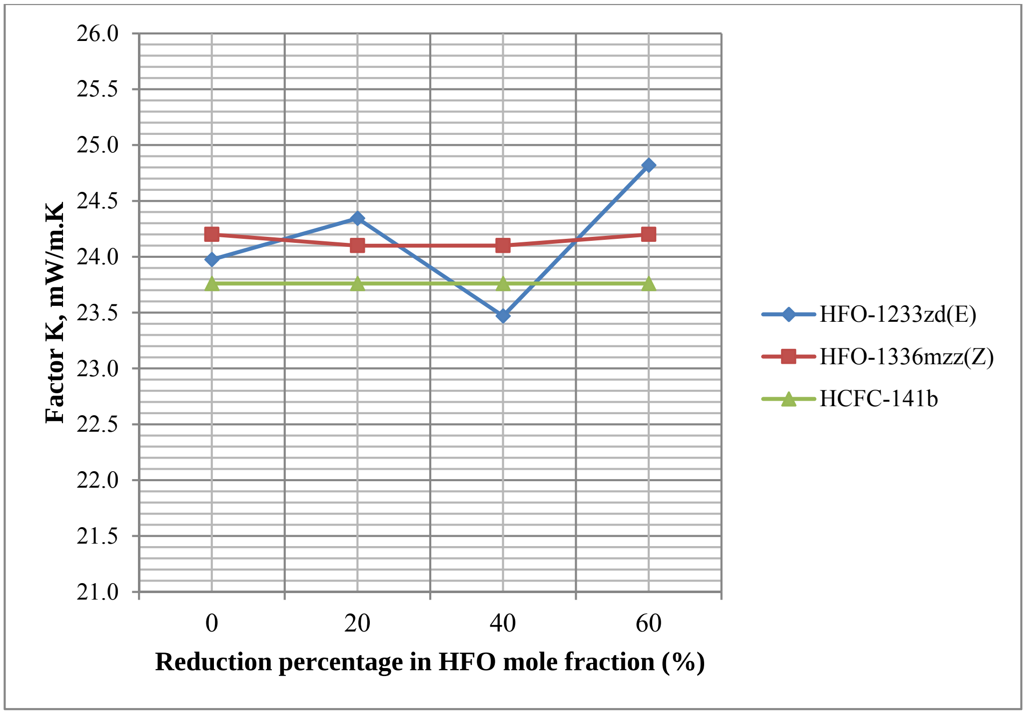


Figure 15. K factor (4 weeks) vs. Reduction percentage in HFO mole fraction

Using the ANOVA results of the foam K factor measured 4 weeks after injection, shown in Table 12, it is concluded that, oppositely to what happened with the initial K factor, the HFO/CO_2 ratio did not show a statistically significant effect on the foam K factor when measured 4 weeks after injection. In the same manner no significant difference between the two types of HFO, HFO-1233zd(E) and HFO-1336mzz(Z), was observed.

Table 12. ANOVA of K factor, 4 Weeks						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type of blowing agent (A)	1	0.000	0.000	0.000	0.994	
HFO/CO_2 ratio (B)	3	1.150	0.385	0.811	0.523	
A*B	3	0.856	0.286	0.602	0.632	
Pure Error	8	3.790	0.474			

Similarly to section 5.1, Tables 13 and 14 compare the HCFC-141b with the HFO reduced systems (40 and 60%). In this case, when the foam K factor was measured 4 weeks after injection and as it could be expected from the Figure 15, a statistically significant difference between the HCFC-141b and the HFO based formulations was not observed.

Table 13. ANOVA of K factor, 4 weeks, HCFC-141b vs. HFO-1336mzz(Z) (40%) vs. HFO-1336mzz(Z) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type de blowing agent	2	0.200	0.100	0.151	0.866	
Pure Error	3	1.990	0.663			

Table 14. ANOVA of K factor, 4 weeks, HCFC-141b vs. HFO-1233zd(E) (40%) vs. HFO-1233zd(E) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type of blowing agent	2	2.020	1.010	0.748	0.545	
Pure Error	3	4.050	1.350			

5.3. Compressive Strength measured 2 months after injection

Table 15 and Figure 16 show a summary of the results of the foam compressive strength measured 2 months after injection.

Table 15. Compressive Strength (kPa), 2 Months, adjusted at 32 kg/m^3					
Reduction Percentage	**HFO-1233zd(E)**		**HFO-1336mzz(Z)**		**AVERAGE**
0%	177.80	157.60	147.10	163.60	161.53
20%	146.90	185.80	171.10	177.10	170.23
40%	111.20	118.60	166.10	144.60	135.13
60%	129.60	118.30	166.90	177.00	147.95
AVERAGE	143.23		164.19		
HCFC-141b standard: 170.85					

Compared to HCFC-141b low compressive strength values were obtained with two HFO-1233zd(E) systems, those reduced at 40 and 60%. From a theoretical point of view and the reported data, this could not be explained by the difference in blowing agent but by other formulation parameters[1]. Further results at the industrial level contradicted these experimental points.

---

1 Compressive strength is directly affected by the structure of the polyurethane polymer and this is related to the blend of polyols used in the formulation. When high water levels are introduced in the formulation, to counterbalance the undesirable effects of poliurea "softer" type of polyols (low functionality, high molecular weight) are used. For each tested formulation (blowing agent, % of blowing agent reduction) it was necessary to develop a specific polyol blend.

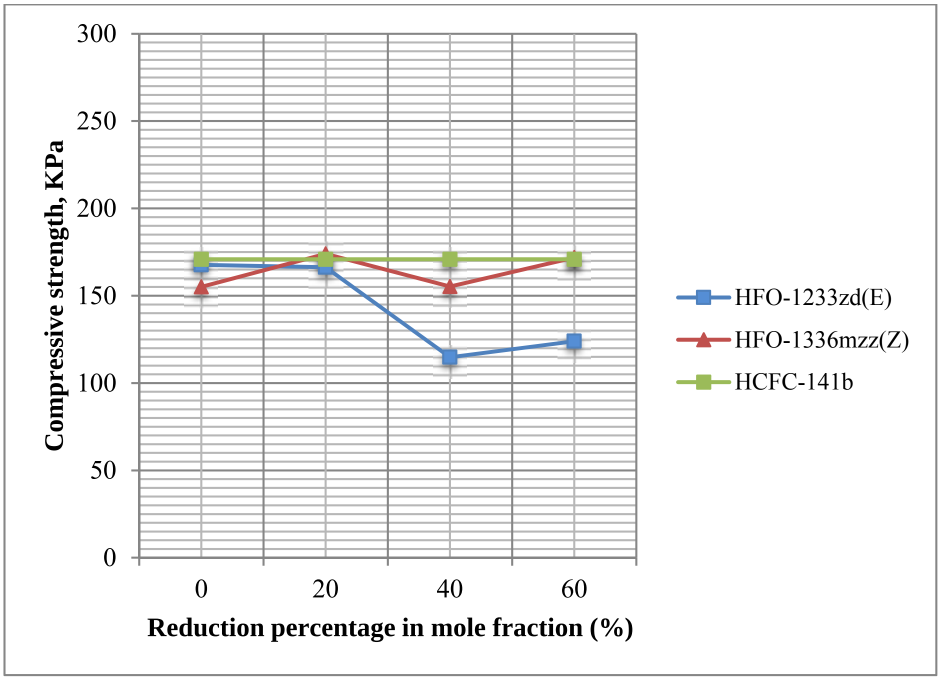


Figure 16. Compressive strength (2 months) vs. Reduction percentage in HFO mole fraction

As expected from the mentioned low compressive strength values, the ANOVA, shown in Table 16, concludes that both factors, the type of HFO and the HFO/CO_2 molar fraction ratio and its interaction, have a statistically significant effect over this physical property.

Table 16. ANOVA of Compressive Strength Adjusted to 32 kg/m^3, 2 months

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	P	
Type of blowing agent (A)	1	1757.710	1757.710	9.450	0.015	Significant
HFO/CO_2 ratio (B)	3	2849.600	949.870	5.110	0.029	Significant
A*B	3	2395.080	798.360	4.290	0.044	Significant
Pure Error	8	1488.110	186.010			

In accordance to Table 17, that compares HCFC-141b with the HFO-1336mzz(Z) reduced systems (40 and 60%), a significant difference in compressive strength measured after two months is not observed.

Table 17. ANOVA of Compressive Strength, 2 Months, HCFC 141b vs. HFO-1336mzz(Z) (40%) vs. HFO-1336mzz(Z) (60%)

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	P	
Type of blowing agent	2	344,680	172,340	0,888	0,498	
Pure Error	3	582,260	194,090			

As expected from the above discussion, Table 18 led to conclude that there is a significant difference in compressive strength at 24 hours between the HCFC-141b and the HFO-1233zd(E).

Table 18. ANOVA of Compressive Strength, 2 months, HCFC 141b vs. HFO-1233zd(E) (40%) vs. HFO-1233zd(E) (60%)

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	P	
Type of blowing agent	2	3.607,940	1.803,970	13,830	0,031	Significant
Pure Error	3	391,350	130,450			

5.4. Aging of Compressive Strength, 2 months versus 24 hours

Table 19 shows the variation percentage of compressive strength, 2 months versus 24 hours. According to the ANOVA, presented in Table 20, there is no evidence of aging difference between the two types of HFO.

Table 19. Variation percentage in compressive strength (%) 24 hours vs. 2 months, adjusted at 32 kg/m^3

Reduction Percentage	HFO-1233zd(E)		HFO-1336mzz(Z)		AVERAGE
0%	3.13	-4.83	-8.41	-2.97	-3.27
20%	-6.61	11.12	-0.35	1.43	1.40
40%	-26.65	7.62	-3.26	11.57	-2.60
60%	11.05	6.29	-3.47	16.91	7.70
AVERAGE	0.14		1.43		

Table 20. ANOVA of variation percentage in compressive strength, 24 hours and 2 months

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	P	
Type de blowing agent (A)	1	1.6700	6.6700	0.048	0.833	
Mole fraction (B)	3	306.290	102.100	0.728	0.563	
A*B	3	210.370	70.120	0.500	0.693	
Pure Error	8	1121.420	140.180			

5.5. Dimensional Stability at 70°C and -30°C

The dimensional stability results at 70 ºC and -30°C are shown in Tables 21 and 22 and illustrated in Figures 17 and 18. The negative values represent foam contraction and the positive ones foam expansion. The ANOVA results are shown in the annex 1, Tables A-1 to A-6. In average, at 70 ºC, the HFO based systems provides lower values than HCFC-141b. There was no evidence of any significant difference among the systems based on the three analysed blowing agents.

Table 21. Dimensional Stability at 70 ºC , 2 Weeks, Vol. %

Reduction Percentage	HFO-1233zd(E)		HFO-1336mzz(Z)		AVERAGE
0%	0.73	1.36	2.79	2.79	1.92
20%	0.26	0.50	2.24	1.16	1.04
40%	0.21	-0.70	0.69	-1.83	-0.41
60%	-1.01	-1.11	0.22	-0.27	-0.54
AVERAGE	-0.31		0.37		
HCFC-141b standard: 1.62					

Table 22. Dimensional Stability at -30 ºC, 2 Weeks, Vol. %

Reduction Percentage	HFO-1233zd(E)		HFO-1336mzz(Z)		AVERAGE
0%	-0.13	-0.05	-0.29	-0.19	-0.17
20%	-0.13	-0.32	0.04	-0.24	-0.16
40%	-0.18	-0.05	-0.15	-0.38	-0.19
60%	-0.47	-0.52	-0.24	-0.69	-0.48
AVERAGE	-0.28		-0.28		
HCFC-141b standard: 0.07					

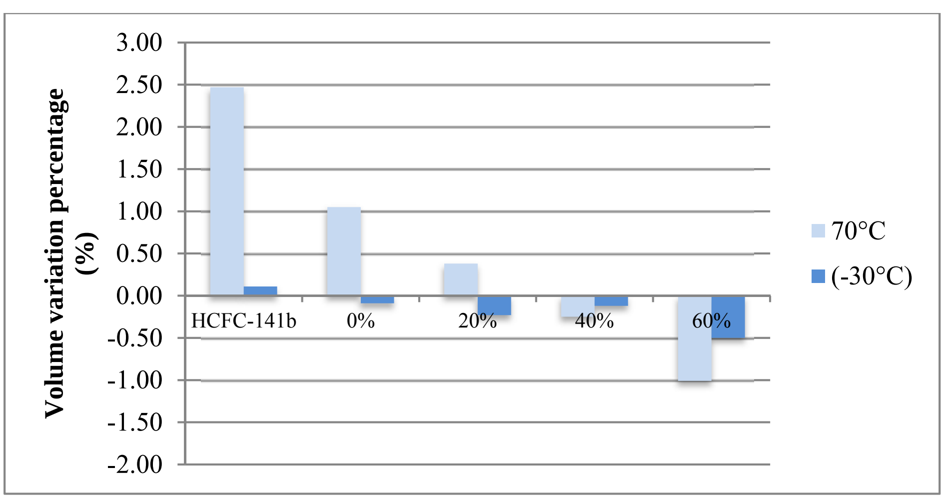


Figure 17. Percentage variation by volume. HFO-1233zd(E)

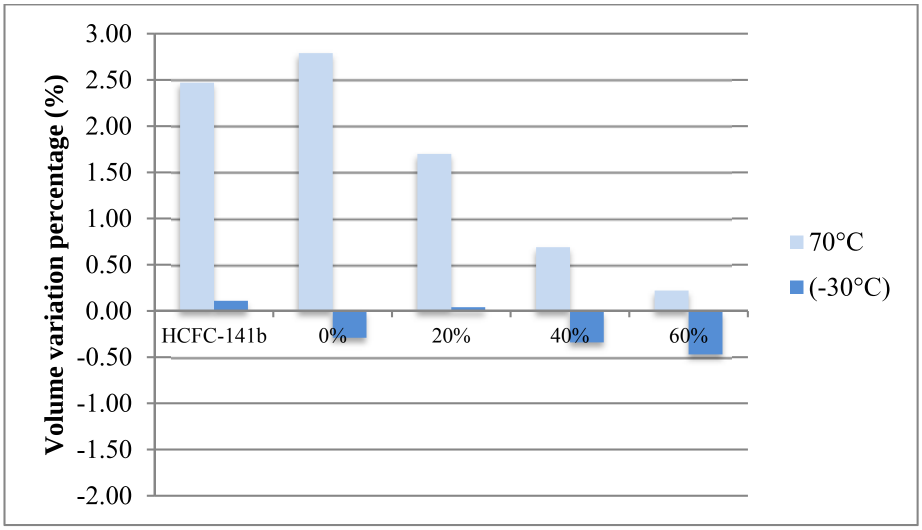


Figure 18. Percentage variation by volume. HFO-1336mzz(Z)

5.6. Adhesion to Metal

The results of the foam adhesion strength to metal (galvanised steel) measured one week after injection are shown in Table 23 and Figure 19. It was observed a better behaviour of the HFO based systems than the standard blown with HCFC-141b.

Table 23. Adhesion Strength to Metal (galvanised steel), kPa

Reduction Percentage	HFO-1233zd(E)		HFO-1336mzz(Z)		AVERAGE
0%	159.10	179.60	148.00	163.90	162.65
20%	171.70	224.60	224.60	206.40	206.82
40%	246.50	225.70	148.40	155.50	194.02
60%	216.50	216.50	151.20	146.20	182.60
AVERAGE	216.92		172.05		
HCFC-141b standard: 166.03					

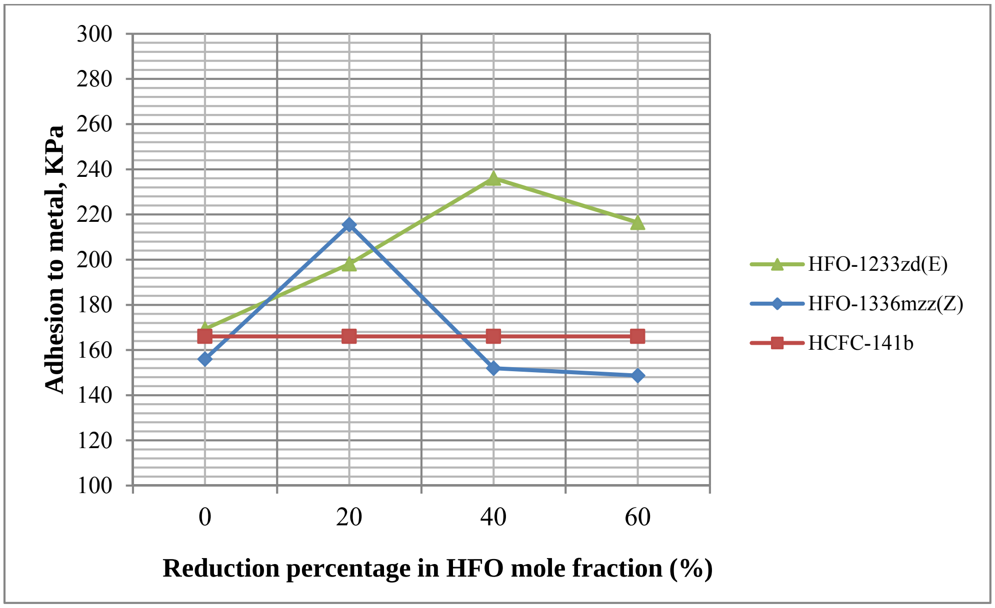


Figure 19. Adhesion to metal vs. Reduction percentage in HFO mole fraction

6. FIELD TESTS

Rojas Hermanos, a Colombian manufacturer of PU foam discontinuous panels for thermal insulation located in Bogota, equipped as shown in Figure 20, with a high pressure injection machine and two Manni type presses, was chosen to conduct the field tests. In two different working days 40 and 60% reduced formulations of HFO-1233zd(E) and HFO-1336mzz(Z) were run. The commercial HCFC-141b system, used as standard for the described laboratory trials, was run both days for comparison.

Figure 20. Field trials conducted at Rojas Hermanos

3m x 1m x 0.05m panels were injected at a single point located 1.3 m from the bottom. Pre-heated stainless steel faces were used. Once the minimum fill density was determined the panels were injected aiming at the same moulded density currently used in the industrial production (40 kg/m^3). Surface temperature was taken at three different points as illustrated in Figure 21.

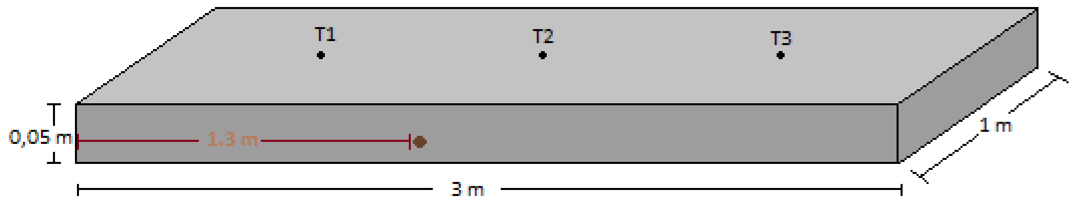


Figure 21. Injection Panel Scheme

An additional panel with 8 m x 1 m x 0.05 m dimensions was injected for each formulation to run the flammability test. Figure 22 illustrates this additional panel.

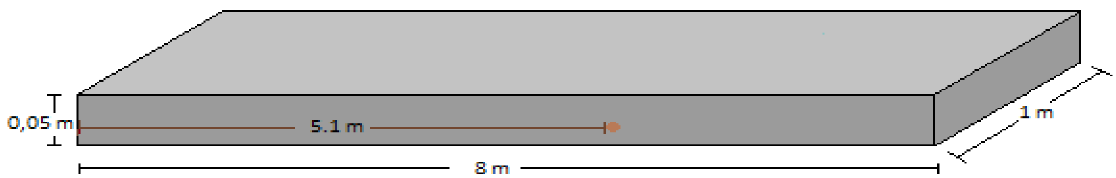


Figure 22. Injection Panel Scheme for Flammability Test

The injection conditions are described in Table 24.

Table 24. Injection Conditions at Rojas Hermanos	
Machine	Cannon A-Compact 200FC
Operative pressure, bar	130 +/- 10
Isocyanate Temperature, ºC	20 +/- 2
Polyol Temperature, ºC	19 +/- 2
Output, g/s	1300
Substrate Temperature, °C	39 +/- 1

After adjusting the injection conditions, the determination of the Minimum Fill Density (MFD) was done, as shown in Figure 23.

Figure 23. Determination of Minimum Fill Density (MFD) at Rojas Hermanos

The results of the foam properties measured 24 hours after injection are summarized in Table 25. No differences were observed between the 40 and 60% reduced systems. The HFO based formulations provided a superior foam flowability (lower flow index), similar compressive strengths and K factor values 3.8 and 7.2% higher than HCFC-141b.

Table 25. Initial results of mechanical and thermal properties of panels

Blowing agent	HCFC 141b (1)	HFO 1233zd(E)		HCFC 141b (2)	HFO 1336mzz(Z)	
Mole fraction in the gas cells	0.83	0.50	0.33	0.83	0.50	0.33
Machine reactivity						
Cream/gel/tack free time (s)	17/119/149	8/121/184	8/112/167	13/115/151	7/133/228	7/106/177
Free rise density (kg/m^3)	18.7	19.8	21.7	18.9	19.3	22.4
Minimum Fill Density (kg/m^3)	26.9	24.8	26.2	26.4	24.3	26.0
Flow Index	1.44	1.25	1.21	1.39	1.26	1.16
Moulded density (target) (kg/m^3)	40.0	40.0	40.0	40.0	40.0	40.0
De-mould time (minutes)	22					
K factor (mW/m.K)	20.62	22.17	21.90	20.59	21.97	22.26
Compressive strength (kPa)	168.2	169.3	156.7	160.8	172.9	171.9
Dimensional stability, 70°C (% ΔV), 24 hours	0.91	-0.68	-1.15	1.11	-0.18	-1.02
Dimensional stability, -30°C (% ΔV), 24 hours	-0.06	-0.26	0.22	0.25	-0.19	0.13

(1) (2): replicates run at two different days

7. COSTS OF HFO BASED POLYURETHANE SYSTEMS

7.1. Incremental Capital Cost

Compared to HCFC-141b no additional capital was required for the preparation and testing -at laboratory and industrial levels- of the HFO formulations. As it is shown in Table 1 the HFO 1233zd(E) and 1336mzz(Z) have boiling points of 19 and 33 ºC and the trials were run in Bogota at an ambient temperature ranging from 10 to 20 ºC. At hotter climates there may be a need with the HFO 1233zd(E) to cool the formulated polyol storage and the formulated polyol day-tank to 20-25ºC storage to avoid the excessive build-up of pressure. It should be also noted that all the moulds used during the tests were equipped with heating systems and associated temperature controls (39 and 45ºC). This is a critical condition to ensure a good performance with reduced HFO PU formulations.

7.2. Incremental operating cost

The disaggregated formulation costs of the HFO reduced systems compared to the HCFC-141b based formulation are shown in Tables 26 and 27. The different blends of polyols (sugar/glycerine, glycerine and amine initiated) used to formulate the PU systems had a similar cost that ranges between US$2.14 and US$2.16 per kg. The only exception was the 60% reduced HFO-1233zd(E) based formulation which required the introduction of a special relatively expensive polyol. A similar statement applies for the additives packages (catalysts, silicon surfactant, flame retardants) whose costs per kg varied between US$ 1.47 and US$ 1.61.

The reduction of the HFO mole fraction in the gas cells made possible a significant decrease of the cost of HFO based systems. In the case of HFO-1336mzz(Z), compared to the cost of the unreduced HFO system, a 60% reduction represented a 31.45% less expensive formulation. In the case of HFO-1233zd(E), by going from a mole fraction of 0.82 (0% reduction) to 0.32 (60% reduction), the system cost was cut off by 19%. This is illustrated in Figure 24.

Table 26. Cost of PU systems based on HFO-1233zd(E)

	HCFC-141b		**HFO-1233zd(E)**							
			0% reduced		**20% reduced**		**40% reduced**		**60% reduced**	
Mole fraction in the gas cells	0.83		0.82		0.66		0.51		0.32	
Reduction percent of HFO by weight (%)			0		26.85		45.04		63.76	
FORMULATION	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**
Polyol blend	100.00	2.16	100.00	2.15	100.00	2.15	100.00	2.14	100.00	2.42
Additives (catalysts, surfactant, additives)	27.39	1.47	27.48	1.53	27.43	1.52	27.63	1.55	27.58	1.61
Water	1.54		1.34		2.39		3.22		4.28	
Blowing agent	47.25	2.97	45.76	12.00	33.82	12.00	22.88	12.00	14.92	12.00
FORMULATED POLYOL	176.18	2.25	174.58	4.61	163.64	4.05	153.73	3.46	146.78	3.17
PMDI	190.28	3.18	166.67	3.18	180.98	3.18	156.68	3.18	160.01	3.18
TOTAL SYSTEM COST	**2.73**		**3.91**		**3.59**		**3.32**		**3.18**	

Table 27. Cost of PU systems based on HFO-1336mzz(Z)

	HCFC-141b		**HFO-1336mzz(Z)**							
			0% reduced		**20% reduced**		**40% reduced**		**60% reduced**	
Mole fraction in the gas cells	0.83		0.83		0.66		0.50		0.33	
Reduction percent of HFO by weight (%)			0		17.70		41.94		60.77	
FORMULATION	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**	**PPHP**	**US$/kg**
Polyol blend	100.00	2.16	100.00	2.14	100.00	2.16	100.00	2.16	100.00	2.14
Additives (catalysts, surfactant, additives)	27.39	1.47	27.63	1.53	27.45	1.51	27.18	1.48	27.33	1.50
Water	1.54		1.29		2.34		3.48		4.78	
Blowing agent	47.25	2.97	56.71	20.00	42.28	20.00	32.33	20.00	21.89	20.00
FORMULATED POLYOL	176.18	2.25	185.62	7.49	172.07	6.41	162.99	5.54	153.99	4.50
PMDI	190.28	3.18	156.51	3.18	180.75	3.18	173.22	3.18	182.90	3.18
TOTAL SYSTEM	**2.73**		**5.52**		**4.75**		**4.32**		**3.78**	

COST					

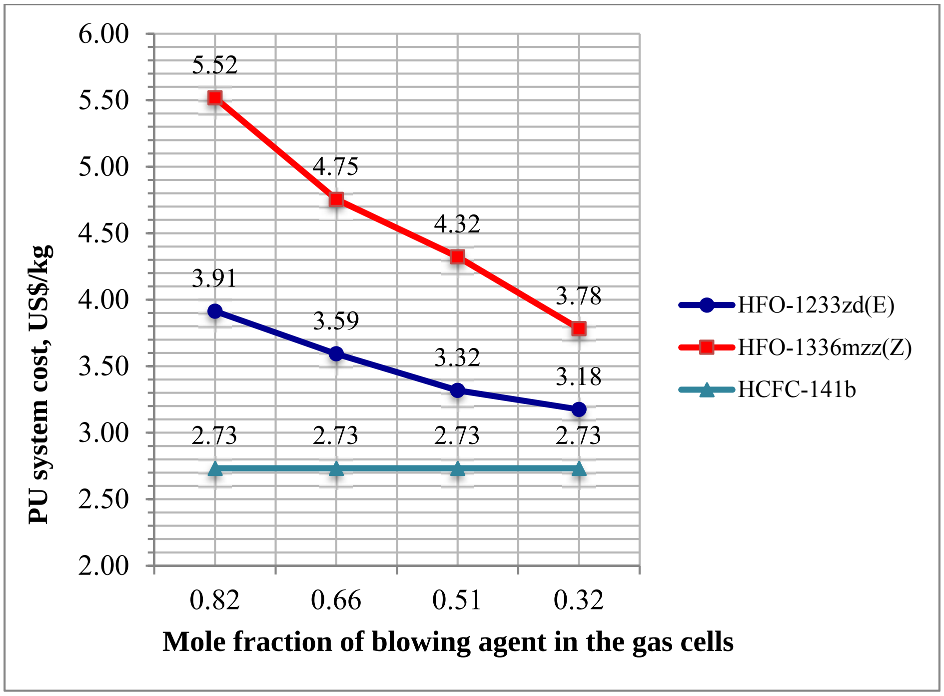


Figure 24. Cost of PU systems vs. Mole fraction of blowing agent

7.3. Final words about further trials with better cost/performance balance

At the end of the project and after an extensive formulation work, stable HFO based systems reduced by 80% were developed using N, methyl dicyclohexylamine and two tertiary amine catalysts of proprietary composition (Dabco 2039 and 2040). The results of the foam testing were promising and are shown in Table 28.

Table 28. Physical properties of 80% reduced HFO formulations

Blowing agent		HCFC 141b	HFO 1233zd(E)	HFO 1336mzz(Z)
Mole fraction in the gas cells		0.83	0.17	0.17
Machine reactivity				
	Cream/ gel/ tack free times (s)	10/111/155	8/69/99	9/78/110
	Free rise density (kg/m^3)	20.1	21.2	21.2
Minimum Fill Density (kg/m^3)		29.3	31.5	31.8
Flow Index		1.46	1.49	1.50
K-Factor initial (mW/m.K)		21.51	22.48	22.48
Compressive strength 24 hours (kPa) adjusted at 32 kg/m^3		107.6	147.1	161.9
Dimensional stability, 70°C (% ΔV), 24 hours		1.02	-3.47	-2.74
Dimensional stability, -30°C (% ΔV), 24 hours		0.38	-0.48	-1.23

8. SAFETY AND INDUSTRIAL HYGIENE

The Material Safety Data Sheets (MSDS) of the HFOs referenced for the project evaluation are provided by separate in Annex 2. The HFO-1233zd(E) and 1336mzz(Z) are non-flammable substances and no special precautions are needed from the safety point of view. There are no additional issues concerning industrial hygiene compared to HCFC-141b. The 8-hour Time Weighted Average (TWA), reported by the suppliers, are 800 ppm for 1233zd(E) and 500 ppm for 1336mzz(Z).

The specialised literature concludes that these specific HFO do not generate any significant amount of trifluoroacetic acid (TFA) in the atmospheric degradation process[2].

9. CONCLUSIONS

From the above results and analysis the following conclusions can be pointed out:

1. In the framework of this project supported by the Multilateral Fund, HFO based formulations with blowing agent reductions of 61 to 64 by weight were developed. This is equivalent to an HFO reduction in the gas cells of 60%.
2. Compared to HCFC-141b, the HFO reduced formulations showed:
   - Better foam flow reflected by a lower flow index (ratio between the free rise density and the minimum fill density).
   - An initial foam K factor higher by 7% in laboratory (Brett injections). This value was reproduced at industrial plant.
   - Similar values of foam K factor when measured one month after injected.
   - Similar laboratory and production plant values of compressive strength, dimensional stability and adhesion to metal.
3. There was not observed -from a statistical point of view- a difference between the performance of foam based on the two types of HFO: 1233zd(E) y 1336mzz(Z).
4. Considering that the foam HFO based technology is not flammable, it does not deplete the ozone layer (0 ODP) and has a low GWP (< 2), it was confirmed that compared to HCFC-141b, the foam HFO based technology does not present any additional environmental and safety and industrial hygiene issue.
5. The handling and processability at the production plant of the HFO reduced formulation was similar to HCFC-141b.
   - In hot weathers the PU systems based on HFO-1233zd(E) could require a storage conditioned at low/ medium temperatures.
6. Regarding to the Incremental Capital Cost of the foam HFO based technology, it is important to point out that at hotter climates there may be a need with the HFO 1233zd(E) to cool the formulated polyol storage and the formulated polyol day-tank to 20-25ºC storage to avoid the excessive build-up of pressure. Additionally, it is relevant to consider that for discontinuous

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2 For 1336mzz(Z) see: Baasandorj, M., et al. (2011), *J. Phys. Chem.* A 115(38): 10539-10549. Chiaperro, M. S., et al. (2006), *J. Phys. Chem.* A 110(43): 11944-11953. Cadle, R. D., (1980). *Rev. Geophys. Space Phys.* 18: 746-752.
For 1233zd(E) see: Wallington T.J., et al. (2015), *Chemosphere* 129: 135–141. Sulbaek Andersen M.P., et al (2012), *Phys. Chem. Chem. Phys.*14: 1735-1748.

panels and other rigid foam applications, the moulds should be equipped with heating systems and associated temperature controls to ensure a good performance with reduced HFO PU formulations. Costs related to these items must be considered.

7. Thanks to the technology formulation it was possible to significantly reduce the cost of the HFO based formulations. Nowadays the HFO reduced systems have higher costs than HCFC-141b by 16.4 and 33.2%, but these figures could be lower in the future.
8. Notwithstanding the positive results of this project, further trials are required to take into consideration the diverse boundary conditions (climate, injection equipment, etc.) typical of the SMEs universe and the higher cost of the special catalysts of proprietary composition that may be necessary.

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ANNEX 1. ANALYSIS OF VARIANCE OF THE FOAM PROPERTIES

In Section 6 of the report, the ANOVA corresponding to the foam K-Factor and its aging and compressive strength were presented. In this annex the results of the ANOVA analysis of the rest of the foam properties are shown.

A.1 Dimensional Stability at 70°C

Table A-1. ANOVA of Dimensional Stability at 70 ºC, two weeks						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type de blowing agent (A)	1	3.560	3.560	6.300	0.036	Significant
Mole fraction (B)	3	16.850	5.620	9.930	0.005	Significant
A*B	3	2.400	0.801	1.420	0.308	
Pure Error	8	4.520	0.566			

Table A-2. ANOVA of Dimensional Stability at 70 ºC, two weeks, HCFC 141b vs HFO-1336mzz(Z) (40%) vs. HFO-1336mzz(Z) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type HFO	2	2,030	1,020	1,460	0,362	
Pure Error	3	2,100	0,699			

Table A-3. ANOVA of Dimensional Stability at 70 ºC, two weeks, HCFC 141b vs HFO-1233zd(E) (40%) vs. HFO-1233zd(E) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type HFO	2	1,360	0,679	1,300	0,393	
Pure Error	3	1,570	0,523			

A.2 Dimensional Stability at -30°C

Table A-4. ANOVA of Dimensional Stability at -30 ºC, two weeks						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type de blowing agent (A)	1	0.005	0.005	0.207	0.661	
Mole fraction (B)	3	0.286	0.095	3.753	0.060	
A*B	3	0.056	0.019	0.740	0.557	
Pure Error	8	0.203	0.025			

Table A-5. ANOVA of Dimensional Stability at -30 ºC, two weeks, HCFC 141b vs HFO-1336mzz(Z) (40%) vs. HFO-1336mzz(Z) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type HFO	2	0,160	0,080	1,820	0,304	
Pure Error	3	0,132	0,044			

Table A-6. ANOVA of Dimensional Stability at -30 ºC, two weeks, HCFC 141b vs HFO-1233zd(E) (40%) vs. HFO-1233zd(E) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type HFO	2	0,221	0,111	24,130	0,014	Significant
Pure Error	3	.0137	0,005			

A.3 **Foam adhesion to metal (galvanised steel)**

Table A-7. ANOVA of Adhesion strength to metal						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type de blowing agent (A)	1	5476.000	5476.000	20.325	0.002	Significant
Mole fraction (B)	3	4215.045	1405.015	5.215	0.028	Significant
A*B	3	6682.645	2227.548	8.268	0.008	Significant
Pure Error	8	2155.380	269.423			

Table A-8. ANOVA of adhesion to metal, HCFC 141b vs HFO-1336mzz(Z) (40%) vs. HFO-1336mzz(Z) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type HFO	2	339,220	169,610	13,410	0,032	Significant
Pure Error	3	37,940	12,650			

Table A-9. ANOVA of adhesion to metal, HCFC 141b vs HFO-1233zd(E) (40%) vs. HFO-1233zd(E) (60%)						
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F**	**P**	
Type HFO	2	5.228,260	2.614,130	36,210	0,008	Significant
Pure Error	3	216,560	72,190			

ANNEX 2. MATERIAL SAFETY DATA SHEETS (MSDS) OF THE REFERENCED HFOs

PROJECT COVER SHEET

TYPE OF PROJECT	Demonstration project
TITLE OF THE PROJECT	**Replacement of a HCFC-22 refrigeration system by a R-717/R-744 (NH_3/CO_2) system in cold storage warehouse finished product of Premezclas Industriales para Panadería S.A.**
COUNTRY NAME	**Costa Rica**
IMPLEMENTING AGENCY	UNDP
GOV. COUNTERPART	Ozone Unit of Costa Rica. Government of Costa Rica.

DATES OF RATIFICATION OF AMENDMENTS TO THE PROTOCOL			
London	June 1998	**Copenhagen**	June 1998
Montreal	May 2005	**Beijing**	October 2008

GENERAL INFORMATION		
Sector / Sub-sector	Refrigeration and Air Conditioning / Food manufacture industry	
ODS Consumption (sector)	8.92 Ton ODP	
Baseline	14.1 Ton ODP	
Starting Point for Aggregate Reductions		
Project Impact (ODP t.)		
Participating Company (ies)	**Premezclas Industriales para Panadería S.A.**	
Eligibility of participating company (ies)	100 % (A5)	% (non-A5)
Project Costs (US $)	943,000	
MLF Funding (US $)	524,000	
I.A. Supporting Costs (US $)	36,680	
Total cost of the Project for the MLF (US $)	560,680	
Project Duration (months)	14	

Report drafted by: Ing. Rodolfo Elizondo

Report cleared by: Dr. Roberto Peixoto

Executive Summary

During the 76th meeting of the Multilateral Fund´s Executive Committee for the Implementation of the Montreal Protocol, Costa Rica´s implementation proposal was approved, it consisted in a pilot project called “Replacement of a HCFC-22 refrigeration system by a R-717/R-744 (NH3/CO2) system in cold storage warehouse finished product of Premezclas Industriales para Panadería S.A.”; this refrigeration system is characterized by using two circuits, one of NH3 (ammonia) and another of CO2 (carbon dioxide), being NH3 in the high temperature system and CO2 in the low temperature circuit driven by pumps, where CO2 is used as a heat transfer fluid (*Brine*). This characteristic makes this project not only innovative but also being the first and only one in the Central American region that has been adopted in the food manufacturing industry.

The project replaced an original refrigeration system that used HCFC-22 as a refrigerant with a cooling capacity of 176 kW (50 TR), responsible for maintaining an average temperature of -11° Celcius in the finished product chamber.

The new NH3/CO2 cascade system began its implementation on June 2017 and it was launched on January 2018.

The works were contracted to a Costa Rican company called *CUESA Construcciones HU Sociedad Anónima* under a "turnkey" contract with a total cost of US$943,000, who acquired Mycom brand equipment, through another Costa Rican based company named *Mayekawa de Centroamérica SA*. The direct contribution of the Multilateral Fund for the Montreal Protocol to execute this project was US$444,000, and the rest was funded by a company´s counterpart.

The project´s implementation achieves the displacement of 909 kg of HCFC-22 that were installed in an equipment that exceeded its useful life, for more than 15 years, and reduced the emission of HCFC-22 used in the system´s maintenance activities due to the leaks of this refrigerant, whose average consumption during fiscal years of 2015-2016 and 2016-2017 was 1314 kg. Therefore, considering the ODP and GWP of HCFC-22 there is a benefit in the protecting the ozone layer and climate.

The new technology that was adopted allows PINOVA to reach temperatures of -18° Celcius in the finished product chamber, a result never achieved before with the original system and from the energy consumption point of view, the NH_3/CO_2 system is more efficient than the original installation. During the first two months of 2018 (January and February) PINOVA company reports a 10% reduction in the billed energy with regards to the normal manufacturing levels during 2017. It is expected that when the system stabilizes and there is better administration culture of opening of freezer´s doors of the finished product chamber, the energy saving can reach up to 20%, according to the estimate that was made.

It is demonstrated that the use of NH_3/CO_2 cascade system, with recirculated CO_2 brine, is an innovative solution for medium manufacturing companies in Costa Rica, which can be adopted by other national and/or regional companies that require finding a definitive solution due to the imminent displacement of refrigerants that deplete the ozone and produce atmospheric warming.

The new system provides PINOVA lower production costs due to the reduction of the operational costs by lowering the electricity consumption, fewer maintenance interventions, the non-acquisition of HCFC-22 to replace the refrigerant gas that escapes into the environment and the use of natural gases that cost less with respect to chemical refrigerants.

The alternative selected by PINOVA allows it to contribute to the business commitment of Carbon Neutral and to Costa Rica´s Carbon-Neutrality target by 2021.

1. Introduction

1.1 Background.

Premezclas Industriales para Panadería S.A. (PINOVA) requires the use of low temperature refrigeration systems for its manufacturing process and then the temporary storage for the different bakery and confectionary bases that are manufactured.

During the manufacturing process, rapid freezing tunnels are required with temperatures of -35°C, the refrigeration systems operate with ammonia as the main refrigerant in direct expansion.

In order to storage the finished products, a freezing chamber of 9000 cubic meters and a system of three pre-chambers are required for the entry and exit of the finished product. The maximum storage capacity in the chamber is of 250 tons of finished product, which has been limited by the operating capacity of the refrigeration system that worked until December 2107, with an average temperature of -11°C that was directly related to the age of the equipment, that exceeded fifteen years and is based on the use of HCFC-22 with a 909 kg cargo.

During the fiscal year of 2015-2016, the consumption of HCFC-22 refrigerant reached 1,655.71 kg and during the fiscal year of 2016-2017 it reached 971.75 kg of HCFC-22, generating the equivalent of 4730 tons of CO_2, compromising the company´s public carbon neutrality agreement.

In 2013 comes the opportunity to present to the Executive Committee of the Montreal Protocol proposals to develop pilot projects with the characteristic that these will be energy and environmentally efficient. Therefore, the reconversion project of a HCFC-22 system to a NH_3/CO_2 cascade system with recirculated CO_2 brine for the finished product freezing chamber of the company Premezclas Industriales para Panadería S.A (PINOVA), is submitted and approved at the 76th meeting of the Executive Committee of the Montreal Protocol.

1.2 HPMP and HCFC-22 consumption

Costa Rica does not produce HCFCs, therefore, all HCFCs that exist in the country is imported. HCFC-22 is the main HCFC imported into the country, used mainly for the service and maintenance of refrigeration and air conditioning equipment (RAC).

Consistent with this situation, a phased approach is adopted for the HCFC phase-out management plan, based on the average consumption for the years 2009 and 2010, respectively.

Since 2010, Costa Rica applies a licensing system for the importation of HCFCs and HFCs covered by regulation 35676 S-H-MAG-MINAET. This system is implemented by the National Ozone Unit, the Office for Environmental Quality Management of the Ministry of Environment and Energy (MINAE), in coordination with other government institutions, universities, business chambers and private companies.

In 2014, Costa Rica eliminated 83% of HCFC-141b import, through the implementation of a project to reconvert the foaming lines in the manufacture of domestic refrigerators. Currently, small amounts of pure HCFC-141b are imported to be used in refrigeration and air-conditioning system (RAC) service, as well as some smaller quantities of pre-blended polyol used by small foam manufacturing companies.

Table #1
HCFC Consumption in Costa Rica.

HCFC ODP tons	2009	2010	2011	2012	2013	2014	2015	2016
HCFC-22	10.60	9.45	18.62	16.98	9.80	9.80	8.56	8.55
HCFC-141b *	3.11	4.06	3.13	5.35	2.58	2.55	2.19	2.23
HCFC-142b	0.34	0.46	0.00	0.61	0.16	0.16	0.14	0.10
HCFC-124	0.13	0.04	0.00	0.05	0.02	0.02	0.01	0.01
HCFC-123	0.01	0.00	0.00	0.01	0.06	0.06	0.05	0.00
HCFC-225ca	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.00
HCFC-225cd	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.00
Subtotal	**14.20**	**14.01**	**21.75**	**22.99**	**12.60**	**12.64**	**11.08**	**10.89**

(*) Only use as cleaning agent.

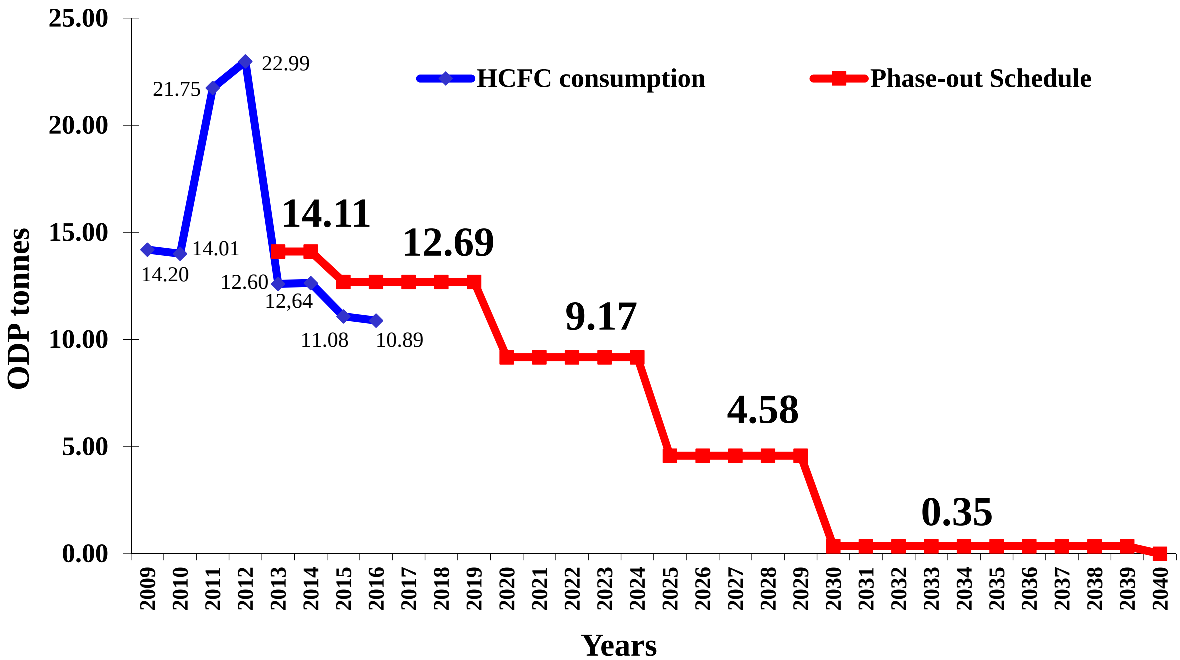
(Source: HPMP CR 2016 Progress Report)

Table # 1 shows the volume of HCFC imports in ODP (Ozone Depletion Potential) for the years 2009 to 2016 compared to the baseline (2009-2010), during 2011 and 2012, imports had an expected increased, because HCFC importers knew about the implementation of the import quota system in 2013. With the implementation of import quotas for HCFC, the consumption of these substances was reduced in 2013 to the maximum levels allowed. The total import of

HCFCs in Costa Rica should not exceed 14.1 ODP tones (baseline value), as established in national legislation.

Chart No. 1

HCFC consumption vs Phase-out Commitment



(Source: HPMP CR 2016 Progress Report)

Chart #1 shows the behavior of HCFC imports with respect to the phase-out commitment assumed by Costa Rica, which shows that the level of consumption is below the authorized quantities.

2 Importance of the pilot project

Regarding the importance of the implemented project, the following points can be highlighted:

- Allows the food manufacturing sector to have a definitive technological option available in light of the HCFC refrigerant elimination process and the HFC refrigerant control process recently approved in the Kigali Amendment of the Montreal Protocol.

- Start up a technologically advanced refrigeration system, with less environmental impact and greater energy efficiency.
- Reduce imports of HCFC refrigerants, which impact stratospheric ozone and increase global warming.
- Shows the users of refrigeration systems, both national and Central American, based on the success of the implemented project, that it is possible to adopt a technology based on natural refrigerants that covers the refrigeration needs that currently use HCFC -22.
- Generate confidence within the decision-making levels, related to the adoption of definitive natural technologies in RAC systems, in the commercial and industrial sector of Costa Rica.
- Provide the country with the opportunity to receive technology transfer in the installation, operation and start-up of RAC systems by experts, where this technology has already been implemented.
- Eliminate 900 kg of HCFC-22 installed in one single industrial equipment, which will be destroyed through the program of destruction of refrigerant gases in cement kilns in Costa Rica.
- Create national technical capacity for the use, installation and design of the NH_3/CO_2 cascade technology with recirculated CO_2 brine.
- Innovate technologies used for refrigeration in the food manufacturing sector.
- Develop and implement a pioneering refrigeration NH_3/CO_2 cascade system with recirculated CO_2 brine, in the food manufacturing sector in the Central America and the Caribbean region.
- Break paradigms regarding the installation of refrigeration systems using B3 (NH_3) classified natural refrigerants with high working pressures (CO_2).
- Promote sustainable technologies from a technical, environmental and energy efficient point of view.

3. Project Description

3.1 Characteristics of the original installation with HCFC-22

The original equipment that used HCFC-22 and that the base for this demonstrative project, was the result of a first conversion carried out by the company in the early 2000s, which at that time used CFC-502.

The original refrigeration system, that PINOVA operated for more than 15 years to cool the finished product chamber, was composed of a single-stage direct expansion system, with a refrigerant charge of 909 kg of HCFC-22.

3.1.1 Characteristics of the equipment installed in the original system.

The general characteristics of the equipment that constituted the original installation are shown in the following table.

Table #2

General characteristics of the original equipment that used HCFC-22 refrigeration system and power of its electric engines.

Equipment	Quantity	Number of Engines	Type	Unit Power		Total Power
				HP	kW	kW
Compressor #1	1	1	Screw	60	44.76	44.76
Compressor #2	1	1	Screw	60	44.76	44.76
Compressor #3	1	1	Screw	50	37.30	37.30
Compressor #4	1	1	Reciprocating	6	4.48	4.48
Compressor #5	1	1	Reciprocating	6	4.48	4.48
Compressor #6	1	1	Reciprocating	7	5.22	5.22
Evaporator #1	11	13	Axial fan	5	3.73	48.49
Evaporator #2	3	6	Axial fan	1.5	1.12	6.71
Condenser#1	1	2	Axial fan	3	2.24	4.48
Condenser #2	1	2	Axial fan	3	2.24	4.48
Condenser #3	1	8	Axial fan	3	2.24	17.90
						223.05

Source: own creation

The total drive power that was installed in the compressors of the original HCFC-22 system was 223 kW (299 HP), with a cooling capacity of 176 kW (50 TR), this would require a manufacturing process that demanded the operation of the system to be of 24/7[1]. Annex #1 shows photographs of the original installation.

[1] 24 hours a day 7 days a week

3.1.1 System operating parameters.

- Chamber temperature.

  The original system reached an average temperature of -11°C inside the finished product chamber, not allowing lower temperatures in this chamber, which limited the possibility of taking advantage of all the available space for storage.

- Energy consumption

  The energy consumption of the original installation was related to old equipment that was installed, shown in table #2. Due to the conditions of the manufacturing process, the operation of the refrigeration system was 24/7. According to company estimates, 18% of the monthly electricity consumption corresponded to the energy consumption of the HCFC-22 system.

Table #3
Estimate energy consumption of the original cooling system of the finished product chamber.

Energy consumed (kWh)		
Day	Month	Year
5,353.30	160,598.88	1,927,186.56

Source: own creation

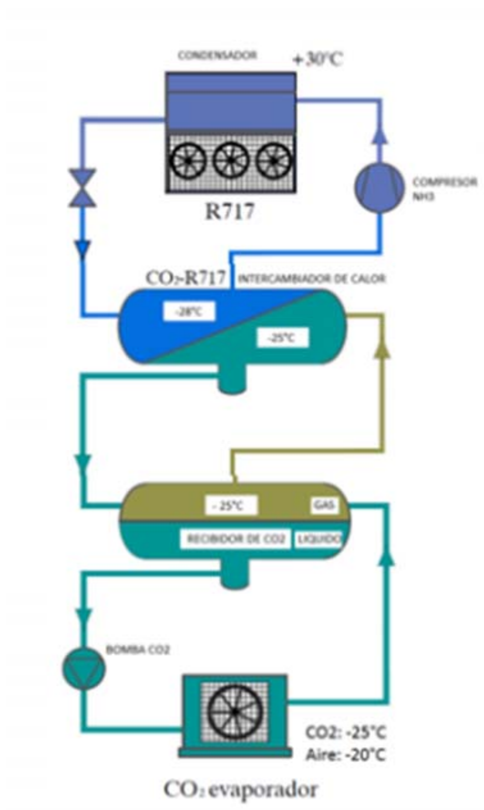
Appendix #1 shows the calculation details made to determine the energy consumption, where the variable is the daily operating time of each equipment. According to the information provided by PINOVA's maintenance and production departments, the limited capacity of the original system versus the demand for finished product, makes this system operate continuously at its nominal capacity (24/7/30/12), data that was used the estimate of the energy consumption in Appendix # 1.

3.2 Characteristics of the new NH3/CO2 cascade installation with recirculated CO2 brine.

The new system that was installed is characterized by having a recirculated CO2 secondary circuit, known as brine system, which operates under a principle similar to "iced water" installation used in central air conditioning systems with chillers. In the installed system, the CO2 refrigerant condensed at low temperature is circulated by a centrifugal pump system. The following diagram shows in a simplified manner the new installation made in PINOVA.

Diagram # 1

NH3/CO2 cascade system with recirculated CO2 *brine*



Source: Mayekawa

Until this date, the existence of another similar facility in Central America is not known. However, if there are 2 "brine" NH3/CO2 installations in South America, specifically in Argentina and Ecuador. Being this last one, the installation that served as inspiration to duplicate this technology in Costa Rica.

3.2.1 Characteristics of the installed equipments.

The new installation has high end technology equipment and systems, the electric engines integrated into the different equipment of the NH3/CO2 "brine" system are Premium efficiency, with electronic low voltage starting systems, solid state type.

The tanks and containers were built in carbon steel, inspected and stamped under ASME standards Section VIII, Div. 1. Year 2005. All the equipments were imported, built under the specifications of PINOVA through the Mayekawa company and its network of suppliers.

The following table shows the general characteristics of the new facilities equipment.

Table #4

General characteristics of the new refrigeration equipment with NH3/CO2 brine cascade system and electric motors power

Equipment	Quantity	Number of engines	Type	Unit Capacity		Total Power
				HP	kW	kW
Compressor #1	1	1	Screw	100	74.60	74.60
Compressor #2	1	1	Screw	100	74.60	74.60
Oil pump Co. #1	1	1	Positive displace	1.5	1.12	1.12
Oil pump C0. #2	1	1	Positive displace	1.5	1.12	1.12
Compressor #3	1	1	Reciprocating	30	22.38	22.38
Evaporative condenser	1	1	Axial fan	0	11.00	11.00
Evaporative condenser pump	1	1	Centrifuge	0	1.50	1.50
Evaporator PH #1	1	3	Axial fan	3	2.24	6.71
Evaporator PH #2	1	3	Axial fan	3	2.24	6.71
Evaporator PH #3	1	3	Axial fan	3	2.24	6.71
CO2 pump #1	1	1	Centrifuge	0	2.20	2.20
CO2 pump #2	1	1	Centrifuge	0	2.20	2.20
Antechamber evaporator #1	1	2	Axial fan	0.75	0.56	1.12
Antechamber evaporator #2	1	2	Axial fan	0.5	0.37	0.75
Antechamber evaporator #3	1	2	Axial fan	0.5	0.37	0.75
						213.47

Source: own creation

The total cooling capacity is 359.4 kW (102.2 TR), and total installed electrical power is 213 kW (280 HP), the operation of the system is still 24/7 and all engines are highly efficient.
A detailed characteristic of the equipment that constitutes the new facility are shown in Appendix # 2.

3.2.2 Technical and system operating parameters.

- Chamber temperature.

  The operating conditions of the new brine NH_3/CO_2 refrigeration system are defined by:

  - Temperature of the finished product chamber of -18°C.
  - Antechamber temperature from 0°C to 5°C.
  - Evaporation temperature on the ammonia side (NH_3) of -30°C.
  - Condensation temperature 35°C.
  - Wet bulb temperature of 26°C.
  - Thermal load of finished product chamber 274.2 kW (78 TR).
  - Thermal load of the loading platform 30.9 kW (8.8 TR)
  - Thermal load of the band area 27.8 kW (7.9 TR)
  - Thermal load of the filling chamber 22.9 kW (6.5 TR)

Table # 5 shows the monitoring of three points of the finished product chamber, points specially defined by PINOVA´s technical staff which were define as hot spots by the effect of convection currents. The monitoring was performed for a period of 6 days, 17 hours, 20 minutes. It shows that the average temperature remains above -18°C, which was the design temperature of the new cooling system.

Table #5

Temperature monitoring of finished product chamber with NH_3/CO_2 system

Temperature	Zone 1	Zone 2	Zone 3
Minimum (°C)	-13.10	-13.90	-12.10
Maximum (°C)	-21.80	-21.50	-20.10
Average (°C)	-19.65	-20.11	-19.65

Source: Cuesa Construcciones HU Sociedad Anónima.

- Estimated energy consumption.

Just like in the original cooling system, the new NH3/CO2 system also works 24/7. Table # 6 shows the average energy consumption of the new system.

Table #6

Estimated energy consumption of the NH3 / CO2 cascade "brine" cooling system of the finished product chamber.

Energy Consumption (kWh)		
Day	Month	Year
4,258.11	127,743.30	1,532,919.60

Source: own creation

As it can be seen, between the data that is shown in tables #3 and #6, there is a reduction in energy consumption, estimated in regards with the original system, of 20%.

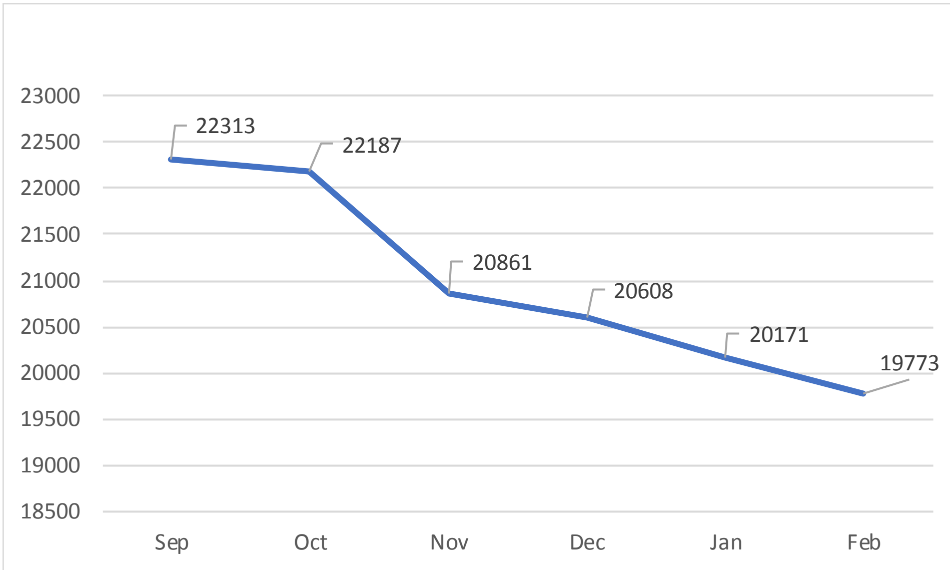
Appendix #2 shows the calculations made to estimate the energy consumption, where the variable is the daily operation time of each equipment. According to PINOVA´s maintenance and production department records, the new system works 24/7, however, of the three compressors installed, only one worked at nominal capacity during this period.

The new refrigeration system began its trial and tuning period during January 2018. Since that moment, the original system went out of operation, therefore, according to the electricity bill there was a saving of energy consumption recorded during the months of January and February of 2018.

Graphic #2 shows the behavior for the first two months of 2018, with respect to the 4th quarter of 2017. During November and December there is a reduction in the amount billed on electricity, this corresponds to non-working days according to PINOVA´s production schedule, also during December there were some non-working days because of the social activities carried out by the staff.

Graphic # 2

Average energy invoiced per day during the first months of fiscal year 2018



Source: PINOVA´s maintenance department

Considering the average billed between September-October and January-February, a decrease of 10.23% in energy consumption was obtained. This value can grow once the system is stabilized, and the company generates a better management culture of opening the chamber doors to reduce infiltration, which should reach about 20%, according to estimates made.

4. Project´s installation process and start-up

The project´s installation and start-up process was carried out under a series of duly planned activities, with the goal of minimizing risks that could generate delays, compromising the installation and start-up of the new equipment.

4.1 Structural evaluation

Before starting with the assembly process of the acquired equipment, the structural assessment of the sites where the new equipment would be installed was carried out by specialists in structural engineering.

4.2 Bidding process

A bidding process was carried out where the technical and administrative conditions of the execution of the project were defined.

4.3 Offer Reviews.

UNDP national and international consultants reviewed and validated the offers that were received. From this review, PINOVA selected the most convenient offer.

4.4 Execution of contracts, agreements and purchase orders.

The parties (applicant and supplier) transcribed their agreements into a contract, in which all the conditions were established, they included:

- The project would be executed turnkey.
- The supplier would supply all the equipment, materials, labor and structures necessary for the project´s start-up.
- The project´s total cost and the amount to be paid was established as $943,000 USD.
- The execution period would be 22 weeks.
- Once signed, the execution period of the project was considered official, and the purchase orders were issued in order to contract the necessary services and equipment.

A MINAE-PINOVA agreement was also executed, this agreement defined how the project´s disbursements will be made with the co-financing received by the Multilateral Fund of the Montreal Protocol, which was $ 444,000 USD for the acquisition of equipment. The funds were administered by UNDP Costa Rica, and the disbursements were executed according to the project´s progress.

4.5 Work Plan.

The supplier developed a work plan, this was reviewed and approved by the technical committee that was established to follow up the project and assess the compliance of the proposed activities.

4.6 Follow up meetings.

During the project´s execution period a weekly meeting was held to show the implementation progress and coordinated the weekly activities that interfered with the operation of the manufacturing plant, transportation and internal movements of equipment

4.7 Equipment Assembly.

The equipment was acquired from the company Mayekawa of Central America S.A., through the project´s contractor, CUESA Construcciones HU Sociedad Anónima. The import and nationalization of the equipment was in charge of Mayekawa de Centroamérica S.A. The assembly, electromechanical installation and testing of mechanical systems was in charge of the contractor CUESA Construcciones HU S.A.

Annex #1 shows the chronological photographic record of the project´s development from the beginning of the works until the start-up of the new system.

4.8 Testing process.

Before the start-up, the system was subjected to different tests, among them:

- Testing of welded connections of pipes and parts, using non-destructive tests such as penetrating liquids and ultrasound. (See Annex #3)
- Sweep pipes with nitrogen to remove solid waste.
- Leak test of the refrigeration circuit, by positive gauge and vacuum pressure, under the recommendations of the specialists, the project´s national and international consultant from UNDP.

4.9 Refrigerant charge in the equipment.

The refrigerant charge was executed with the participation of specialized companies that supply of industrial gases and natural refrigerants, with the assistance of CUESA and Mayekawa of Central America´s technical personnel, under protocols established for this purpose.

5. Benefits expected with the project.

5.1 Environmental.

From an environmental point of view, the project provides the following benefits.

- Lower emissions of ozone-depleting gases and greenhouse gases. Both, the direct emissions from the consumption of R22 in the maintenance processes of the previous system, and the indirect emissions due to the consumption of energy.
- Opportunity to maintain PINOVA and Costa Rica´s social commitment of "Carbon Neutrality".
- The project is consistent with Costa Rica´s commitment acquired in the Paris agreement.
- Reduction of indirect effect due to lower energy consumption

5.2 Technological and business

- Technology transfer that involves the acquisition of new knowledge for national technical personnel.
- Strengthening of national capacity (contractor and technicians) in the installation of refrigeration systems that work with natural refrigerant gases in Costa Rica (NH_3/CO_2).
- Real opportunity to show the benefits of using natural technologies in refrigeration systems.
- Offer of technical capacity for new future projects in the country or in the Central American region.
- South-South cooperation between PINOVA in Costa Rica and UNILEVER in Guayaquil, Ecuador, before and after the system´s start-up.

- Opportunity to provide technical assistance and carry out a technology transfer to other national and regional industries.
- The technical training stage of PINOVA´s personnel held in March 2018 in Guayaquil, Ecuador; the new installation of PINOVA and specifically the use of Penhouse type evaporators, represent an option that could be adopted by UNILEVER Ecuador, in order to solve maintenance problems in their installation.

5.3 Economic.

- Savings due to the elimination of HCFC-22 consumption in PINOVA´s finished product chamber, which reached on average of 1314 kg during 2015-2016 and 2016-2017 fiscal years.
- Reduction of service operations demanded by the finished product chamber and unscheduled shutdowns of the cooling system.
- Savings in energy consumption and in the cost for cooling PINOVA´s finished product chamber.
- Decrease in the outsourcing of refrigerated warehousing services contracted due to the lack of cooling capacity of the old HCFC-22 system.

5.4 Dissemination for other users in Costa Rica and Latin America

- It is expected to disseminate the project within the national business chambers where food manufacturing industries are located in the following sectors:
    - Baking industry.
    - Dairy industry.
    - Meat and sausage industry.
    - Fishing industry.
    - Frozen products storage services industries.
- At the regional level, the project will be disseminated through the national ozone offices, which are the focal point for programs and projects under the Montreal Protocol.

- It will also be disseminated among other non-governmental organizations that support migration to the use of natural refrigerants that generate less environmental impact and more efficient in energy consumption.

6. **Problems faced and lessons learned.**

- During the development of the project there were climatic phenomena (hurricanes) that affected the process of importing equipment, these are incidental causes that cannot be considered in the general planning of the project.
- It is necessary to maintain a strict control of the projects in order to generate corrective actions when there are unforeseen events, so that the schedule is not affected.
- It is important that the implementation of projects, such as the one adopted by PINOVA, generate national capacity.
- The option provided to PINOVA´s staff to previously know a similar facility in Guayaquil, Ecuador; was fundamental for the final decision about the technology to be adopted.

7. **Conclusions and recommendations**

- It is demonstrated that the use of NH_3/CO_2 cascade system, with recirculated CO_2 brine, is an innovative and viable solution to be implemented in medium manufacturing companies in Costa Rica.
- The implementation carried out by PINOVA can be adopted by other national and/or regional companies, that need to find a definitive solution to replace refrigerants that deplete the ozone and produce atmospheric warming.
- The implementation of the new cooling system for the finished product chamber based on the use of NH_3/CO_2 cascade, with recirculated CO_2 brine, provides PINOVA savings in electricity consumption.
- During the first two months of operation with the new system, the electric power billing already reflects a reduction of 10%.
- According to the estimate that was done, the new system can save up to 20% in the electricity billing, as long as there is a culture in managing the door openings of PINOVA´s finished product chamber.

- The technology based on natural refrigerant gases, adopted by PINOVA, eliminates the emission of ozone-depleting substances and will reduce emissions and greenhouse gases.
- The technology adopted and implemented by PINOVA, demonstrates that it is possible to break the barriers to apply natural gases with levels of toxicity, flammability and that work at high pressures.
- The start-up of the new system provides PINOVA with lower production costs due to the reduction in electricity consumption, less maintenance interventions, the non-acquisition of HCFC-22 to replace the refrigerant gas that escape into the environment, the use of natural gas of lower cost in comparison to chemical refrigerants.
- The alternative selected by PINOVA allows it to contribute to the business commitment and the government of Costa Rica´s target of Carbon Neutral and the Carbon-Neutrality target by 2021.
- In the medium term it will be necessary to execute another training to the technical personnel, according to the increased experience in the operation, service and maintenance of the new NH3/CO2 equipment. As well as specific service procedures required as the age of operation of the new system advances.
- The technology should be shown to technicians, refrigeration and engineering students as a role model and recommend. Likewise, business decision-makers are key to promote the change in similar industries.
- It is fundamental to perform a regular monitoring of the system´s operation in order to document and show the stakeholders the benefits of the technology related to energy consumption and operational data. Additionally, this information can be published in business journals, institutional publications, including UNDP.

Ministry of Environment and Energy

Male’, Republic of Maldives.

Progress Report

Demonstration Project for Fisheries Sector

April, 2018

Submitted for the consideration of the 81st Meeting
of the Executive Committee of
the Multilateral Fund for the implementation of the Montreal Protocol

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Abbreviations

DPND	Department of Planning and National Development
GWP	Global Warming Potential
HCFC	Hydrocholorofluorocarbon
HFC	Hydroflourocarbon
MIFCO	Maldives Industrial Fisheries Company
UNEP	United Nations Environment Program
MIT	Maldives Institute of Technology
UNDP	United Nations Development Program
RSW	Refrigerated Sea Water Systems

1. HCFC phase-out in the Maldives

The Maldives is a small island country and consumes HCFC-22 in refrigeration and air-conditioning applications. The consumption of HCFC-22 in the year 2017 was approximately 43.6 MT, which was a 35% reduction from the baseline. Of this total consumption, fisheries sector applications make for approximately 15-20% of the total consumption.

Fisheries sector plays an important role in the Maldives economy. It is the second largest contributor to Maldives' economy and employs a significant population of the country. The fish catch of Maldives is stored, processed, and exported globally. HCFC-22 is consumed in fisheries sector in a range of applications and predominantly in fishing vessels, processing and storage applications. Many of this equipment still have an economic life, although old and require continued use of HCFCs for their operations. Given that fishing vessels operate in sea and many times under rough sea and/or weather conditions, it is difficult to control leakage and adopt good servicing practices like in other equipment such as refrigeration equipment using HCFCs in land.

Stage I of HPMP, included retrofitting HCFC based equipment in the fisheries sector. Due to technological constraints and the need for compliance of the country, ODS free alternatives were selected as retrofit/drop-in substitutes. Due to high GWP of the selected refrigerant, the further usage was not advised to fishing sector. Based on these experiences, UNDP in May 2016 submitted a "Demonstration project for HCFC-free low-global warming potential alternatives in refrigeration in fisheries sector" to the 76th ExCom, got approval to find out the low GWP alternatives for fisheries sector. Fishing industry has agreed with the Government of the Maldives to continue their efforts to convert to low GWP alternatives that are technically feasible and economically viable, as and when such alternatives become available in the market. Hence, in order to help the fishing industry, particularly sea-borne vessels that use HCFCs, this project aims to demonstrate low-GWP HCFC free alternatives for use by fishing industry in the Maldives.

2. Maldives Fisheries sector

The fisheries sector plays a critical part in the country's economic development, with the fisheries sector contributing a significant contribution to food security, as fish is the primary source of protein in the local diet (FAO, 2016). It is one of the most important primary economic activity in almost all of the country's inhabited islands.

Maldives benefits from access to high quality fisheries stock, but a large share of its value is lost through export of fish as commodities to intermediary markets. Previously, Maldives shipped 90 percent of its fishing catch of tuna in dried form to Sri Lanka. In 1979, Maldivian government created the Maldives Fisheries Corporation.

As opposed to tourism, fisheries accounts for a very small contribution to GDP (1.7 percent) but a larger share of employment (10.5 percent). Currently the fisheries sector generates USD 110 million in export revenue.

The fisheries sector includes local fishing communities and enterprises developed for collection and processing of the catch. As shown in **Table 1**- **Table 5**, there are about 17 fisheries enterprises in operation, 4 facilities not in operation at the moment, 4 enterprises under construction, 7 facilities planned and 1 facility construction delayed.

Table 1: Fisheries Enterprises/Facilities in Operation

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
1	R	Dhuvaafaru	MWSC	50	Operating
2	K	K. Atoll (Barge)	IOF Cooperation Pvt Ltd. FV	100	Operating
3	K	Hura	Blue Line - Euro Global Maldives Pvt ltd	60	Operating
4	K	Gaagandu	Marine Coral Fish Processing Factory	15	Operating
5	K	Hulhumaale	Ensis Fisheries Pvt Ltd	110	Operating
6	Aa	Ukulhas	United Regional Corperative Society	32	Operating
7	V	Thinadhoo	Ilyas Ibrahim / Ufanveli / N. Holhudhoo	10	Operating
8	Dh.	Meedhoo	Beach Builders Pvt Ltd	25	Operating
9	Dh	Kudahuvadhoo	Bright Brother's Pvt Ltd	12	Operating
10	Ga	Kooddoo	Kooddoo Fisheries Maldives Ltd	2000	Operating
	Gdh	Thinadhoo		100	Operating
	Gdh	Faresmaathoda		10	Operating
11	Gn	Fuvahmulah	Big Fish South Pvt. Ltd	40	Operating
12	S	Hithadhoo	Addu Fresh Pvt. Ltd.	40	Operating
13	K	Hulhumale	Umar Jamaal	-	Operating
14	Laamu Maandhoo	Maandhoo Fisheries Complex	Horizon Fisheries	3500	Operating
15	Lh. Felivaru	Felivaru Fish Processing	STO	750	Operating
16	Hulhumale	Maldives Marine Products	Maldives Marine Products	80	Operating
17	K. Kandu Oiygiri	Kandu Oiygiri Maldives	STO	120	Operating

Table 2: Fisheries Enterprises/Facilities not in operation

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
17	Sh	Keekimini	Island Enterprises Pvt. Ltd.	50	Not operational
18	K	K. Atoll (Barge)	Alize (FV)	10	Not operational
19	Th	Tha. Atoll (Guraidhoo)	IOF Cooperation	50	Repairing
20	Th	Funadhoo	Funnadhoo Tuna Products Pvt. Ltd.	15	Not operational

Table 3: Fisheries Enterprises/Facilities under Construction

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
21	K	Himmafushi	Bigfish Pvt Ltd	40	Under Construction
22	F	Nilandhoo	Kooddoo Fisheries Maldives Ltd	25	Under Construction
23	GDh	Fiyoree	Kooddoo Fisheries Maldives Ltd	25	Under Construction
24	GDh	Gahdhoo	Kooddoo Fisheries Maldives Ltd	25	Under Construction

Table 4: Fisheries Enterprises/Facilities Planned

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
25	N	Lhohi	Felivaru Fisheries Maldives Ltd	20	Requested for land
26	R	Alifushi	Felivaru Fisheries Maldives Ltd	20	Requested for land
27	B	Thulhaadhoo	Felivaru Fisheries Maldives Ltd	20	Land allocated
28	Th	Hirialndhoo	Kooddoo Fisheries Maldives Ltd	20	Land allocated
29	Ga	Kolamaafushi	Kooddoo Fisheries Maldives Ltd	20	Land allocated
30	Ga	Dhehvadhoo	Kooddoo Fisheries Maldives Ltd	20	Land allocated
31	Ga	Dhaandhoo	Kooddoo Fisheries Maldives Ltd	20	Requested for land

Table 5: Fisheries Enterprises/Facilities delayed

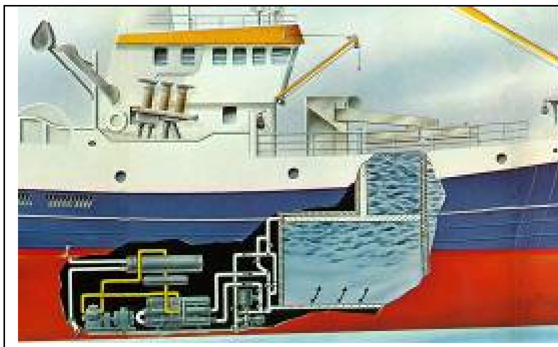
No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
32	K	Male' (barge)	Ocean Fresh Pvt. Ltd.	50	delayed Construction

The government of Maldives strongly focus on development of solutions with low GWP alternatives and energy efficient systems while phasing out HCFCs. In this regard, the facilities planned/under construction will definitely be with low GWP refrigerants as these facilities are land based where ammonia are predominant.

2.1 Technologies used in sea-borne refrigeration applications

An assessment was carried out to find out the refrigeration technologies used across the fisheries vessels by the fisheries enterprises of the Maldives. Most commonly used systems are Refrigerated Sea Water (RSW) Systems that are used both at Mother Vessels as well as the collector vessel. Figure 1 shows a general RSW system and Figure 2 shows a collector vessel of Maldives. Figure 3 shows a RSW system used in the Maldives.

Referred RSW systems are used to cool down the fish being collected and stored across the tanks and are currently installed for usage in the mother vessel and fish collector vessels of the fisheries enterprises.



Refrigerated Sea Water (RSW) systems chill fish through a mechanical process that pulls heat from the catch within the fish into an evaporator, and then discharges that heat overboard through a condenser. Most RSW units require between 5hp and 15hp, and this energy is supplied to the unit through auxiliary diesel generators installed in the vessel.

Figure 1: Refrigerated Sea Water (RSW) System

(Available at https://www.teknotherm.no/fisheries/fisheries-systems/rsw-systems/)

Figure 2: Collector Vessel


Figure 3: Vessels and their RSW systems

2.2 Technologies used in land based storage and processing

The review of the land based refrigeration systems revealed that the following technology applications are in use across the fish processing and transportation enterprises of the Maldives.

These technology options contribute to the various process of applications of fisheries sector operations of the Maldives.

Table 6: Commonly used Shore-based refrigeration equipment

No	Name of the Equipment	Image of the Equipment	Purpose
1	**Freezer Containers**		A **refrigerated container** or **reefer** is an intermodal container (shipping container) used in intermodal freight transport that is refrigerated for the transportation of fish. As per the use in the fisheries sector, enterprises use them as additional storage for the fish processing activities.

2	**Transport Trucks**		A **refrigerator trucks** are used to carry fish at specific temperatures. Refrigerator trucks used in the fisheries sector are ice-cooled, equipped with mechanical refrigeration systems powered by small displacement diesel engines. These trucks transport the fish to various locations such as to the airport or other locations.
3	**Ice Plants**		**Ice plants** are used for the production and storage of ice, including the icemaker itself that is the unit that converts water into ice together with the associated refrigeration machinery, harvesting and storage. Ice plants used in the fisheries sector include block and flake ice plants used across various enterprises
4	**Cold Rooms**		All the fisheries enterprises in the Maldives possess refrigerated **cold rooms** as a storage facility attached to the fisheries enterprises. They are designed as a 'walk-in' facility and are used for various functions within the stated enterprises. Besides storing fish, these cold rooms are used as a processing room, waste room, for provisions, sorting room, packing room-glazing room, receiving room, offal room and for storing ice.
5	**Blast Freezers**		Fisheries enterprises in the Maldives also use **blast freezers** also known as shock freezers. Such freezers are intended to rapidly lower temperature of fish catch down, freezing them extremely quickly. These specialized freezers are used across the fisheries enterprises in the Maldives.
7	**Air conditioners**		Besides the aforementioned equipment, several **air-conditioning units** are also used across the fisheries sector.

8	**Refrigeration Complexes**		The refrigeration complexes use industrial cold rooms within the fisheries enterprise and as such investments are high, there are only limited numbers of such refrigeration complexes in the Maldives.

2.3 Review of refrigerant usage across Fisheries Sector

The fisheries sector consumes approximately 20% (MEE, 2016) of the HCFC imported into the country. With the review of the technology options present in the fisheries sector and the amount of HCFC still being used there is a considerable effect on the ongoing phase out activities of HCFC across the fisheries sector, as the Government of Maldives has committed to completely phase out HCFCs across the country by 2020. The Figure 4 shows usage of HCFCs in fisheries applications.

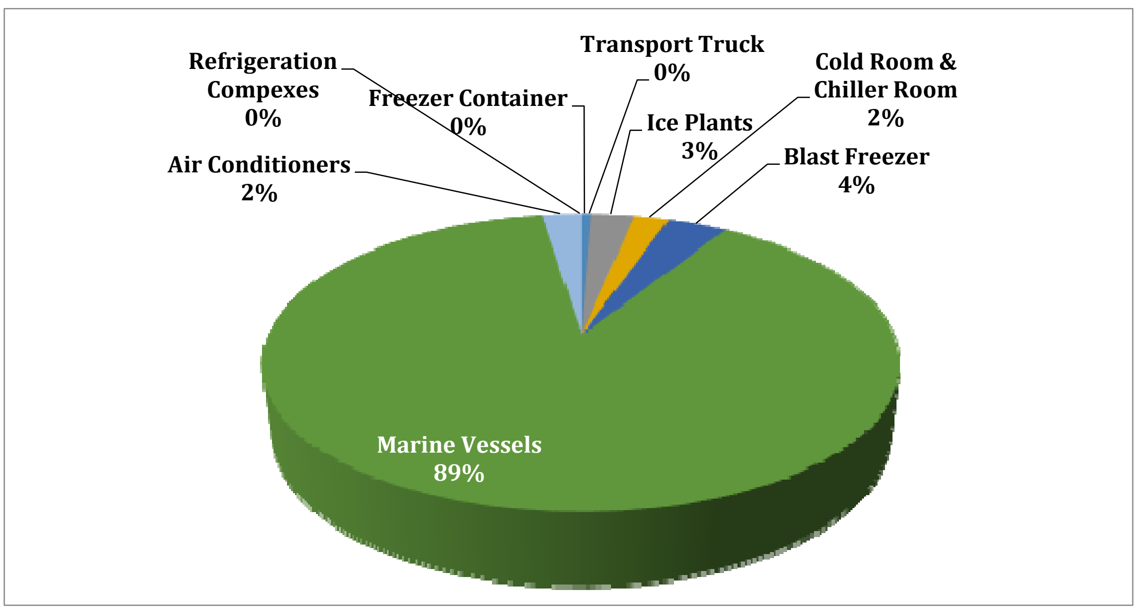


Figure 4 Presence of HCFC across Fisheries Enterprises of the Maldives

With the import control on HCFCs accompanied with the ban on HCFC based equipment, a significant increase in the import of Hydroflourocarbons (HFCs) has been observed in the recent years. The ODS survey carried in the Maldives in 2016 shows that with the start of HPMP implementation in 2010 and subsequent enforcement of regulations, the percentage of HCFC consumption has gradually decreased and consumption of ODS alternative refrigerants has increased.

The ODS report shows that the consumption level of HCFCs at the end of 2015 was at 40% while ODS alternatives account for 60% of the total refrigerant consumed in the country. According to the ODS Alternative Survey, the commonly used HFC blends in the Maldives are R-404A, R407C, R410A, R417A; while occasionally consumed HFC blends are R-507C and R-438A. HFC 134a is reported as the most commonly used HFC, accounting for 13% of the total refrigerant consumed; and 31% of the total ODS alternatives consumed in the Maldives.

The projection shows overall growth of ODS alternatives use in the Maldives is 15% per annum for the period 2016-2030. R-410A is projected to have the highest annual growth followed by R-407C, 48% and 18% respectively. R134a and R-404A is projected to grow over 200% by 2030 and R-407C and R-410A is expected to grow over 380% by 2030 from the consumption levels in 2015. Consumption of all ODS alternatives are projected to grow more than 250% during 2016-2030 period.

The tourism sector is found to be the largest consumer of R&AC equipment and refrigerant in the Maldives. More than 13% of the total ODS alternatives imported into the country is directly imported by the tourist establishments and a large amount imports by the local suppliers are also consumed in tourism sector. The fisheries sector seems to the largest consumer of HCFC as most of the fishing vessels are still using HCFC based equipment. Furthermore, 16% of the ODS alternative refrigerant imported into the county is for use in fisheries sector. Most commonly used ODS alternatives in fisheries and food processing sectors are R-134a, R-404A and R-410A (ODS inventory report, 2016). Some of the fisheries related facilities use Ammonia especially in cold storages. However, as shown in Table 7, except for Ammonia, all the other refrigerants used in the fisheries sector are high GWP options.

Table 7: common refrigerants used in the fisheries sector of the Maldives

#	Refrigerant	Common Applications	GWP
1	R-22	Filled within Freezer Containers, Ice Plants, Blast Freezers, RSW Systems of Fish Collector and Mother Vessels, Cold Rooms and Chillers and Air-conditioners	1810
2	R-134 A	Freezer Containers	1430
3	R-404 A	Transport Trucks, Ice Plants, Cold Rooms and Chillers, Ice Plants, Blast Freezers and land based refrigeration complexes.	3922

4	R-418A	Air Conditioners	1500
5	R- 410 A	Air Conditioners	2088
6	R-438 A	Air Conditioners, RSW Systems of Fish Collector and Mother Vessels	2265
7	Ammonia	Ice Plants, RSW Systems of Fish Collector and Mother Vessels and land based refrigeration complexes.	0

As is evident, it is important to find a low GWP alternative option to the fisheries sector and mostly to the sea-borne applications.

2.4 Technology options versus refrigerants used across fisheries enterprises

The Table 8 below summarizes the various refrigeration technologies used across the fisheries enterprises of the Maldives. HCFCs are used in almost all the applications except in transport trucks and refrigeration complexes.

Table 8: Common Refrigerants and their Applications

#	Name of the Equipment	Equipment Functions	Types of Refrigerants
1	Freezer Containers	Often used for storing fish and fish products	**R-22 (62%)** **R-134 (38%)**
2	Transport Trucks	For Transportation of Fishery products	**R-404 A (100%)**
3	Ice Plants	Used for making Ice	**Ammonia (88%)** **R-22 (4%)** **R-404A (8%)**
4	Cold Rooms/Chiller Rooms	Processing Room/Semi Processing Room/Waste Room/Storing Fish/Provision Room/Packing Room/Finished Products/ Sorting Room/Glazing Room/ Cooling Room	**R-22 (59%)** **R-404 A (41%)**
5	Blast Freezers	To freeze fish within a short duration	**R-22 (81%)** **R-404 A (19%)**
6	Fish Collector/ Mother Vessels and Burges	Marine vessels are used for both collection and sometimes processing	**Ammonia(15%)** **R-22 (85%)**

7	Air conditioners	Like other sector sectors Air conditioners are also used within the Fisheries Sector	**R-22 (70%)** **R-410 A (20%)** **R-418 A (10%)**
8	Refrigeration Complexes	Limited refrigeration complexes are also used in the Maldivian Fisheries Sector	**Ammonia (99%)** **R-404 A (1%)**

3. Overview of the demonstration project

This Demonstration project was approved at the 76th ExCom in May 2016, for a 24 month period. The demonstration project is to identify low-GWP alternative technologies to HCFCs for use in refrigeration equipment with a charge of 150 kg to 200 kg of refrigerant in the fisheries sector.

With the implementation of the Demonstration Project, it is envisaged that the following will be attained.

a. The demonstration project will lead to: (i) research and analyse existing technology options used in both sea-borne refrigeration equipment and in land storage and processing applications; (ii) undertake a technical assessment of low-GWP options in terms of their feasibility as drop-in refrigerants as well as replacement options; (iii) test the performance of substitutes including optimization of drop-in or replacement systems; and (iv) demonstrate the use of the selected substitutes.

b. The project proposes to convert the HCFC-22-based refrigeration equipment in three fishing vessels to low-GWP technologies, by assessing alternative technology performance, and evaluating the suitability of the selected technology based on the cost of retrofitting and maintaining best possible performance of the equipment without much hassle to the client. Based on the evaluation, suitable technologies will be disseminated to the fishing industry during HCFC phase-out. The project will eliminate the use of 0.6 MT of HCFC-22 in fishing vessels.

The demonstration project also includes;

- ✓ Undertaking a detailed technology research and analysis of existing options available and technology choice and retrofit options
- ✓ Conducting Information sessions to the stakeholders

- ✓ Preparation of bid documents for the purchase of refrigerants and other spare parts if required
- ✓ Assisting selected enterprises on retrofitting of the selected equipment
- ✓ Preparation of manuals for all three retrofitted equipment applications
- ✓ Trainings for the technical staff on both retrofitting and their maintenance

Keeping in view the above mentioned outputs, to find a suitable HCFC free and low-GWP refrigerant to be used across the fisheries sector in different applications and on shore based applications, the public fisheries company, Maldives Industrial Fisheries Company Limited (MIFCO) was selected for this assessment. This is the largest fisheries enterprise in the country. MIFCO was mainly selected because of the uncertainties involved in the project along with the unavailability of alternatives for this sector. Hence, a Memorandum of Understanding (MOU) was signed between the Ministry of Environment and Energy (MEE) and MIFCO to undertake the assessment and to provide three vessels for the demonstration.

4. Review of technology options

Various consultative processes were carried out to carryout the assessments and selection of three vessels. Some of the parameters considered in selecting the vessels include the age, refrigerant use, willingness to participate in the project and possible risks associated with the implementation. The government of Maldives alonwith their technical experts participated in an "International Conference on Sustainable Management of Refrigeration Technologies in Marine and offshore Fisheries Sector" held at Bangkok from 6-8 April 2017 to understand the global scenario on fisheries sector. Further to carry forward the message on low GWP available technologies as technology roadshow was organized by UN Environment on 14-15 August 2017, where large number of manufacturer and refrigerant suppliers were present. A special focus group meeting during the technology roadshow held in August 2017 provided an excellent platform to discuss some of the challenges in finding and retrofitting new refrigerants. The fisheries sector owners were present and round table discussions session was organized. It was found that industry is not willing to move to A2L refrigerants. To understand the difficulties faced by fisheries vessels an expert team who was present at the roadshow a trip was made to different locations where MIFCO enterprises are located. The team included experts from MIT, Honeywell, UNDP and Johnson Controls (Anshu Kumar, UNDP, Bangkok, Alex Cohr Pachai, Johnson Controls, Denmark, Nitin Karwa, Sr. R&D Engineer, Honeywell, India, Anand Joshi, Ex-President Association of Ammonia Refrigeration, India, Musthafa Rafeeu, Manager Business development, MIFCO (Felivaru fisheries complex, kaduoiygiri fish village , kooddoo fish complex and addu fish complex). Main purpose of the visit was to analyse the retrofitting options and possible vessels that could be selected for the project. Meetings were carried out with other fisheries vessel owners who were reluctant to move toward to flammable and toxic refrigerants.

The following section provides details of the three vessels selected for the demonstration project.

4.1 Overview of the Vessels selected

The Maldives Industrial Fisheries Company (MIFCO), is a public company engaged in the production, processing and marketing of fish and fish products. Established in 1993, MIFCO was relocated as a subsidiary of State Trading Organization (STO) in September 2016. As the key manufacturers and exporters of frozen fish and fish products, Maldives Fisheries Corporation (MFC) has a history dating back to 1979 when Maldives Nippon Corporation was formed, in partnership with Marubeni Corporation of Japan, to process and can fresh tuna. MFC was renamed as the Fisheries Projects Implementation Department (MFID), which was transformed into MIFCO in 1993. At present, MIFCO have no partnership with Japan, and are a 100% indigenous company.

MIFCO manages the largest fish procuring operation in Maldives, collecting Pole and Line and Handline caught Yellowfin and Skipjack Tuna. MIFCO owns three EU standard factories namely, Felivaru Fisheries, Kooddoo Fisheries and Kandu Oiygiri Maldives which process canned, chilled, frozen and value added tuna which is exported to International markets and sold locally.

For the purpose of the demonstration project, the equipment from MIFCO and Maandhoo Fisheries were assessed (Table 9). The main focus was to assess the capacity of vessels, compressors used in these installations, and the refrigerant quantities used in applications of both Mother and Collector Vessels that use RSW systems to store chilled catch.

Table 9: details of the refrigeration systems across some of the fisheries enterprises of the Maldives

No	Name of the company	Equipment category	Model/ additional details	No. of compressors / system	Total capacity (HP)	Ref used	Gas weight (kg)
1	**MIFCO**	Randhi-19	Sabroe Compressor	2 Compressors	40	R-22	35
		Randhi-20	Sabroe Compressor	2 Compressors	40	R-22	35

		Randhi-21	Sabroe Compressor	2 Compressors	40	R-22	35
		Randhi-22	Sabroe Compressor	2 Compressors	40	R-22	35
2	**Maandhoo Fisheries Complex**	HF 106/Ship to Chill Fish	Dakin 2x model # 6CX75	2	30x2= 60HP	R-22	45
		HF 107/Ship to Chill Fish	Dakin 3x model # 6CX75	3	30x3= 60HP	R-22	45
		HF 108/Ship to Chill Fish	Dakin 2x model # 6CX75	3	30x3= 60HP	R-22	45
		HF 109/Ship to Chill Fish	Dakin 2x model # 4CX75	2	20x2= 60HP	R-22	45
		HF 110/Ship to Chill Fish	Dakin 2x model # 4CX75	2	20x2= 60HP	R-22	45
		Oivaali 102	Mycom F62B2	4	100x4=4 00HP	R-22	298.4

After the assessment three vessels from the public company, MIFCO, were selected for the demonstration project. Table 10 provides the details of these vessels.

Table 10: Selected Vessels for the Demonstration Project

#	Name of the Vessel	Brief Description of the Vessel
1	**Randhi-19**	Randhi-19 is a fish collector vessel that is approximately 29 years old. Vessel is now operated from Felivaru Fish Processing Plant.
2	**Randhi-24**	Randhi-24 is a fish collector vessel that is approximately 18 years old. Vessel is now operated from Kooddoo Fisheries Complex
3	**Randhi-30**	Randhi-30 is a fish collector vessel that is approximately 15 years old. Vessel is now operated from Kooddoo Fisheries Complex

These vessels though old are still being operated for the purpose of collecting fish, and include brine tanks that are cooled using the installed Refrigerated Seawater Systems.

Figure 5: Fish collector vessel selected for the project

4.2 Existing refrigeration technology in the selected vessels.

The Maldives Institute of Technology (MIT) is engaged with the above three vessels to study the technology options being used in these vessels, and analyze what alternate technologies can be provided to the end users to preserve the ozone layer.

It was observed that all the selected vessels use Refrigerated Sea Water (RSW) Systems for cooling the brine tank installed in the vessels, which in turn cool the collected fish, before they are transported to the fish processing plants. All three vessels use R-22, and the amount of refrigerant in each RSW system were on average between 60 - 70 kg.

4.3 Overview of the refrigeration systems

Every vessel released for the demonstration project includes the presence of RSW systems with one unit installed on the starboard side, and another installed on the hull side of the vessel. The **Error! Reference source not found.** shows the installed RSM system.

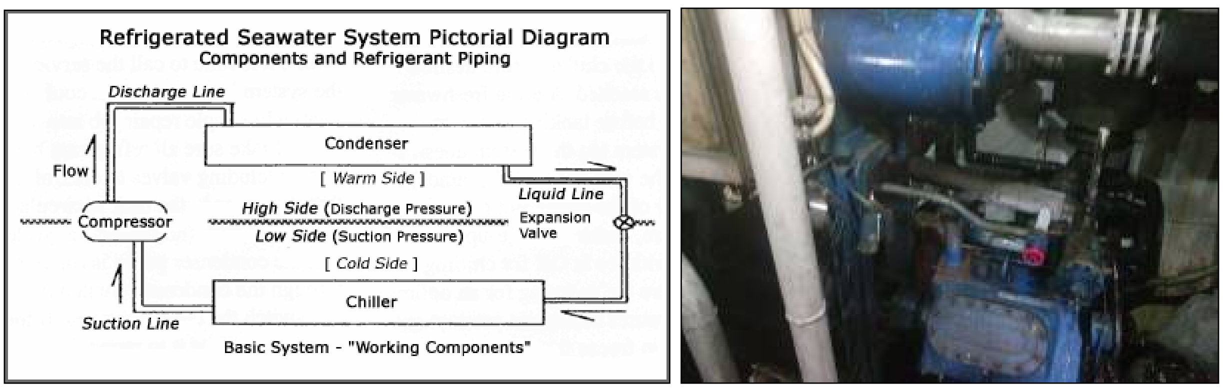


Figure 6 Illustration of installed RSM system

Seawater is re-circulated by pumps through the tanks and the chilling system. The refrigeration machinery chills the seawater before it enters the tanks in the lower layer of the ship, and is distributed evenly over the complete bottom cross-section of the tanks through a set of perforated plates or similar distribution devices. The chilled seawater passes upwards through the tank and layers of fish, thus keeping the fish suspended in the chilled seawater, simultaneously cooling the catch. The water returns through suction screens in the top of the tanks to the chilling unit of the system, passing through this, and repeating the circulation process. To keep the circulating water in good condition, a limited amount of feed water may be added, and “dirty” water bled off. The water circulating system is arranged such that the flow can be reversed by the operation of certain valves in the main water distribution manifold.

4.3.1 Components and their functions

Within all three selected demonstration vessels, there are two individual refrigeration systems installed on both the sides of each vessel, each system including the following main components.

- ✓ Compressors
- ✓ Chillers
- ✓ Condensers
- ✓ Expansion valves

The following sections provide details of these components.

a. Compressors

The purpose of the compressor is to draw the low-temperature, low-pressure vapour from the evaporator via the suction line. Once drawn, the vapour is compressed. When vapour is compressed, it rises in temperature. Therefore, the compressor transforms the vapour from a low-temperature vapour to a high-temperature vapour, in turn increasing the pressure. The vapour is then released from the compressor in to the discharge line.

Table 11: Compressors of the selected vessels

Vessel	Refrigeration System	Compressor Maker	Brand / Model	Type	Manufacture Year	Compressor Capacity	Oil Used	Last Service
Randhi-19	01	Nippon Sabroe	BF0-5	Piston	1996	36160 Kcal/hr	Capella wax	2010
	02	Nippon Sabroe	BF0-5	Piston	1996	36160 Kcal/hr	Capella wax	2010
Randhi-24	01	GRAM	HC-4075	Piston	1998	77KW	Aircol-299	2013
	02	GRAM	HC-4075	Piston	1998	77KW	Aircol-299	2013
Randhi-30	01	GEA	FX-16/1751	Piston	2011	120KW	Aircol-299	Unknown
	02	GRAM	HC-4075	Piston	1998	77KW	Aircol-299	2013

b. Chillers and Condensers

The major function of chiller is to chill the water to the set temperature and circulate to the desired location with the help of external pump. The heat absorbed by the refrigerant during the process of chilling is being discharged by condenser to the atmosphere as the design of condenser is (air-cool/watercool).

The following tables summarize the properties of the chillers and condensers used in the systems selected for the study.

Randhi-24

Chiller (evaporator)			**Condenser**		
Type	Maker	Build Year	Type	Maker	**Build Year**
Details of Heat Exchanger (chiller) Randhi 24, Heat Exchange (Shell and Tube) Tubes, Pure Titanium Sell pp Model# WHC 20- 2EKG Cooling Capacity 93KW	China	2000	HBY 10-150-4CIB		1998

Randhi-19

Chiller (evaporator)			***Condenser***		
Type	Maker	Build Year	Type	Maker	Build Year
Direct expansion	Nippon Sabroe	1996	Water cool shell and tube	Nippon Sabroe	1986

Randhi-30

Chiller (evaporator)			***Condenser***		
Type	Maker	Build Year	Type	Maker	Build Year
Direct expansion	Nippon Sabroe	1996	Water cool shell and tube	Nippon Sabroe	1986

5. Selection of refrigerants

MIT Consulting Team undertook an exhaustive process of identifying a suitable refrigerant to replace the HCFC-22 being used across the RSW systems of the three selected vessels for the Demonstration Project.

In this regard, MIT Consulting Team reviewed the following.

1. **Desk Study of the possible refrigerants available in the Market**

   MIT consulting team conducted a desk study review of the various refrigerants available in the market that could be used as a potential replacement technology for the selected three vessels. The available technical literature and published papers were analysed.

2. **Consideration of potential technologies for Demonstration.**

   Information gathered from the desk study on refrigerant developments across the globe, led to the identification of potential refrigerants for demonstration within the project.

   Available data on the performance of these refrigerants were compared against the current performance parameters of the selected RSW systems, with special consideration of low GWP refrigerant options.

3. **Discussions with the Technical team of the Demonstration Vessels Owner (MIFCO)**

   The technology reviews and potential options were presented to the technical teams of the demonstration vessel owners(s) to foster project ownership and inclusion.

The literature review revealed a number of low GWP refrigerants being made available in the global market place, although many are new with limited trials {eg: HC-600a, HFC-1234-1234yf, HFC-1234ze(E)}. These limited trial alternatives pose challenges as a suitable retrofitting agent for the fisheries sector in the Maldives. Indeed Kauffeld (2012)[1] indicates that apart from Ammonia, there are limited usages for natural refrigerants for seaborne vessels due to its toxicity and size of charge.

[1] Michael Kauffeld, 2012: Availability of low GWP alternatives to HFCs Feasibility of an early phase-out of HFCs by 2020

For potential alternatives that had moved beyond limited trials, there was a summarization of the Material Safety Data Sheet (MSDS) parameters of the potentially feasible, low GWP refrigerants to replace HCFC in the three selected demonstration vessels (see Table 5).

Table 12: Low GWP refrigerants and its characteristics

Name of the Refrigerant	Composition	Mass%**	ASHRAE Safety Class	Boiling T (°C)	Critical T (°C)	Critical P (MPa)	Glide	GWP
R450A	R134a/R1234yf/R1234ze	42/18/40	A1*	-25.6	100.18	3.74	0.1	547
R513A	R134a/R1234yf	44/56	A1*	-27.9	97.51	3.67	-0.3	573
R448A	R-32/R-125/R-134a/R-1234yf	25/25/20/30	A1*	-38.50	84.62	4.47	5.2	1273
L40	R-32/R-152a/R-1234yf/R-1234ze(E)	40/10/20/30	A2L**	-22.00	89.89	4.84	19.5	<300
DR-5	R-32/R-1234yf	72.5/27.5	A2L**	-45.40	83.11	5.40	3.9	500
R444B	R-32/R-152a/R-1234ze(E)	45/20/35	A2L**	-36.70	90.56	5.07	7.60	295
HFC-32		52	A2L**	-51.7				677

** : A1: Non Flammable ** : A2L: Mildly Flammable*

(Source: Atilla Gencer Devecioğlua, Vedat Oruça, 2015)

Further consideration and discussion between MIT Consulting Team and the MIFCO Technical Teams resulted in a joint decision not to proceed with any A2L refrigerant due to the equipment being old and leak prone, risking fear of accidental fire. With this final decision, the following non-flammable refrigerant options remained for demonstration.

Table 13: Short Listed Refrigeration Options

Name of the Refrigerant	Composition	ASHRAE Safety Class	GWP	Application
R448A	R-32/R-125/R-134a/R-1234yf	A1*	1273	Non-flammable HFO blend, used as a replacement for R404A and R22 in low and medium temperature refrigeration applications.
R444B	R-32/R-152a/R-1234ze(E)	A2L**	295	The refrigerant is mildly flammable and works as an excellent replacement for R-22 in Room Air conditioners.
L40/D8	R-32/R-152a/R-1234yf/R-1234ze(E)	A2L**	<300	The refrigerant is mildly flammable and primarily used for low temperature applications.

Prior to locking on a refrigerant for the demonstration project, it is vital to review and refresh again on the three vessels selected for the Demonstration Project and some of the factors that we need to take into account prior to selecting a refrigerant since most of the short listed refrigerants are under class A2L where the industry does not prefer due to equipment being too old and leak prone, risking fear of accidental fire. .

5.1 *Issues associated with the selected vessels and final recommendations for refrigeration selected*

Recalling the characteristics of the selected demonstration vessels, including their age, as laid out previously in Tables (*Table 8: Common Refrigerants and their Applications*) the following factors will further influence selection of a refrigerant for the Demonstration Project.

1. RSW Systems installed in the above Vessels are old and will be resistant to significant system modifications
2. Aged pipelines installed in these vessels make it extremely difficult to provide a 100 percent leak proof system
3. There is increased risk associated with the selection of a flammable refrigerant due to the lack of ventilation within the rooms in which the RSW systems are installed

With the consideration of these additional factors, the Consulting Team for this technical report propose the following options as an alternate to the demo project:-

1. ***Complete Replacement of the RSW Systems installed in the selected vessels using three possible trial replacement technologies.***

    a. Purchase and Install Ammonia based RSW systems
    b. Purchase and Install R32 A RSW Systems
    c. Purchase and Install R-429 A

Options proposed are reviewed against the following.

Name of the Refrigerant	ASHRAE Safety Class	GWP	Comments
Ammonia	B2L (High Toxicity)	0	Sealed ammonia units can be used for complete replacement of the used RSW systems.
R-32 A	A2 (Mildly flammable)	675	It is suitable for new equipment designed for R32 in applications that commonly use R410A. R32 is designated flammable and therefore is not suitable as a drop-in retrofit replacement for R410A.
R-429A	A3(High Toxicity)	14	Sealed RSW systems for 100 percent replacement can be done and is available in the international market. Properties of this exhibit excellent refrigeration qualities to that of R-22.

2. ***Selection of a Drop in Refrigerant Compatible with the RSW systems***
   The Consulting Team together with the MIFCO Engineering Team reviewed the options for selecting a possible refrigerant for the demonstration project and compiled the following list.

Selection criteria developed for the selection of the refrigerant using the short listed table of refrigerants in Table-14 are as follows.

a. **Flammability**
   Flammability remains as a crucial safety criterion that need to be reviewed prior to selecting a suitable refrigerant. In this regard, both R-444B and L40/D8 remains mildly flammable while R-448A remains less flammable.

b. **Cost of Retrofitting**
   RSW systems used in these vessels are old and any modifications that need to be brought will be expensive. Retrofitting using R-444B and L40/D8 remains risky and thus may involve significant costs.

c. **Performance**
   It is important that each selected refrigerant doesn't impact performance of the selected three RSW systems. When reviewed it is seen that only R-448A remains the best refrigerant that can be used without impacting much on the performance of the selected RSW systems.

With the above criteria, and based on the desk study undertaken, it is found that the R-448A remains as the best Drop in Refrigerant for replacing R-22 being used in the selected RSW systems of the three vessels as of now

#	Name of the Refrigerant	Refrigerant Information	Rationale for Recommendation
1	R 448A*	ODP: O GWP: 1273	1. Refrigerant performance seemed suitable to retrofit the selected RSW systems without affecting performance of the system. 2. Limited system modification of the RSW systems required to support the planned retrofitting process. 3. Technical Support available for the retrofitting from the refrigerant manufacture is believed to be adequate.

* It should be noted that, in response to the suggestion of the ExCom to liaise with Nordic Council of Ministers, UNDP did indeed send out enquiries to this body on the "Alternatives to HCFCs and High GWP HFCs in marine vessels"; but UNDP came to know that report has not been finalized as of now. The Norwegian Environmental Agency publication "Study on

environmental and health effects of HFO refrigerants" (December 2017) states that HFO blends R448A, R-449A, R-450A and R452-A are commercially available with R448A and R-449A being the most widely used (Page-12 of report)
(Source:http://www.miljodirektoratet.no/Documents/publikasjoner/M917/M917.pdf)

5.2 Implications for selecting a refrigerant

Although the consulting team is proposing the above options, Maldives is aware of the fact that MLF may have issues with the above options.

As per the recommendations made for the project, we understand that the selected refrigerant should have low GWP option at present in A1 category of refrigerants.

However, the Consulting Team together with the MIFCO Engineering Team explored varying avenues for identifying a refrigerant that fits within the above range and is equally suitable to retrofit the RSW systems of the selected three vessels.

6. Retrofitting the selected equipment

6.1 General retrofitting procedure

All the six RSW systems, selected from the three vessels are old and require extreme care and precaution when being retrofitted

A generalized procedure should be followed when retrofitting any refrigeration system with an alternative refrigerant. However, there may well be specific variations according to the particular characteristics of the system under consideration and the refrigerants involved. See the interactive diagram to see how this flow works for a retrofitting of HCFC refrigeration equipment.

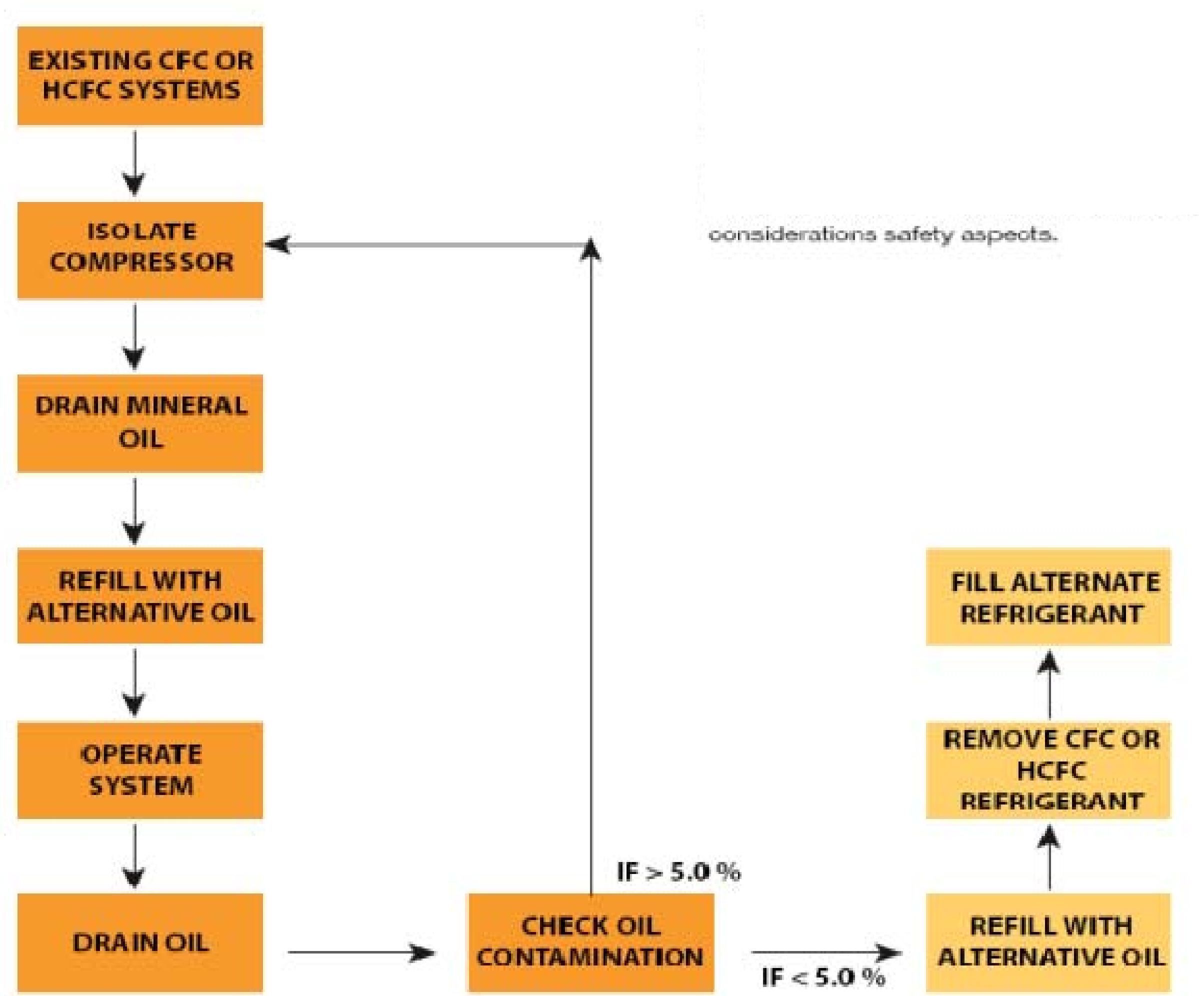


Figure 7 Flow works for a retrofitting of HCFC refrigeration equipment

The procedures to perform this retrofitting are explained below. If the refrigerant replacement is being performed with the use of a “drop- in” refrigerant, some of the steps presented may not be necessary. It is important always to consult the refrigerant manufacturer’s guidelines for retrofitting and the use of “drop-in” refrigerants. The retrofit of flammable refrigerants (such as hydrocarbons) must be executed taking into considerations safety aspects.

7. Lessons learnt

Challenges observed with the Fisheries Equipment Selected for the Demonstration Project

While progressing with the work on identifying a suitable refrigerant that has low GWP and qualifies a good replacement for the currently used R-22.

1. ***Equipment selected for the Demonstration Project is old and fragile***

   All the RSW systems selected for the project are approximately 20 years old and look fragile due to years of operation. Retrofitting with another refrigerant has to be cautiously undertaken as any modification may affect performance of the systems.

2. ***Refrigerant Leakage is Imminent across all the selected systems***

   Due to years of operation, it is difficult and hard to ensure the selected systems are leak proof, making it hard and challenging for any complex retrofitting across this equipment selected for the project.

3. ***Selected RSW systems have undergone modifications***

   It is also observed that all the selected equipment for the project had undergone modifications due to years of operation within the fish collector vessels. Referred modifications need to be carefully reviewed prior to bringing any retrofitting on the selected equipment.

4. ***All the selected equipment are installed in a limited and confined space***

   All the selected equipment for the project is confined to very limited space within the collector vessels. Due to the nature of the installations, it is important that no flammable refrigerant that be used for retrofitting.

5. ***Systems are operated and maintained by semi-skilled technicians***

   While reviewing the selected equipment, it was also noted that the personnel involved with the repair and daily operation of the systems are semi-skilled, making it hard for complex retrofitting.

8. Conclusion and recommendation

This report was developed to present the finding of the research undertaken to find an alternative refrigerant, which are low GWP refrigerant for the phase-out of HCFCs.

Major findings of the research includes;

1. With the review of the technology options being used in the fisheries sector, it is noted that Maldives has a HCFC consumption baseline of 64 metric tonnes , of which approximately 20 percent is consumed in the fisheries sector.

2. MIT consulting Team conducted a detailed desk study to review the refrigerants R-448A as potential refrigerants for the demonstration project. However, as per the recommendation from the 80^{th} ExCom, testing of R448A was stopped because of its high GWP value but at the same time there is no other alternate available in A1 category of refrigerants.

3. A new desk study began in search of a low GWP alternative that are corresponding with R-22. The lower GWP refrigerant R444B has come out tops in the study which further test are needed since the refrigerant is mildly flammable (Safety Class: A2L) and it needs the due consideration of the end users.

4. It has been interacted during the "International Conference on Sustainable Management of Refrigeration Technologies in Marine and offshore Fisheries Sector" with few presenters and it has been found that the shift of technology trend is from R-22 to R404A (GWP 3922) and R-407F (GWP 1824), which is on higher side that R448A (GWP 1273). Ammonia with low charge has been introduced in marine vessels in the last 10 years, but as of 2017 HCFC22 dominates in most of the vessels.

REFERENCE:

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MEE, 2016: ODS Inventory Report

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Panel World Test Report   April 2018

Vacuum Assisted Injection System – Description

The plant has been designed for Vacuum Assisted Injection technology
The panel production method, the so-called Vacuum Assisted Injection (V.A.I), applies into the press a depression surrounding the metal faced insulation panel. Prior to the foaming operation, a controlled degree of vacuum is applied between the press platen where the pre-assembled panel is positioned. The reduced pressure applied during the injection and the expansion of the foam, facilitates the filling of the panel, providing substantial benefits.

Manni press 2+2 equipped with vacuum device

Release of vapors with Pentane as blowing agent

Many tests have been performed on operating production lines and prudently one can establish that the maximum loss of Pentane, by evaporation, is 5% of the Pentane content. The loss also occurs during the foam expansion phase in the first 90 sec. after the pouring. The vapors of

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Pentane overpass the LEL limit inside the cavity where the foam expands. This vapor is sucked by Vacuum Assisted Injection System.
A dedicated suction channel (connected to the Dry equipment ventilation system) must collect all the vapors sucked by Vacuum Generators.
In case of a standard production press, these vapors released by the cavity or junctions all around the exterior surfaces of the mold and are dispersed in the atmosphere around the press itself!

Calculation of exhaust ventilation around the press
We must consider that the press can produce two panels with max dimensions 8300 mm x 1200 mm and thickness 130 mm. Assuming:

- Foam density (max value) = 45 kg/m3
- Content of Polyol Blend (Polyol + Pentane) in the foam = 47 %
- Content of Pentane in the Polyol Blend (by weight) = 12 %
- Pentane loss during foaming = 7 % of the total content
- Panel max volume = 8,3 x 1,2 x 0,130 = 1,3 m3
- Max foamed weight per panel [PTot]= 45 x 1,3 = 58,3kg (116,6 Kg two panels)

The max quantity of Pentane emission is: 116,6 x 47% x 12% x 7% = 0,46 Kg
In this case the requested ventilation during foaming is 3000 m3/h.
This value must be increased by a safety coefficient. In this press the installed value is **10.000 m3/h**.

Note 1: We can state that in case of a press equipped with the VAI Technology we can save completely the a.m. ventilation: the ventilation is replaced by the vacuum. The only precaution we must foresee is, in case of vacuum failure during the injection, the use of a suction device to remove the vapors still in the cavity before to opening the platens.

VAI technology: Vacuum pumps

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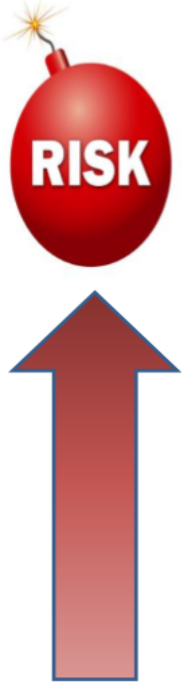
Area classification and electrical system inside the press area

The criteria to follow is:

<u>ZONE</u> CLASSIFICATION IEC



- ***Zone 0*** – zone where an explosive atmosphere, for presence of gas, is likely to be **present continuously** or for long period or frequently
- ***Zone 1*** – zone where an explosive atmosphere, for presence of gas, is likely to be **present occasionally during normal operation**
- ***Zone 2*** – zone where an explosive atmosphere, for presence of gas, is **not** likely to be **present during normal operation** but, if this is done, it is possible only for **short periods**

Note 2: In a standard plant we must consider that around the press we are Zone 1. Specifically, in the zone within 400 mm around the panel mold, all the electrical devices shall be switched off during the foaming period or in alternative they must be protected with Exi barriers or Exd.
In case of a VAI press the a.m., area become Zone 2. That mean we can use standard electrical devices.

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Trial Descriptions

DAY 1 (20171130)
To start a small size panel has been selected: 3 m long, thickness 80 mm.
Different densities have been applied, from 35 to 39 g/l, to reach a correct filling of the panel.
The low flow ability of the Polyol formulations used did not give us the possibility to produce panels with a good quality. Many foam voids are present especially at the far edges of the panel.
Conclusion: this first day can be considered as a production start to verify the "mechanical "functionality" of the line.

Air voids trapped inside the foam

DAY 2 (20171201)
Several panels have been foamed with and without vacuum.
A new thickness, 130 mm, with different lengths, 8.4 and 2.4 m, has been tested with a density from 37 to 47 g/l.
Unfortunately, the problem was still the same: voids. By the way the adhesion to the metal was good especially with the use of vacuum.
Everybody agree that a new session of trials with a modified/slower new formulation is necessary.

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Foamed panel manual unloading

DAY 3 (20180302 morning)
The trials made in December 2017, DAY 1, has been repeated with a new formulation. The new formulation shows clearly an improved flow ability with evident better results.
The use of vacuum has improved the good filling of the panel confirming a better adhesion also.

Panel Word workshop

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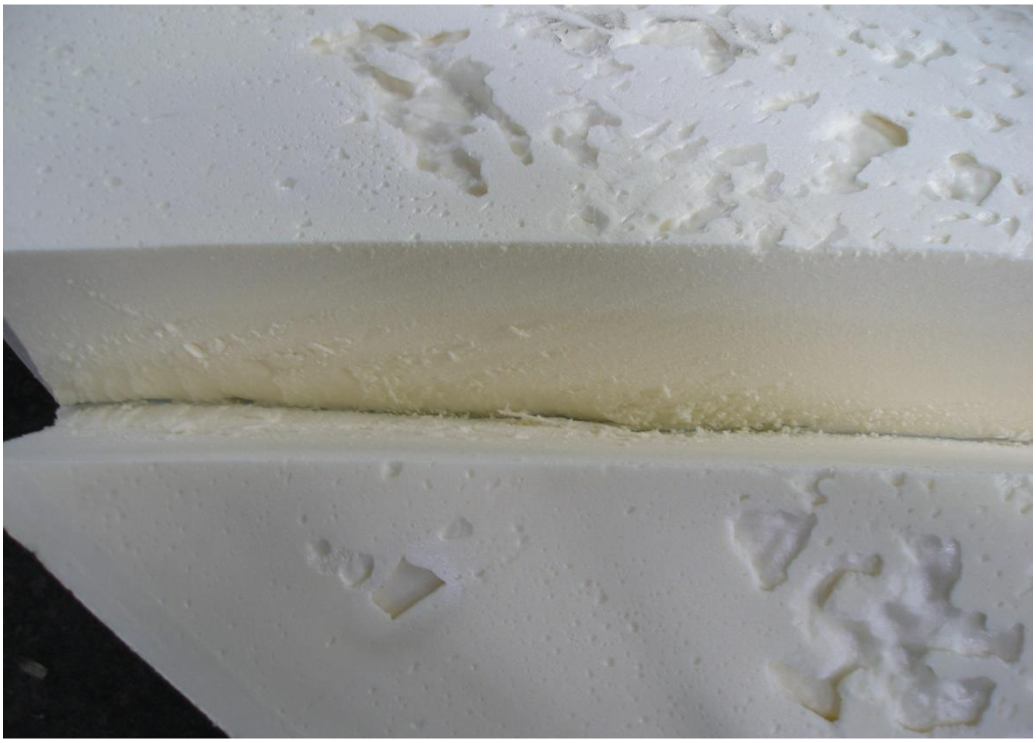
DAY 4 (20180302 afternoon)
Again, several panel length and thickness has been tested.
Some voids of reduced dimension are still on the panel.
The vacuum pressure is not very stable during the injection and the expansion of the foam.
Some modification on the vacuum circuit are necessary to stabilize the vacuum at - 0,05 Bar.

DAY 5 (20180312)
The modification done on the vacuum circuit has stabilized the vacuum level.
Considering the good quality obtained, all the panels have been foamed with the vacuum at – 0.05 Bar.



Foam quality

DAY 6 (20180313)

One more day with a fixed thickness of 100 mm but with two panels on the same platen to test the production with multiple panels of reduced length.
The RMS suggested a further test session with some little modification on the formulation regarding the type of Catalyst.
At the same time the Pentane vapor emission test has been made with (VAI) and without (standard) vacuum. A portable gas sensor from Dräger has been used.

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Portable gas sensor

Measured values:

Time After Foam Injectio in Seconds	% Pentane Measured without Vacuum	% Pentane Measured with Vacuum
5	0	0
10	0	0
15	0	0
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	0	0
50	0	0
55	0	0
60	0	0
65	0	0
70	1	0
75	2	0
80	3	0
85	3	0
90	4	0
95	4	0
100	8	0
105	8	0
110	8	0
115	8	0
120	11	0
125	11	0
130	8	0
135	8	0
140	8	0
145	8	0
150	3	0
155	3	0
160	1	0
165	1	0
170	1	0
175	0	0
180	0	0

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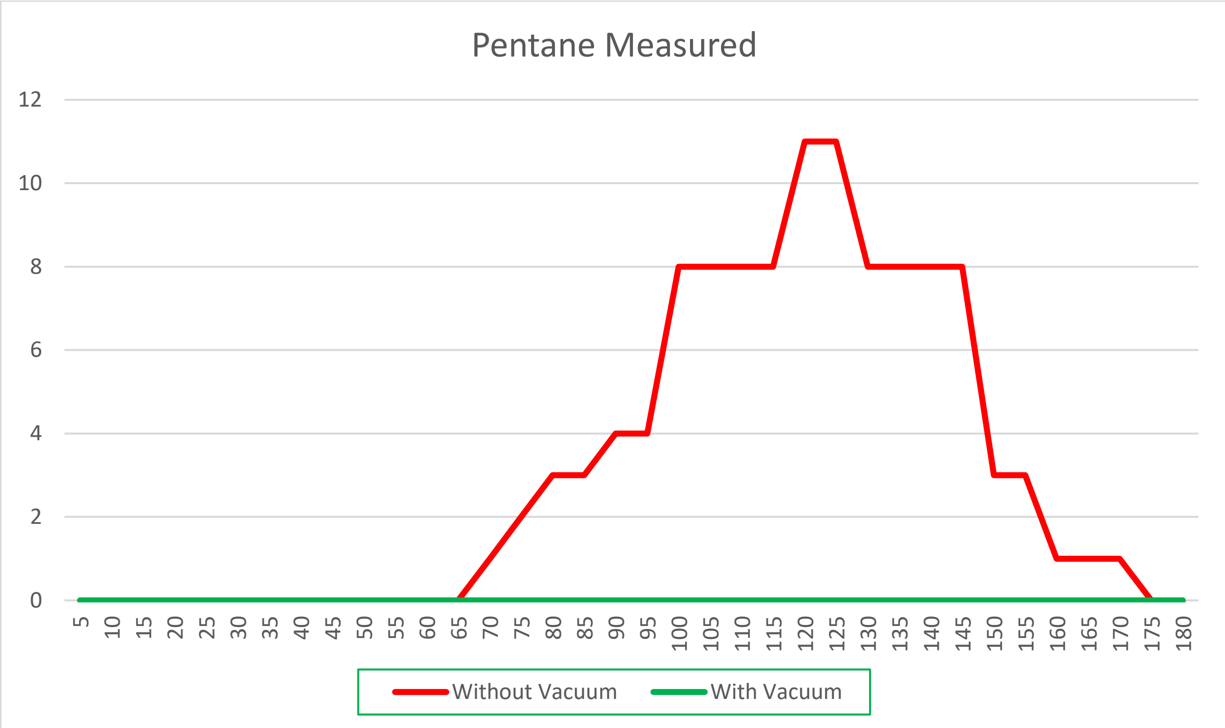

Pentane Emission Table

No Pentane was measured in Work Area during foaming with Vacuum System.

DAY 7 (20180320)
The modified formulation showed a further improved quality.
Excellent panel has been consistently produced.
The process parameters were:

- Vacuum level – 0.05 Bar
- Density 38 g/l
- Thickness 100 mm
- Two panels 3.3 m long per platen (total 4 panels each press cycle/opening)
- Demolding time 20’
- Metering unit throughput 1600 g/s

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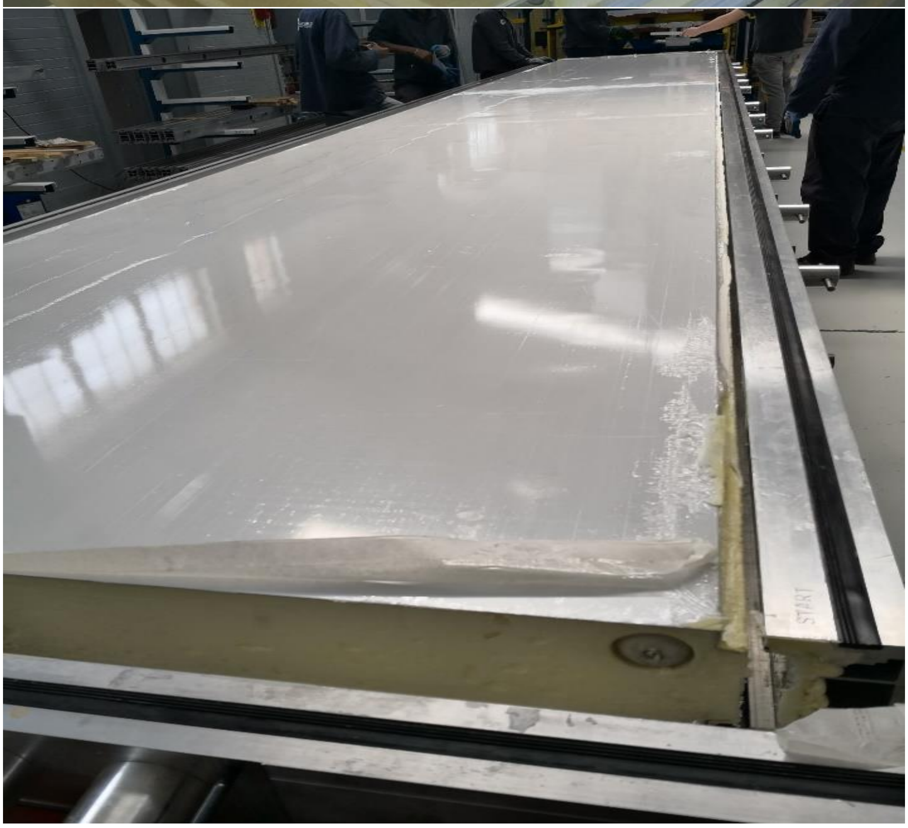

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Lab Test report

- The system uses Pentane as a blowing agent which is dosed via a Cannon Penta Easyfroth 20 to the foam machine.

- The system was processed with a Cannon A100 Compact Penta High Pressure Machine

- Foaming Press is a Manni Press set up for Pentane. 8.5m 2+2 equipped with Vacuum Technology.

- We injected sandwich panels with steel facings out of which
  Two panels were sampled using Resichem Polyurethane System using 9% Pentane and
  One panel was tested with a Dow Chemical System using 7% Pentane.

- Each panel was divided into three equal segments
  Left-Hand Side (L.H.S),
  Center &
  Right-Hand Side (R.H.S) along the length of the panel.

- The test samples were then cut from the middle of each segment.
  This assists in assessing the consistency of the results along the chemical flow path or panel length.

- The tests done are applied density distribution, compressive strength, thermal conductivity and foam stability. (Good dimensional stability results after production is a technical indicator for long term dimensional stability, temperature resistants' and long-term panel quality).
  The adhesion test is ongoing, the results will be incorporated into this report upon the completion of the test.

- The process parameters were recorded.

- The results, observation and conclusion are presented below.

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Panel Sampling

LHS Density Compressive	A D H E S S I O N	**MIDDLE** Density Compressive Thermal insulation	A D H E S S I O N	**RHS** Density Compressive

Fig1- Panel Schematic

Machine Settings & Panels Dimensions

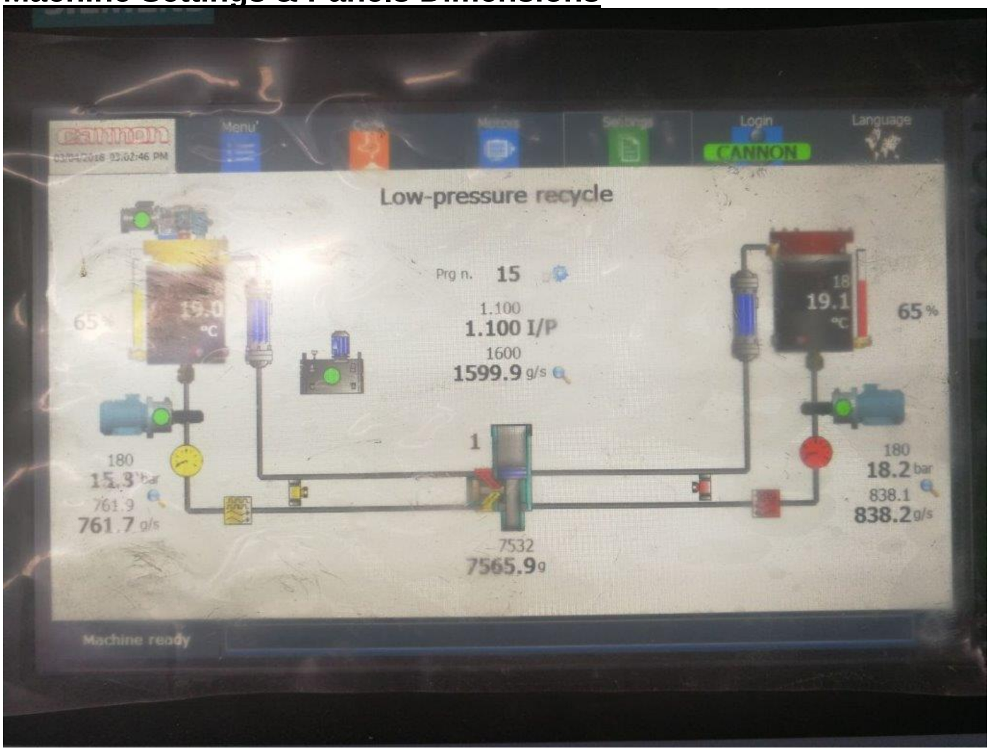

Figure 2- machine settings

Panel Thickness: 60mm
Demold Time: 14 minutes. With Vacuum. (20 minutes Without Vacuum)
Press Temperature: 44ºC

Panel Standard Without Vacuum Available of Current Local Market.
(Resichem Methyl Formate 6% of Polyol)

- 0.060 x 1.170 x 2.90m – target applied density: 42 g/l.

Panel 1 (Resichem System Pentane 9% of Polyol)

- 0.060 x 1.170 x 2.90m – target applied density: 38 g/l.

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Panel 2 (Resichem System Pentane 9% of Polyol)
- 0.060 x 1.170 x 2.90m – target applied density: 36 g/l.

Panel 3 (Dow System Pentane 7% of Polyol)
- Drawn from the customer's production, injected prior to this trial and cut from a 6m long panel.
- 0.060 x 1.170 x 3.0m – target applied density: 38 g/l.

RESULTS

Density Distribution

Current Market Standard Without Vacuum. – Target density: 42 g/l
(Resichem Methyl Formate 6% of Polyol)

	L.H.S	Center	R.H.S	Average
Overall	42.2	41.7	40.8	41.5
Core	36.8	37.7	36.9	37.1
Differential	5.4	4.0	3.9	4.4

Panel 1 – Target density: 38 g/l (Resichem System Pentane 9% of Polyol)

	L.H.S	Center	R.H.S	Average
Overall	37.1	37.0	37.0	37.0
Core	33.8	33.4	33.1	33.4
Differential	3.3	3.6	3.9	3.6

Panel 2 – Target density: 36 g/l (Resichem System Pentane 9% of Polyol)

	L.H.S	Center	R.H.S	Average
Overall	34.9	35.1	35.5	35.1
Core	31.4	31.9	31.9	31.7
Differential	3.5	3.2	3.6	3.4

Panel 3 – Target density: 38 g/l (Dow System Pentane 7% of Polyol)

	L.H.S	Center	R.H.S	Average
Overall	37.0	37.5	37.2	37.2
Core	34.1	34.5	33.4	34.0
Differential	2.9	3.0	3.8	3.2

Observation
- In all the panels the overall density is below the target by 1 g/l.
- The overall density is evenly distributed in all the panels.
- The density differentials are all below 4 g/l (typical for this application).

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Compressive Strength (kPa)

Foam samples were cut into small cubes, compressed by 10% of their original height on a TENSOMETER which registers the force per area (pressure) to do so. As the foam samples were cut out of a panel the direction of test (axis) relative to the dimensions of the panel was assigned and noted as follows:

- Y-axis: the direction along the length of the panel.
- X-axis: the direction along the breadth of the panel.
- Z-axis: the direction along the thickness of the panel.

Upon the measuring of the compressive strength the strength of the foam in Y-axis, which is regarded as the main axis in which the chemicals flow mainly, was compared to the rest of the axes, expressed below as a ratio known as anisotropy.

Figure 3 – TENSOMETER

Current Market Standard Without Vacuum. – Target density: 42 g/l
(Resichem Methyl Formate 6% of Polyol)

Axis	L.H.S	Center			R.H.S
Y	165.0	180.0			166.0
X	249.0	240.0			211.0
Z	199.0	193.0			190.0

Anisotropy

	L.H.S	Center	R.H.S
	Y-axis	Y-axis	Y-axis
X	0.66	0.75	0.79
Z	0.83	0.93	0.87

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Panel 1 – Target density: 38 g/l (Resichem System Pentane 9% of Polyol)

Axis	L.H.S	Center	R.H.S
Y	157.9	164.1	155.5
X	163.0	174.3	147.3
Z	165.0	163.0	153.7

Anisotropy

	L.H.S	Center	R.H.S
	Y-axis	Y-axis	Y-axis
X	0.97	0.94	1.05
Z	0.96	1.00	1.01

Panel 2 – Target density: 36 g/l (Resichem System Pentane 9% of Polyol)

Axis	L.H.S	Center	R.H.S
Y	147.0	126.7	146.9
X	133.7	133.5	137.3
Z	132.4	122.0	121.0

Anisotropy

	L.H.S	Center	R.H.S
	Y-axis	Y-axis	Y-axis
X	1.10	0.95	1.07
Z	1.11	1.04	1.21

Panel 3 – Target density: 38 g/l (Dow System Pentane 7% of Polyol)

Axis	L.H.S	Center	R.H.S
Y	174.3	181.8	146.0
X	170.6	179.3	154.8
Z	164.8	151.0	156.0

Anisotropy

	L.H.S	Center	R.H.S
	Y-axis	Y-axis	Y-axis
X	1.02	1.01	0.94
Z	1.06	1.20	0.93

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Thermal Conductivity

Figure 4 – Thermal Conductivity Tester

Current Market Standard Without Vacuum. Target density: 42 g/l (Resichem Methyl Formate 6% of Polyol)

- 0.02375 W/m.K (10ºC mean)

Current Market Standard Without Vacuum. Target density: 38 g/l
(Pentane 9%)

- 0.02151 W/m.K (10ºC mean)

Panel 1

- 0.02012 W/m.K (10ºC mean) (Resichem System Pentane 9% of Polyol)

Panel 2

- 0.02035 W/m.K (10ºC mean) (Resichem System Pentane 9% of Polyol)

Panel 3

- 0.02054 W/m.K (10ºC mean) (Dow System Pentane 7% of Polyol)

Foam Stability

- Cut foam samples with measured dimensions were separately tested at both 70 and -20ºC over a period of five days. No dimensional changes were observed. (Good dimensional stability results after production is a technical indicator for long term dimensional stability, temperature resistants' and long-term panel quality).

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CONCLUSION and OBSERVATIONS on the VAI TECHNOLOGY

- The compression strength results are within the following ranges:
  Panel 1 160 ±15 kPa, (Resichem System Pentane 9%)
  Panel 2 135 ±15 kPa, (Resichem System Pentane 9%)
  Panel 3 165 ±20 kPa. (Dow System Pentane 7%)

- The foam, in all the tested panels, do not display any irregular change-pattern in compressive strength along the panel length.

- In all the panels the foam strength anisotropy is less than 10% weaker and just below 20% stronger than the main Y-axis. This signifies the good chemical flow during the chemical reaction, assisted by the vacuum, without any sign of foam stretch or cell elongation as well as reasonably balanced foam compressive strength.

- The foam in all the panels have passed the foam stability test.

- The compressive strength is well balanced in all axes and well distributed across the panel surface area.

- The thermal conductivity is good and similar in all the panels. The optimized cell structure Insulation improved the insulation from 23,7 mW/m.K to 20,4 mW/m.K.

- The common trend of physical properties changing as moving away from the injection point of the vacuum assisted panels were not noticed, instead all were well and evenly distributed across the panel surface area. The panels are filled at relatively low applied density. With vacuum the density distribution is excellent. A significant improvement than without vacuum.

- The foam density can be reduced up to the 5% saving PU consumption. This result is a consequence of an improved density distribution within the panel: The Delta is reduced from 1,4 g/l without Vacuum to 0,5 g/l with Vacuum. The difference in density between the core and the average is also reduced from 4,4 g/l to 3,4 g/l.

- The Adhesion, manually tested, is improved. Superior dimensional stability and better appearance quality is clearly perceived.

- The demolding time has been reduced by 40%. Considering the total production cycle, loading/unloading and preparation, we can assume that the press can produce the same

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number of panels with a reduced time of 25% saving the energy necessary to use the plant.

- The Ventilation of the press has the added advantage of removing the Pentane vapors and VOC in the work area, which is the case of production without Vacuum.

- The direct suction by Vacuum inside the panel of the PU expansion results in total extraction of the Pentane & Isocyanate vapor, making the production safe and healthy for the operators.

- The VAI technology because of the increased reactivity-viscosity of the foam reduces the foam leakage at the venting points of the panel keeping the working area cleaner.

Report done by Michael Wainer of Reac Polyurethane Technologies (Pty) Ltd.

Date 23 April 2018

Signed

Final Report on:
Demonstration project on the technical and economic advantages of the Vacuum Assisted Injection in discontinuous panel's plant retrofitted from 141b to pentane

1. OBJECTIVE

- Demonstrate benefits from the application of the vacuum assisted injection in replacement of HCFC-141b with pentane in term of insulation properties in the panel's sector
- Demonstrate the easy applicability of the technology and, consequently, the replicability of the results
- Demonstrate that lower cost structure can be obtained by means of shorter foaming time, lower foam density, lower thermal conductivity
- Demonstrate the advantages in terms of safety against explosion and environmental and health sustainability for the operators
- Objectively analyze, if the incremental capital cost could be reduced overall in similar future projects by means of using Vacuum Assistance applied in the foaming process automatically used also for suction of flammable and harmful gaseous substances. Thus, providing means of reducing the cost of exhaust ventilation system in the hydrocarbon based plant conversions.

2. Budget and Expenditures

Project Budget	Approved Costs	Actual Total Funding Disbursed		Actual Costs
		Grant Funds	Counterpart Funds	
Incremental Capital Costs	202,000	202,000	244,000	446,000
Contingency	20,200	20,200		
IOC	N/A	N/A	N/A	N/A
Total Costs / Funding	222,200	222,200	244,000	446,000
Total MLF Grant	222,200			
Total Counterpart Funding	0			
Total MLF Grant Not Utilized		370		

Detailed list of incremental capital cost and contingency by item:

Project Budget	Approved Costs	Actual Funding		Actual Costs
		Grant Funds	Counterpart Funds	
Incremental Capital Costs				
Modification of press for VAI, Vaccum Kit	80,000	181,200	244,000	425,200
Set of side profiles	20,000	30,000		30,000
Safety Audit	2,000	Included above		
Technology transfer, servcies, consultany and training	25,000	Included above		0
Installation, commissioning, start up and trials and testing of technclogy and end products	75,000	11,000 and 64,000 included above		11,000
Subtotal	202,000	222,200	244,000	466,200
Contingency**	20,200	Included above		

3. Conslusions and lessons learned

- The project objectives have been met; technical report has been submitted to the MLFS for 81st ExCom
- Project funds including counterpart cost-sharing sufficed to meet the objectives of this demo.
- Capital costs as had been projected reflect real prices of the VAI standard equipment and special profiles (frames). The cost of the profiles will depend on the size and the number of sets; depending on customer needs. This demo project used two sets.
- An entire techno-economic replicability is confirmed:

-The technology is globaly applicable for any new installations as well as for retrofittings/upgrades.
-The cost pattern should reflect future commercial prices with a prospective reduction.

Pilot Demonstration Project on ODS-waste Management and Disposal in China

Final Report

Prepared by FECO/MEP, China and UNIDO

April, 2018

CONTENT

ACRONYMS

UNIDO:	United Nations Industrial Development Organization
MEP:	Ministry of Environmental Protection, China
FECO:	Foreign Economic Cooperation Office
EPB:	Environmental Protection Bureau
ExCom:	Executive Committee
MLF:	Multilateral Funds
ODS:	Ozone Depleting Substances
TA:	Technical Assistance

Executive summary

China has phased out the production and consumption of CFCs in 2007. In regard to the stock of products containing CFCs, the government of China has noticed the potential risk to the environmental once these products are out of service and entered into disposal facilities. The Regulation on Ozone Depleting Substances Management became effective in June 2010 prohibits the direct discharge of ODS wastes to the environment, it requires that the unwanted ODS shall be disposed properly, collection, recycling and disposal of ODS shall be reported and kept record at local EPBs.

China with the assistance of UNIDO and the financial support from the Multilateral Fund, implemented a demonstration project on ODS wastes collection and disposal to further explore the technology and policy framework of unwanted ODS.

The demonstration was implemented in three provinces and three municipalities in China. The provinces/municipalities investigated the collection and disposal situation and entrusted certified hazardous wastes disposal companies to pilot disposal of collected refrigerants and CFC foams using rotary kiln incinerators. The demonstration has resulted in more than 192 tonnes destruction of CFC wastes. The project validated the efficiency of rotary kiln in dealing with ODS and helped the environmental authority to analysis cost effectiveness. Through this demonstration the environmental authority reviewed the management regulations of ODS wastes collection, transportation and disposal. Policy and management recommendation were raised to strengthen monitoring of ODS wastes. The demonstration provides important enlightenment and reference value for the management of HCFCs and HFCs in China in the coming years.

1. Introduction

The implementation of Montreal Protocol on Substances that Deplete the Ozone Layer has successfully accomplished its target of phasing out the CFCs global wide. Whereas production and consumption of CFCs were put to an end, it remains a great concern of the products still in use containing CFCs, once these products retired from service, should they be properly taken care of to prevent the ozone depleting chemicals to be released to the air. Management of the waste products with ODS, including collection, recovery, recycling and proper disposal was raised as an important follow up action to the Executive Committee. Between the 58th to the 73rd meetings, the ExCom approved 16 project preparation funding that resulted in fully developed pilot demonstration projects for ODS waste management and disposal in 11 countries, two regional projects and one for technical assistance with a total funding of US $11,278,052. The implementation of these projects are expected to explore best management mechanism for wastes collection, cost effective technologies for ODS wastes disposal as well as policy framework to regulation collection and disposal activities and to ensure sustainability.

As one of the major production and consumption countries of ODS, China announced the phase-out of CFCs in June 2007. Given the considerable size of the chemical and manufacturing industry in China, stocks of CFCs based products, mostly refrigeration equipment and insulation foams are estimated to be in large amount. The environmental risk alongside with the retirement of these products was noticed by the government of China. Collection, recovery, recycling and destruction of ODS wastes was stipulated in the Regulation on Ozone Depleting Substances Management which entered into force on 1 June, 2010.

In order to further explore cost effective disposal of the collected ODS wastes and to set up sustainable model for ODS wastes destruction, the Chinese government, with the assistance of UNIDO, prepared the "*Pilot demonstration project on ODS waste management and disposal in China*" (hereafter "the demonstration project"). The project was approved at the 67th meeting of the Executive Committee of the MLF with the total funding of US$ 2,127,885. The demonstration project consists of three major components to address the key areas of ODS wastes identified in the country. The implementation of the project activities will result in the disposal of 192 MT of CFCs.

2. Planning and selection of implementation approaches

Considering the innovative aspects related to the DEMO project, the project implementation followed a staged approach.

2.1 Waste management in China and survey on existing technical capacity

The industrialization and rapid urbanization has brought tremendous challenges to the wastes management in China. Even though wastes disposal in China is dominated by landfill, incineration developed quickly due to its obvious advantages such as significant volume and mass reduction, complete disinfection and energy recovery. Three main types of incineration technologies have been introduced and applied in China, including the mechanical stoker grate, the rotary kiln and the fluidized bed. There are a total of 151 wastes incinerators in China in 2006, among them 32 rotary kilns (Li et al., 2016).[1]

In December 2013, FECO organized a site survey to four key provinces including Tianjin, Chongqing, Jiangsu and Shanghai. The objective of the survey is to evaluate the technical capability and experiences of incineration facilities in dealing with CFC wastes. The survey team consists of experts in thermophysics and refrigeration technologies.

Three incineration facilities, Tianjin Veolia, Chongqing Tianzhi and Suzhou Tonghe were investigated. Meetings were also held with the EBPs and local wastes collectors to understand the collection and disposal of solid wastes in the city.

The survey has resulted in several key conclusions which helped the advancement of the demonstration project:

(1) There are sufficient streams of wastes containing ODS in the four cities/provinces. Most of the wastes are scraped foams from destruction of refrigerators in electric appliances dismantling facilities. In some cities/provinces, refrigerants were also collected from obsolete ACs, vehicles and ships, but the amount is limited;

(2) The three disposal facilities all have rotary kiln installed which is technically feasible for disposing of CFCs, two facilities have experience in incineration of CFCs;

(3) It is found that in some provinces/cities, foams were sent to solid waste fueled power generation. In other cities, foams were also burnt in cement kiln or buried in landfills;

(4) CFCs based foams were not treated as hazardous wastes but as general municipal solid wastes.

The survey also indicated that most appliances destruction facilities and old vehicle destruction and ship breaking yards were equipped with ODS collections devices. Many of the collection equipment were funded by previous MLF projects.

A few gas cylinders were spotted by the surveyors at some sites, while it was claimed

[1] Xinmei Li, Changming Zhang, Yize Li, Qiang Zhi. The status of municipal solid waste incineration (MSWI) in China and its clean development. Energy Procedia 104(2016) 498-503.

by most collectors that the amount of refrigerants waste was very small and sometimes no refrigerants were found left in the compressors. It is explained that the refrigerator sector had completed CFC phase-out back in 1999, most refrigerators sent to destruction facilities are not CFC-based; secondly, the refrigerants in obsolete household ACs as well as vehicle ACs had leaked before they arrived in the destruction facilities. It is also found by the survey that in some facilities, the proper destruction and collection procedures were not followed due to poor management or lack of collection equipment, the compressors were cut open directly, resulting in immediate discharge of the remaining refrigerants.

2.2 Selection of provinces/municipalities to pilot the disposal demonstration

Based on survey results, six provinces/municipalities were targeted to carry out CFCs wastes collection and disposal demonstrations. The provinces/cities were selected based on:

1) Population and economic scale;

2) Estimated stock of CFCs-based products;

3) Technological capacity and performance in ODS management.

Upon discussion with the provincial EPBs, a detailed implementation plan was developed.

Three provinces (i.e. Jiangsu, Shandong and Guangdong) and additional three municipalities (i.e. Shanghai, Chongqing and Tianjin) agreed to pilot the ODS wastes collection and disposal demonstration. The destruction amount was agreed with provinces and municipalities as indicated in the table below:

Table 1: Disposal targets of selected provinces and municipalities

Province	**Jiangsu**	**Guangdong**	**Shandong**	**Tianjin**	**Shanghai**	**Chongqing**	**Total(MT)**
Amount	45	45	45	19	19	19	192

The selected provinces/municipalities share the following main characteristics:

1) High level of economic development and urbanization with a considerable appliance market and a high turnover rate of refrigerators;

2) The established collection system for electric appliances shows high recycling rates;

3) Locally available destruction facilities.

Although there are similarities in the selected province/municipalities, each province and city represents its own features in terms of sources of ODS wastes and capacity in ODS management and disposal. In particular, Jiangsu has a large collection and dismantling system of electric appliances, the disposal facility in Jiangsu has started to incinerate foam wastes in 2009, and Jiangsu also has the most ship breaking yards in China. Guangdong and Shandong are the top two most populous provinces in China, both have a large stock of refrigerators and room ACs. Guangdong is a manufacturing hub for refrigerators and ACs, it recycles more than 143,000 refrigerators in 2010. Shandong is one of the centers for PU foams products. The municipalities have higher urbanization ratio and the management hierarchy is direct and more efficient. Shanghai, Tianjin and Chongqing were named model cities for ODS management by Ministry of Environmental Protection. The three cities all established efficient appliance recycling system. The regulation on ODS management has been effectively implemented in the three cities. Especially, in the three cities, CFC refrigerants were managed as hazardous wastes, all collected CFC refrigerants were strictly disposed as hazardous wastes.

In the selected provinces/municipalities, there are sufficient streams of ODS wastes and necessary disposal capacity and management system to ensure the completion of the demonstration. The selection of provinces/municipalities also took into consideration the geographical distribution which will provide reference for cost analysis.

2.3 Demonstration activities with local EBPs

Based on the agreed amount of ODS collection and destruction, the EPBs and FECO signed demonstration contracts. The contracts entrusted provincial EPB to select recycle and disposal companies in their jurisdiction to carry out collection and destruction of ODS wastes. The fund will be channeled through the local EBPs to final beneficiaries of wastes collection companies and destruction facilities. About 20% of the fund will be used to support the EPBs for data survey, policy research, dissemination and additional management activities.

A total of 12,327,687 RMB Yuan (equivalent to 1,956,776 US$) were allocated to the six provinces/municipalities as indicated in Table 2.

It should be stressed that local destruction enterprises own the local disposal facility. However, destruction fees were transferred to destruction enterprises via local EPBs, subject to verification on achieved targets.

Table 2: Contracts signed by FECO and local EPBs

Province/ Municipality	Contract Amount(RMB)	Technology Applied	Expected Destruction Amount(MT)	Date of Contract signed
Shandong	2,791,058	Rotary Kiln	45	June 2014
Jiangsu	2,791,058		45	June 2014
Guangdong	2,791,058		45	June 2014
Shanghai	1,318,171		19	June 2014
Tianjin	1,318,171		19	December 2014
Chongqing	1,318,171		19	June 2015
Total	12,327,687		192	

Only Shenzhen has the plasma disposal facility, and the capability is quite small, so rotary kiln is the only disposal technology selected under the ODS-waste DEMO project.

3. Implementation activities

3.1 Data survey

The provincial EPBs carried out additional data survey in the province/city.

The data survey was focused on two aspects:

- Collection channels of ODS wastes;
- Disposal methods and technology.

In the meantime, the EBPs also looked at the existing regulations and management framework in collection, transportation and disposal of solid wastes which are relevant to the ODS wastes.

The ODS wastes are typically from three sources, the collection and dismantling of electric appliances, the disassembling of obsolete vehicles, ship breaking industry and other sources, such as industrial and commercial refrigeration, car services, or stock in chemical companies.

Specific approaches, focuses and details from the 6 selected case studies are reported in the following session.

Chongqing

In order to understand the collection of ODS wastes and the management of these wastes, the EBP surveyed the automobile disassembling sector, the electric appliance destruction sector and the hazardous wastes disposal facilities in Chongqing.

A list of 12 automobile disassembling companies was sorted out. These 12 companies include one group company, 9 small and medium sized private companies and two sub companies to deal with internal disassembling.

It is recorded that 27,040 old automobiles were dissembled in 2014. Chongqing Auto Scrap Group is the largest which has 70 disassembling sites and takes up to 67.4% of markets share.

Investigation shows that in the 70 disassembling sites only 5 have CFCs extraction equipment. However, the collected CFCs were not weighted and were sent to automobile servicing or mobile ACs servicing centers. The 9 SMEs account for 30.3% of the obsolete auto collection market. 5 of these SMEs have CFC collection equipment and it is reported by the companies that 1.24MT refrigerants were collected in 2014. The two internal disassembling sites have no CFC collection equipment.

It is found that all the foams from auto disassembling in Chongqing were mixed with other solid wastes and were sent to landfills.

There are two certified electric appliance dismantling companies in Chongqing with total capacity of 1.4 million units. In 2013 and 2014, 26kg refrigerants were collected and was incinerated in the certified hazardous wastes disposal facility. The waste foam collected was 131.2969MT among which 92.1683 MT were sent to certified hazardous waste incinerator, 38.757MT were disposed in landfills and the remaining 0.3716 were kept in stockpile.

The hazardous wastes disposal company in Chongqing had experience in incineration of CFCs wastes including refrigerants and foams from appliance dismantling.

Shanghai

The EPB in Shanghai targeted the refrigeration servicing sector, the electric appliance dismantling sector, the automobile destruction sector and the large commercial refrigeration users as the scope of the survey. The survey also covered two hazardous wastes disposal companies. There is no ship breaking company in Shanghai and therefore this specific sub-sector was not taken into consideration.

The EPB coordinated with the local industry associations and sent questionnaires to 370 refrigeration companies and cold storages in the city. The data in five electric appliance collection and destruction facilities, four vehicle destruction centers, 48 commercial buildings with large commercial refrigeration equipment were collected.

It is found that in 2013 and 2014, 1,084.9MT CFC-12 were collected in the five electric appliance dismantling companies and 1,002.3 MT were sent to certified hazardous waste disposal facilities. The disposal of these ODS wastes strictly followed the hazardous wastes management regulations in Shanghai.

The foam wastes from destructed refrigerators amounted 75,250.1MT in 2013 and 2014 in the five companies, and 74,952.8MT were disposed.

The survey indicated that before 2014, most of the foam wastes were buried in landfills, a small amount was sent to waste-to-energy power plants.

There are four automobile destruction companies in Shanghai, all of them have ODS collection equipment which were from previous MLF projects. However, the CFC refrigerants collected from automobile destruction is very limited. It may be attributed to two major reasons:

1) Heavy duty trucks are not equipped with ACs;

2) For the buses and sedans, most of the ACs is removed before the vehicles arrived to the destruction facility;

3) Though the AC system is removed, copper pipes of AC are damaged which results in the release of refrigerant.

It is recorded that in 2013-2014, 65.8kg CFC-12 were collected and 160kg were sent to disposal.

In the refrigeration sector, it is found that:

1) 9 refrigeration companies used CFC-11 and CFC-12 as refrigerants in 2013, the amount is 265kg;

2) In commercial refrigeration, no CFC-12 was found;

3) 15 centrifugal chillers were found using CFC-11. The owners have already planned to replace the equipment and the local EPB will monitor these chillers to make sure the proper disposal of the unwanted refrigerants.

Tianjin

The data survey focused on the amount of ODS wastes collected, disposed or recycled and stored in the waste automobile disassembling, home appliance dismantling and ship breaking sectors.

The survey also aimed to understand the cooperation model between wastes collectors and disposal companies, the disposal cost, disposal technology and processes as well as transportation modality of ODS wastes.

A list of ODS recycling enterprises in Tianjin was sort out. Information on amount of ODS wastes collected, recycled and disposed in the past three years in these companies were gathered.

Data from four electric appliance dismantling companies indicated that a large amount of foam was collected through destruction of waste refrigerators.

TCL Aobo is the largest appliance dismantling facility in Tianjin which recorded 1,228MT plastic wastes from destructed refrigerators in 2015. In the same year, the foam wastes in other three companies totaled 225.7MT. The waste is composed mostly of foams but it is also mixed with other plastic scraps.

The waste was sent to landfill after crushing and volume reduction processes. It is found that CFC-12 is rare in appliance dismantling. Only 5.5kg were found during the survey. No CFC-wastes were found in automobile disassembling and ship breaking sectors in Tianjin.

There are 18 certified hazardous wastes disposal companies in Tianjin. Among them, three companies have incineration disposal capacity, and two of them are designated to incinerate certain types of hazardous wastes. Tianjin Binhai Hejia Veolia is the largest integrated facility which is capable to deal with all types of hazardous wastes listed in the Directory of National Hazardous Wastes.

Shandong

The EBPs in Shandong surveyed 4 electric appliance collection and dismantle companies and 18 vehicle disassembling companies.

The survey has indicated that in 2014, a total of 13.4 MT CFC refrigerants were collected, among which 8.1MT from appliance dismantling and 5.3MT from automobile disassembling. In addition, 959.8MT foams containing CFC blowing agents were collected from destructed refrigerators.

There are four certified hazardous wastes disposal companies in Shandong. Three of them have disposed ODS wastes in rotary kiln incinerators. It is recorded that in 2014, 32.82MT ODS wastes were incinerated including CFC-12, foams containing CFC-11 and HCFC-141b.

During the investigation, it was found that the amount of CFCs recovered by each company was relatively small. There are several reasons for this:

1) The collected appliances were damaged and were put in storage for a long time which resulted in the leakage and venting of the refrigerants;

2) The copper pipes of some refrigerators were taken away during collection and improper transportation also led to the leakage of refrigerants;

3) Some companies, especially smaller ones, lacked recovery equipment and the proper operation process was not followed. It also caused the loss of recycled refrigerants.

All four incinerators in Shandong are running at full capacity which delayed the disposal of ODS wastes.

Jiangsu

There are 8 electric appliance dismantling companies in Jiangsu. In 2015, the 8 companies collected 2.92MT CFC refrigerants and foam wastes of 3,298.2MT.

In 2015, 120,245 obsolete vehicles were disassembled in the 16 automobile disassembling companies in Jiangsu. Twenty companies specialized in servicing of automobile ACs in Jiangsu received refrigerants recycling equipment from MLF project in 2008. The EPB had also organized two sessions of training workshops for these companies on appropriate recycling of refrigerants. However, in the car industry, the refrigerants have been switched to HFC-134a before 2010. No CFC-12 was reported during the survey.

Jiangsu is the center of ship breaking in China. There are 17 ship breaking companies in Jiangsu. All of the companies have received the refrigerants recycling equipment and cylinders from previous MLF project and the companies had participated in the training workshops for collection of ODS wastes organized by FECO/MEP.

Picture source: Jiangsu EPB, taken at Jiangsu Changrong (a ship breaking company)

However, the ship breaking sector was seriously affected by the slump of the steel price in recent years. Some of them had to stop breaking ships. In 2016, 0.21MT of waste refrigerants were collected.

Jiangsu Tonghe is a certified appliance dismantling company, the company also has its own rotary kiln which was certified by the environmental authority to treat hazardous wastes. The company has started the development of the ODS disposal technology in 2009. The company retrofitted the feeding system for scrapped foams to make it more efficient.

Guangdong

Guangdong is a manufacture hub for electric appliances. It also has a large stock for appliances such as ACs and refrigerators. The data survey in Guangdong has covered 193 companies in different sectors. The EPB worked together with Guangdong Association of Refrigeration to carry out field survey to six key cities in Guangdong. There are six certified appliance dismantling companies in Guangdong. It is found that in 2016, the six companies generated 1,618MT foam wastes, mostly from refrigerators and solar water heaters. The foams were grounded and sent to landfills.

Picture source: Guangdong EPB, taken at Qingyuan Dongjiang Environmental Technology Company Ltd. (an appliance dismantling company)

By the end of 2015, there are 32 automobile disassembling companies in Guangdong. The investigation showed that due to the slowdown of economic development and decreased demand of steel, these companies keep most of the collected cars in storage; only about 10 % were disassembled. It is also found that the ACs have been damaged before the cars arrived in disassembling facilities, therefore, most of the refrigerants had escaped. Around 100g refrigerants can be collected in cars with good condition, while in most cars less than 10g refrigerants were left. In such case the disassembling companies normally did not collect the refrigerants but discharge them directly.

The EPB visited three ship breaking companies in Guangdong. The companies explained that in some ships refrigerant cylinders can be found, these are backup supply for the refrigeration system on boat. The refrigerants are HCFC-22 and HFC blends, no CFCs were found.

Ship breaking also generates foam wastes. It is reported that about 200kg foam wastes can be collected from a single ship. The foam wastes from ship breaking industry were normally sent to cement kiln to incinerate or buried in landfills.

3.2 Amount of ODS sent to destruction facilities for final disposal

All six provinces/municipalities completed the disposal target as set forth in the agreement with FECO/MEP.

The total CFCs destructed is 194.793MT, among which 11.788MT CFC refrigerants, 172.005MT CFCs in foam wastes and CFC-11 blowing agent 11MT. All the collected wastes were incinerated by rotary kiln. Details of destruction targets are reported in Table 3.

Table 3: Destruction targets by municipality/province

Municipality Province	Expected Destruction Amount(MT)	Actual Destruction amount(MT)	CFC-12 Refrigerants (MT)	CFC-11 in Foams(MT)	CFC-11 (MT)	Technology Applied
Shandong	45	46.23	4.15	42.08	0	Rotary Kiln
Jiangsu	45	46.317	3.269	43.048	0	
Guangdong	45	45	0	34	11	
Shanghai	19	19.1897	4.3637	14.826	0	
Tianjin	19	19.052	0.0055	19.0465	0	
Chongqing	19	19.004	0.000224	19.00378	0	
Total	192	194.793	11.788	172.005	11	

3.3 Project achievement and environmental benefit

The implementation of the project resulted in a direct phase out of 194.793 MT ODP of ODS and 831,218MT CO_2 equivalent reduction of greenhouse gases.

Table 4: environmental benefits of the Demonstration project

Substance	ODP	GWP	Destruction amount (MT)	ODS phased out (MT ODP)	Greenhouse Gas Emission Reduction(MT CO2 Equivalent)
CFC-11	1.0	4,000	183.005	183.005	732,020
CFC-12	1.0	8,500	11.788	11.788	100,198
Total			194.793	194.793	832,218

3.4 Development of sustainable management policy

The Regulation on ODS Management which became effective in June 2010 is the fundamental legislation for ODS recycling. It is stipulated in the second chapter of the regulation that:

1) Enterprises specialized in the servicing and scrapping of refrigeration equipment, refrigeration system and fire-extinguishing system, that contain ODS, shall record under local EPB;

2) Enterprises specialized in the collection, recycling or destruction of ODS, shall record under local EPB;

3) Enterprises specialized in the servicing and scrapping of refrigeration equipment, refrigeration system and fire-extinguishing system, that contain ODS, shall collect, recycle the ODS or transfer the ODS to enterprises specialized in the ODS collection, recycling and destruction to give proper treatment to ODS;

4) Enterprises specialized in the ODS collection, recycling and destruction shall give proper treatment to ODS, and direct discharge is prohibited.

The regulation is national law which applies to all provinces and municipalities. However, it is noticed that in some provinces/municipalities the understanding and implementing of the law is much better than in others. The demonstration in the six provinces/municipalities has shown that the chemical industry and the refrigeration industry paid more attention to the recycling and proper disposal of unwanted ODS, while in the wastes collection sector, in some cases the appropriate procedure of recycling were not strictly followed. During the survey, the EPBs have noticed the issues in relevant sectors and supervision and monitoring measures were suggested accordingly.

Chongqing

The EPB has collaborated with the transportation bureau to strengthen management of hazardous wastes in vehicle disassembling activities. It is requested that information of collected ODS wastes shall be reported to municipal EPB and sent to certified hazardous wastes disposal company for destruction. The EPB also carried out supervision inspections to the vehicle disassembling sector. The collection, storage and disposal of waste refrigerants and foams will be a major focus of the inspection. Inappropriate operations were warned and rectified.

Shanghai

The EPB requested ODS related companies to register in the EPB data base in 2014. By 2017, 108 companies have uploaded their information. Through the implementation of the demonstration project, the EBP worked closely with the wastes collection companies and the disposal companies to evaluate the destruction technology and cost effectiveness of the disposal. This will help the EPB to develop fund supporting schemes and long term management policies.

Tianjin

The EPB updated its data base of ODS related enterprises in Tianjin. The wastes collectors and certified disposal companies will be included.

Shandong

The EPB promulgated a notice in 2015 to requests all ODS producers, sales and consumption enterprises as well as recycling, reclamation and destruction companies to report their data of previous year through the EPB online reporting portal in March every year. The reporting system will help to set up data base which will enable the EBP to monitor the dynamics of ODS related activities.

Jiangsu

The city-level environmental authorities were requested to update the list of ODS related companies timely and include them into the online data reporting system. The EPB coordinated with other authorities in charge of wastes collection and recycling to strengthen regulating collection activities and to avoid discharge of ODS wastes in informal collection, refurbishment and reuse. Subsidies to collection and destruction are under consideration.

3.5 Training and dissemination

In implementing of the demonstration project, the EPBs in the six provinces/municipalities carried out training workshops focused on different topics.

1) Training on enforcement of Regulation on ODS Management and data reporting;

2) Training to the refrigeration sector on operation of refrigerants recycling equipment;

3) Workshops on experience sharing of ODS wastes collection and disposal;

4) Seminars on ODS destruction technology.

Adding to self-sponsored workshops, the EPB in Shanghai worked closely with the national training center of good practice in AC servicing to promote the recycling of ODS in the refrigeration servicing sector. In Shandong, the EPB distributed brochures of national and provincial polices of ODS management to local enterprises.

The training workshops and dissemination activities have benefited more than 300 technicians, engineers and management teams from the appliance dismantling industry, the automobile disassembling industry and wastes disposal facilities.

The training and dissemination activity reinforced the understanding of ODS phase out policy and appropriate treatment of ODS wastes in the wastes recycling industry and disposal sector. The feedback from the workshops and seminars helps the EPBs and other government agencies to look into the sustainable solutions of ODS wastes and other greenhouse gases management.

4. Technology and cost analysis

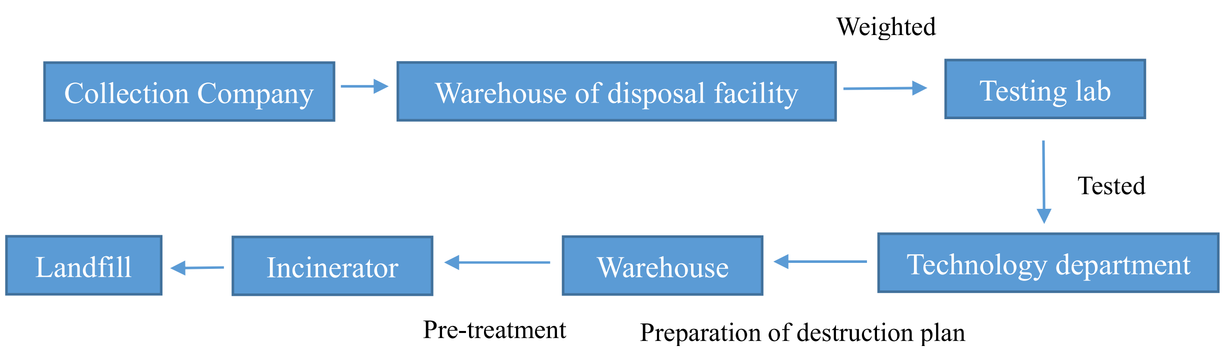
4.1 Technology

In this demonstration project, all six provinces/municipalities have applied rotary kiln for both the collected refrigerants and foam wastes. In consideration of CFC-12 is gas in room temperature, and foams are light weighted but large in volume, the disposal facilities made special retrofit to the feeding system to make sure the material were not left out in feeding.

1) Wastes transfer and destruction process

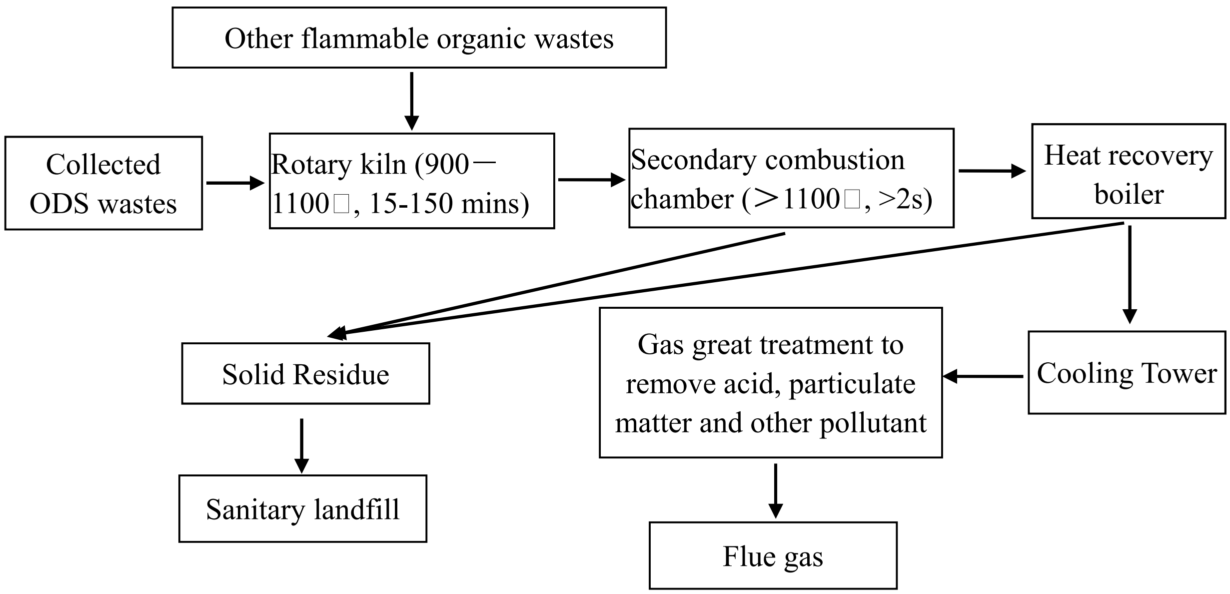
The transfer of wastes follows the transfer process requirements of hazardous wastes management in China. It is illustrated briefly in graph 1 below.

Graph 1: Process of ODS wastes transfer



The incineration of wastes is shown in graph 2 below.

Graph 2 Process of ODS wastes incineration



2) Highlights of the rotary kiln in destruction of ODS wastes

The combustion efficiency of the rotary kiln incinerator is more than 99.99%. There is no secondary pollution throughout the process. Emission from the chimney is examined to check if the gas is 100% destroyed. The testing reports are attached in Annexes.

1) The residue after combustion is discharged to the wet slag removal machine. The burning residue is reduced in heat burning by less than 5%. After being cooled, the slag is discharged from the system and transported regularly to sanitary landfill. The entire incineration system maintains a negative pressure operation, and the minimum negative pressure at the inlet of the incinerator is -5 mmH2O to prevent the leakage of harmful gases.

2) The flue gas from the secondary combustion chamber contains harmful gases such as SO2 and HCl and non-combustible solid particles. The temperature at the outlet of the secondary combustion chamber is higher than 1100°C. From the secondary combustion chamber, the flue gas goes through the waste heat boiler; the heat is collected and used to produce steam for heat demand in process and domestic hot water supply such as winter heating, bathing.

3) The emission index of flue gas shall be strictly implemented in accordance with the emission standards of flue gas pollutants specified in GB18484-2001 "Control Standards for Incineration of Hazardous Wastes" to ensure that environmental protection requirements are met.

4.2 Cost analysis

In this demonstration project, all six provinces/municipalities used rotary kiln technology. It is proved that this technology is efficient and economically viable. The disposal cost for ODS related foam wastes and refrigerants were composed of direct cost and indirect cost. Directly, the incineration will involve energy cost including electricity and gas, water and other materials for flue gas treatment and testing cost. The indirect cost includes shared investment cost of fixed asset, overheads, management cost and others, such as tax, etc. Although the cost is different from province to province, it is found that the cost range is between 8US$ to 12.5 US$ per kilogram, equivalent to 8US$-12.5US$/ODP kg.

This cost only indicates the cost at disposal facility.

In Jiangsu province, it is estimated that collection of refrigerator costs 6.35US$ and 12.38US$ per unit depending on sizes. The cost of dismantling is 4.02US$ per refrigerator regardless of size. Dismantling of refrigerator can collect foams 6-12 kg, and it is estimated that blowing agents account for 20% of the foam weights.

I the case of a small size refrigerator, the overall destruction cost calculation looks as it follows:

6kg foams *20% CFC-11=0.12kg CFC-11

Collection and dismantle =6.35+4.02=10.37US$/ refrigerator

Dismantling of 8.33 refrigerators can collect 1 kg CFC-11

The total cost for collection, dismantle and destruction of 1kg CFC-11 is:

10.37*8.33+12.5= 31.2US$

It is also found that the disposal cost for foam wastes and refrigerants are similar. It is proved more cost effective when foams were disposed in large batch. But this is not recommended, for foams are flammable and the storage of large volume of foam takes space and requires extra investment of fire protection equipment in the warehouse.

5. Lessons learned and recommendations

The disposal of unwanted CFCs is the *sine qua non* of implementing the Montreal Protocol of Ozone Depleting Substances. In addition, the incineration of these high GWP chemicals will avoid emission of greenhouse gases and contribute to the mitigation of climate change. Given the large stock of ODS and HFC based products, this demonstration has not only validated the technological and economic feasibility of ODS destruction in China, but also shown important enlightenment and reference significance for cradle to grave management of HCFCs, HFCs and other hazardous chemicals. Some of the lessons learnt and recommendations are summarized in the following.

5.1 Strengthen management of waste collection

The survey in the six provinces/municipalities has indicated that some of the waste ODS products, especially household ACs, refrigerators and obsolete vehicles went through informal collectors first before they entered into formal destruction facilities. The informal collectors removed components, such as compressors and motors for reuse, or took out the metals such as copper wires and pipes to sell.

The informal collection activity is an important cause that very few refrigerants were left in obsolete appliances and vehicles. Informal collection has always been a problem to the management of wastes.

The government authorities are looking for resolution to better manage this sector. It is recommended that the EPB work together with other agencies to define clear responsibilities for the collection, reuse, refurbishment and recycling of obsolete appliances and vehicles. Regulations shall be enforced to avoid irresponsible discharge of ODS wastes. The collection sector should be educated with ozone protection knowledge and ODS management policies.

5.2 Establishment of reliable and complete data base for ODS related activities

In recent year, many experts have called for the legislation on lifecycle management of chemicals in China. This demonstration project in the six provinces/municipalities has gained experience in the lifecycle management of ODS.

In the enforcement of the regulation on ODS management, the provincial EPBs have all set up data base to track ODS related enterprises in their jurisdiction, but much of the attention was paid to production, consumption and sales companies.

The demonstration in the six provinces/municipalities has confirmed that wastes collectors and disposal companies are important segment on the lifecycle chain of ODS. The activities of these companies should be monitored and updated timely. Only to include wastes collectors and disposal companies in the data base, the ODS lifecycle chain can be complete and the ODS will be traceable from cradle to grave. The experience from the demonstration should be spread to all other regions in China.

From a long term prospective, a reliable data base will be an important tool for future monitoring of HCFCs and HFCs.

5.3 Technological capability versus disposal capacity

The demonstration project has validated the rotary kiln technology is efficient for the destruction of CFC-12, CFC-11 and foams with CFC-11. However, some provinces have pointed out that the hazardous wastes disposal facilities in their province are operation at full capacity dealing with other solid wastes. China has surpassed the United States as the world's largest wastes generator in 2004 (World Bank, 2005). Considering the large amount of HCFCs and HFCs based products getting out of service in the coming years, it is recommended that extra disposal facilities shall be invested in advance, especially in some key provinces with faster economic development and higher ratio of urbanization.

Although the rotary kiln technology is proved effective, the cost is relatively high. It is recommended that the destruction process to be further optimized in order to improve efficiency and reduce cost. There is only one plasma equipment in China, and the capacity is rather small. In this demonstration, the plasma technology was not applied. It is recommended that the technology could be tested in future to evaluate cost effectiveness.

5.4 Government subsidies to encourage the ODS wastes destruction

It is found in many provinces that the high cost of incineration is an obstacle for the destruction of unwanted ODS. It is recommended that the government to review possibility of establishing special funding to encourage ODS wastes destruction. The found could be sourced from the MLF, the ODS producers. In addition, destruction of ODS contributes to the reduction of CO_2 emissions, the credit should be given to the collection and disposal sectors to encourage them.

Annex I Foam Test Report

正本

检验检测报告

Inspection and Detection Report

编号：和信德　检（YZPM）字 2017 年 第 002 号

产品名称：硬质聚氨酯泡沫

委托单位：山东中再生环境服务有限公司

检验检测类别：委托检测

报告日期：二 O 一七年六月二十二日

山东和信德检测技术有限公司

（检测专用章）

检验检测报告

和信德　检（YZPM）字 2017 年 第 002 号　　　　　　共 1 页 第 1 页

产品名称	硬质聚氨酯泡沫		规格型号	——	
生产日期/批号	——/——		商标	——	
委托单位名称	山东中再生环境服务有限公司				
委托单位地址	临沂市莒南县壮岗镇				
检验检测类别	委托检验	任务来源/任务号	/	抽样单编号	/
抽样日期	/	抽样基数	/	样品编号	1-1、1-2、2-1、2-2
样品送达日期	2017.6.19	样品状态	固体，硬质聚氨酯泡沫块		
检验检测日期	2017.6.21		检验检测地点	本公司实验室	
检验检测和判定依据	DB32/T 1718-2011《硬质聚氨酯泡沫中残留发泡剂的测定》				

检验检测结果

序号	样品类别/编号	检测项目	检测结果
1	1-1	CFC-11	检出
2	1-2	CFC-11	检出
3	2-1	CFC-11	检出
4	2-2	CFC-11	检出
备注	本检测结果只对本次送检样品负责。		

以下空白

填表人员：陈婧　　　审核人员：曹波　　　签发人员：王春丽

日　期：2017.6.22　　　日　期：2017.6.22　　　日　期：2017.6.22

Annex II Gas Online Test Data

山东中再生环境服务_小时数据

时间	二氧化硫			氮氧化物			烟尘			氧气	废气排放量	烟气压力	烟气温度	烟气湿度	流速
	实测浓度 (mg/M3)	折算浓度 (mg/M3)	排放量 (kg)	实测浓度 (mg/M3)	折算浓度 (mg/M3)	排放量 (kg)	实测浓度 (mg/M3)	折算浓度 (mg/M3)	排放量 (kg)	(%)	(m3/h)	(百帕)	(℃)	(%RH)	()
2017-07-29 00	0	0	0	64.3	60.7	7.44	3.7	3.65	0.43	10.6	115622	4.64	70.6	24.8	91.9
2017-07-29 01	0	0	0	69	67.9	8	3.65	3.67	0.42	11	115848	1.43	70.8	24.9	92.1
2017-07-29 02	0	0	0	82.4	77.6	9.62	3.6	3.49	0.42	10.6	116815	-13.38	71.2	25.4	93
2017-07-29 03	0	0	0	43.9	44.7	5.11	3.53	3.8	0.41	11.6	116180	-31.88	71	25	92.4
2017-07-29 04	0	0	0	90.9	85.8	10.5	3.48	3.33	0.4	10.4	115878	-37.6	71.1	25.1	92.2
2017-07-29 05	0	0	0	51.1	57.9	6.25	3.4	3.91	0.42	12.3	122432	-60.64	71	24.7	97.5
2017-07-29 06	0	0	0	38	41.7	4.61	3.53	4.12	0.43	12.3	121168	20.7	71.2	24.9	96.4
2017-07-29 07	0	0	0	110	95.6	13.1	3.56	3.12	0.43	9.55	119574	-15.59	71.4	27.2	95.2
2017-07-29 08	0	0	0	95.1	87.6	10.6	3.74	3.48	0.41	10.2	111058	99.3	71.9	29.6	88.5
2017-07-29 09	0	0	0	86.1	78.4	10.1	3.8	3.56	0.44	10.2	116876	51.3	72	31.3	93.2
2017-07-29 10	0	0	0	41.5	40.2	4.81	3.79	4.05	0.44	11.4	115917	12.2	71.7	28.4	92.4
2017-07-29 11	0	0	0	49.1	47.8	5.62	3.99	3.98	0.46	10.6	114504	-30.76	71.2	27.8	91.2
2017-07-29 12	0	0	0	48.4	48.7	5.55	4.06	4.54	0.47	11.9	114757	-11.16	71.4	27.6	91.4
2017-07-29 13	0.22	0.14	0.02	57.8	55.2	6.63	4.16	4.18	0.48	10.7	114684	-4.89	71.9	29.1	91.5
2017-07-29 14	0	0	0	84.3	77.7	9.62	4.36	4.01	0.5	10.1	114106	-26.17	72.2	29.8	91.1
2017-07-29 15	0	0	0	60.5	59.4	6.61	4.2	4.29	0.46	11.1	109194	-51.86	71.9	27.9	87.1
2017-07-29 16	0	0	0	67.4	60.8	7.32	4.16	4.05	0.45	10.5	108585	-61.73	72.5	28.7	86.8
2017-07-29 17	0	0	0	62.4	62.4	6.69	3.94	4.08	0.42	11.2	107299	-51.72	72.9	27	85.9
2017-07-29 18	0	0	0	47.6	47	5.24	3.88	4.01	0.43	10.9	109957	-47.11	72.8	26.2	88
2017-07-29 19	0	0	0	53.9	52.7	6.13	3.96	4.02	0.45	11.1	113798	-53.47	72	27.4	90.8
2017-07-29 20	0	0	0	99.2	86.9	10.9	3.78	3.42	0.41	9.73	109822	-47.65	71.8	29.3	87.6
2017-07-29 21	0	0	0	57.1	55.2	6.51	4.03	4.29	0.46	11.4	113926	-35.88	71.5	27.9	90.8
2017-07-29 22	0	0	0	127	124	14.6	4.13	4.04	0.48	10.8	115386	-29.46	71.8	27.5	92
2017-07-29 23	0	0	0	59.7	62.4	6.75	4.01	4.62	0.45	12.2	113129	-44.56	71.3	25.7	90.1
平均值	0.0046	0.0029	0.0004	73.4	69.9	8.39	3.91	4.02	0.449	11	114897	-25.79	71.9	26.8	91.6
最大值	0.22	0.14	0.02	151	135	16.4	4.8	5.83	0.56	13.8	123227	99.3	73	31.3	98.2
最小值	0	0	0	2.47	2.72	0.3	3.11	3.1	0.37	7.94	107299	-87.59	70.7	23.4	85.9
累计值			0.02			402			21.6		5515075				

Annex III Dioxin Test Report

CTI 华测检测 CENTRE TESTING INTERNATIONAL

CMA
161020340329

检 测 报 告

报告编号 EDD36J011842 第 1 页 共 16 页

委托单位 山东中再生环境服务有限公司

地 址 临沂市莒南县壮岗镇

检测类别 有组织废气

编制：

审核：

批准：

实验室负责人

日期：2017、11.22

采样日期：2017 年 11 月 06~07 日 检测日期：2017 年 11 月 15~21 日

苏州市华测检测技术有限公司 苏州市相城区澄阳路 3286 号

NO. 2220925235

苏州市华测检测技术有限公司 检验检测专用章

检 测 报 告

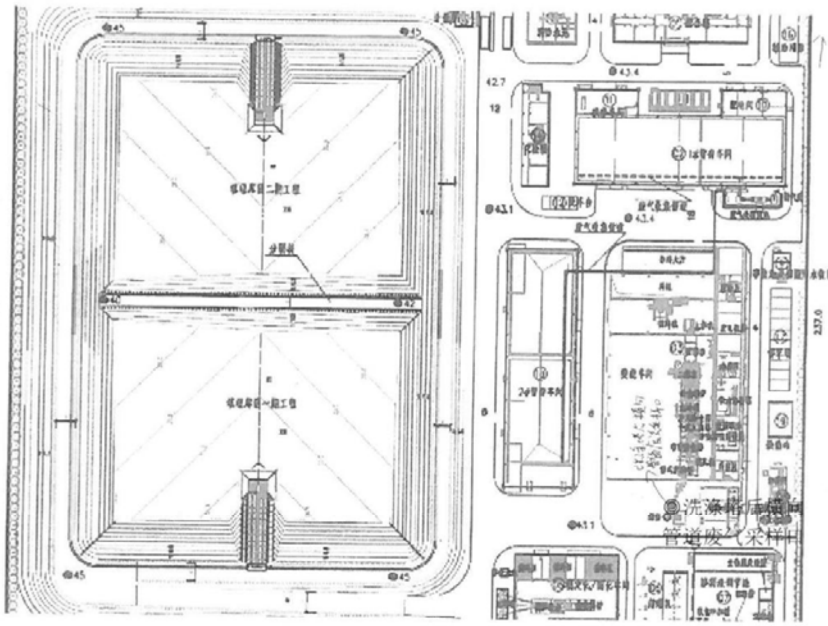
报告编号：EDD36J011842　　　　第 2 页共 16 页

样品信息：

检测类别	采样点	采样人	采样方法	样品状态
有组织废气	详见检测结果表	张轩、潘江	连续	完好

受检客户名称　　山东中再生环境服务有限公司
受检客户地址　　临沂市莒南县壮岗镇

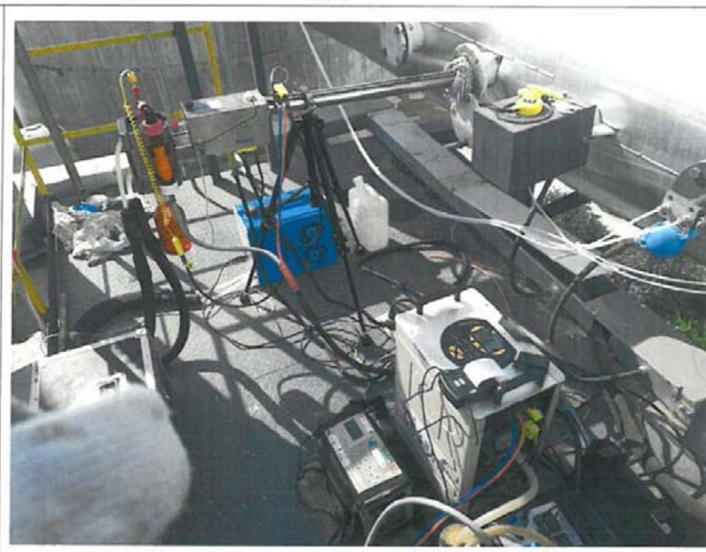
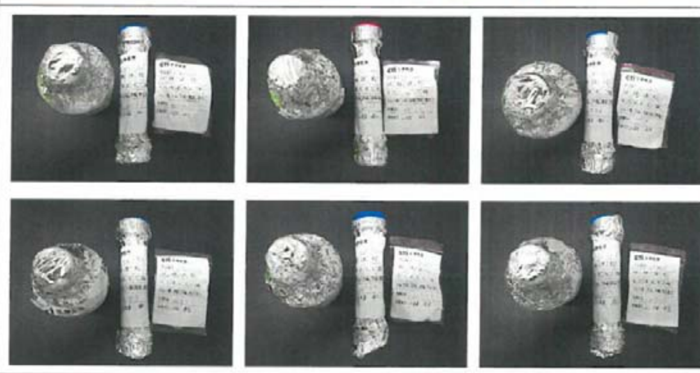
附:检测布点图及照片



说明：◎废气采样点

检 测 报 告

报告编号：EDD36J011842

采样点	照片	
洗涤塔后横向管道废气采样口	采样照片	
	样品照片	

注：样品照片第一排从左到右分别为第一天第一频次、第二频次、第三频次；第二排从左到右分别为第二天第一频次、第二频次、第三频次。

检 测 报 告

采样点	采样时间	检测项目	实测浓度	换算浓度	毒性当量（TEQ）	
			ng/m³	ng/m³	I-TEF	ng/m³
洗涤塔后横向管道废气采样口	2017.11.07 13:06~15:06	2,3,7,8-四氯代二苯并呋喃（TCDF）	0.099	0.085	0.1	0.0085
		1,2,3,7,8-五氯代二苯并呋喃（PeCDF）	0.14	0.12	0.05	0.0060
		2,3,4,7,8-五氯代二苯并呋喃（PeCDF）	0.27	0.23	0.5	0.12
		1,2,3,4,7,8-六氯代二苯并呋喃（HxCDF）	0.21	0.18	0.1	0.018
		1,2,3,6,7,8-六氯代二苯并呋喃（HxCDF）	0.25	0.21	0.1	0.021
		2,3,4,6,7,8-六氯代二苯并呋喃（HxCDF）	0.42	0.36	0.1	0.036
		1,2,3,7,8,9-六氯代二苯并呋喃（HxCDF）	0.083	0.071	0.1	0.0071
		1,2,3,4,6,7,8-七氯代二苯并呋喃（HpCDF）	0.65	0.56	0.01	0.0056
		1,2,3,4,7,8,9-七氯代二苯并呋喃（HpCDF）	0.065	0.056	0.01	0.00056
		八氯代二苯并呋喃（OCDF）	0.23	0.20	0.001	0.00020
		2,3,7,8-四氯代二苯并二噁英（TCDD）	0.008	0.007	1	0.0070
		1,2,3,7,8-五氯代二苯并二噁英（PeCDD）	0.036	0.031	0.5	0.016
		1,2,3,4,7,8-六氯代二苯并二噁英（HxCDD）	0.032	0.027	0.1	0.0027
		1,2,3,6,7,8-六氯代二苯并二噁英（HxCDD）	0.073	0.062	0.1	0.0062
		1,2,3,7,8,9-六氯代二苯并二噁英（HxCDD）	0.036	0.031	0.1	0.0031
		1,2,3,4,6,7,8-七氯代二苯并二噁英(HpCDD）	0.28	0.24	0.01	0.0024
		八氯代二苯并二噁英（OCDD）	0.30	0.26	0.001	0.00026
		二噁英类总量（PCDDs+PCDFs）	——		——	0.26

注：1. 毒性当量因子（TEF）：采用国际毒性当量因子 I-TEF 定义。

检 测 报 告

报告编号：EDD36J011842　　　　第 11 页 共 16 页

检测点：洗涤塔后横向管道废气采样口			2017.11.07　08:06~10:06		
参数	结果	单位	参数	结果	单位
大气压	101.5	kPa	静压	40	Pa
烟温	74	℃	含氧量	9.7	%
截面	0.4410	m^2	含湿量	14.3	%
流速	12.1	m/s	烟气流量	19269	m^3/h
动压	102	Pa	标干流量	15167	m^3/h
检测点：洗涤塔后横向管道废气采样口			2017.11.07　10:46~12:46		
参数	结果	单位	参数	结果	单位
大气压	101.5	kPa	静压	-20	Pa
烟温	76	℃	含氧量	9.9	%
截面	0.4410	m^2	含湿量	13.9	%
流速	11.9	m/s	烟气流量	18880	m^3/h
动压	98	Pa	标干流量	14761	m^3/h
检测点：洗涤塔后横向管道废气采样口			2017.11.07　13:06~15:06		
参数	结果	单位	参数	结果	单位
大气压	101.4	kPa	静压	-170	Pa
烟温	74	℃	含氧量	9.3	%
截面	0.4410	m^2	含湿量	14.6	%
流速	11.1	m/s	烟气流量	17655	m^3/h
动压	86	Pa	标干流量	13869	m^3/h

检 测 报 告

报告编号：EDD36J011842

检测点：洗涤塔后横向管道废气采样口 2017.11.07 10:46~12:46

项目		回收率%
采样内标	^{13}C-23478-PeCDF	103.8
	^{13}C-123478-HxCDF	106.1
	^{13}C-1234789-HpCDF	86.5
	^{13}C-123478-HxCDD	95.0
净化内标	^{13}C-2378-TCDF	91.9
	^{13}C-12378-PeCDF	89.0
	^{13}C-123678-HxCDF	88.7
	^{13}C-123789-HxCDF	101.8
	^{13}C-1234678-HpCDF	91.1
	^{13}C-2378-TCDD	87.0
	^{13}C-12378-PeCDD	93.1
	^{13}C-123678-HxCDD	101.8
	^{13}C-1234678-HpCDD	87.6
	^{13}C-OCDD	62.6

检测点：洗涤塔后横向管道废气采样口 2017.11.07 13:06~15:06

项目		回收率%
采样内标	^{13}C-23478-PeCDF	116.5
	^{13}C-123478-HxCDF	116.0
	^{13}C-1234789-HpCDF	91.0
	^{13}C-123478-HxCDD	108.1
净化内标	^{13}C-2378-TCDF	63.4
	^{13}C-12378-PeCDF	71.1
	^{13}C-123678-HxCDF	66.4
	^{13}C-123789-HxCDF	102.2
	^{13}C-1234678-HpCDF	74.9
	^{13}C-2378-TCDD	64.6
	^{13}C-12378-PeCDD	75.2
	^{13}C-123678-HxCDD	90.0
	^{13}C-1234678-HpCDD	71.2
	^{13}C-OCDD	52.5

检 测 报 告

报告编号：EDD36J011842

1. 本次检测的依据：

类别	项目	标准（方法）名称及编号（含年号）
气	二噁英类	环境空气和废气 二噁英类的测定 同位素稀释高分辨气相色谱-高分辨质谱法 HJ77.2-2008

2. 检测地点

CTI 实验室　　　苏州市相城区澄阳路 3286 号。

3. 本报告无 CTI 报告章无效。

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Pilot demonstration project on ODS waste management and disposal in Colombia

UNDP REPORT

Submitted on behalf of the Government of Colombia

APRIL 2018

Table of Contents

Acronyms and Abbreviations

ANDI	Asociación Nacional de Empresarios de Colombia (National Business Association of Colombia)
APC	Air Pollution Control
B/L	Baseline
CEMS	Continuous Emission Monitoring System
CFC	Chlorofluorocarbon
CFC-11	Trichlorofluoromethane
CFC-12	Dichlorofluoromethane
CFC-13	Chlorotrifluoromethane
Cl	Chlorine
DE	Destruction Efficiency
DRE	Destruction Removal Efficiency
EAF	Electric Arc Furnace
EC	European Commission
ESM	Environmentally Sound Management
EOL ODS	End of Life ODS
EU	European Union
EXCOM	Executive Committee of the Montreal Protocol Multilateral Fund
EPR	Extended Producer Responsibility
F	Fluorine
FENOGE	Fund for Non-Conventional Energy and Efficient Energy Management
g	Gram
GEF	Global Environment Facility
GEF STAP	Global Environment Facility Scientific and Technical Assessment Panel
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbons
HCFC-141b	1,1-Dicloro-1-fluoroethane
HCFC-22	Chlorodifluoromethane
HCl	Hydrogen Chloride
HF	Hydrogen Fluoride
HFC	Hydrofluorocarbons
HTI	High Temperature Incineration
HW	Hazardous Waste
kg	Kilogram
LFR	Lateral Flow Reactor
m	metre
MADS	Ministry of Environment and Sustainable Development
M&E	Monitoring and Evaluation
MLF	Multilateral Fund for the Implementation of the Montreal Protocol
NAMA	National Appropriate Mitigation Actions
NSP	NAMA Support Project
ODP	Ozone Depleting Potential

ODS	Ozone Depleting Substances
OECD	Organization for Economic Cooperation and Development
PCDD/F	Dioxins and Furans
PM	Particulate
POPs	Persistent Organic Pollutants
PROURE	Programme for the rational and efficient use of energy and other forms of non-conventional energy
RAC	Refrigeration and Air Conditioning
T	Metric tonne
TA	Technical Assistance
TEAP	Technical and Economic Assessment Panel
UTO	Ozone Technical Unit
UNDP	United Nations Development Programme
US	United States
US EPA	United States Environmental Protection Agency
WEEE	Waste Electrical and Electronic Equipment

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Colombia: Pilot Demonstration Project on ODS Waste Management and Disposal

Final Report on Project Results and their Application

Executive Summary

This document reports on the results to date of a Multilateral Fund for Implementation of the Montreal Protocol (MLF) funded Project in Colombia. The Project's primary objective is to put in place a sustainable, environmentally sound, and affordable capability for Colombia to destroy the "end of life" (EOL) ODS inclusive of qualifying available destruction technologies in accordance with Montreal Protocol requirements. The following has been prepared for submission to the Executive Committee of the MLF (EXCOM) as a final report on project results and their application, upon completion of the Project's major milestone activities associated with qualifying national technical capability for EOL ODS destruction. Additionally, it outlines the country's continuing innovative work in applying these results in development of a sustainable EOL ODS management capability and Extended Producer Responsibility (EPR) system.

The Project is being undertaken within a broader national policy framework covering an integrated approach to special and hazardous waste management, energy efficiency and the national response to management of greenhouse gas releases as well as the country's commitments to meeting its obligations under the Montreal Protocol. This includes a priority attached to the environmentally sound management of EOL ODS increasingly being generated as a result of developing national policy initiatives in these areas in the refrigeration and air conditioning (RAC). The MLF support for demonstration of EOL ODS capture and destruction to date is a key component of this, along with sustaining national program and bi-lateral financial support now in place that should ensure its sustainability.

The Project design is based in three components: i) demonstration of ODS Destruction capability, specifically through a comprehensive test burn program in a high temperature rotary kiln hazardous waste incinerator with subsequent financing for destruction of initial volumes of EOL ODS from the developing EPR program on domestic refrigerators, as well as an independently funded program on foam destruction in an electric arc furnace (EAF) steel making facility; ii) technical assistance support for regulatory measures, EPR system development and public awareness initiatives; and iii) project management, monitoring and evaluation. The overall status to date is that the demonstration of destruction technology has been successfully completed, and the EPR system has completed its initial voluntary pilot phase and is moving to a sustainable mandatory model supported by an appropriate regulatory framework and an ongoing public awareness component. Of the initial MLF grant of US$1,195,000, US$861,201 has been disbursed and the remaining US$333.799 has been committed at the end of 2017. The main remaining commitment is US$245,000 allocated for destruction of initial volumes of ODS from the EPR program. To date the estimated co-financing from partners and the government is US$1,098,358.

The demonstration test burn work on the TECNIAMSA facility showed that a domestic capability is qualified in principle for the destruction of EOL ODS, specifically CFC-11 and HCFC-141b based foam and CFC-11 and CFC-12 chemicals up to established limits of chlorine feed content. However, the results show some commercial issues associated with the practical application in its use in the overall EPR based system. While the facility more than meets the destruction efficiency requirements for the subject chemicals, there are limitations related to air emissions, particularly acid gasses (HCl and HF) that limit chlorine and fluorine content of the feed, hence impact productivity and cost effectiveness in destroying the

EOL ODS tested. Positively, the cost effectiveness for destruction of CFC-11 and CFC-12 chemicals is less than half of the maximum specified by the MLF and should be affordable relative to application to the planned EPR system. However, for foam the cost effectiveness is approximately four times this threshold and would not be considered affordable within an EPR system framework. Based on this, the current focus is on the use of an EAF steel making plant processing intact refrigerator cabinet and doors. Additionally, consideration is being given to qualification of a commercial cement kiln to destroy foam and potentially EOL refrigerant. Depending on the option, pro-forma overall EPR system cost estimates per refrigerator are projected to range from US$6.4 to 12.3/refrigerator depending on foam destruction option selected.

The development of a sustainable EPR system, started in 2013, has progressed to the point of transition from the voluntary pilot phase to the incremental implementation of a mandatory system. The institutional capacity in the form of an industry administered model is now established and operational in five major cities. It is supported by legislative and regulatory measures now in place, and by financial incentives related to VAT reductions and energy efficiency incentives applicable to equipment replacement. Substantial bi-lateral funding is in place through a NAMA Support Project that will support accelerated introduction of climate friendly refrigeration equipment along with technical assistance for their design and production as well as expanded processing of EOL domestic refrigerators. This has an overall target of 300,000 units replaced by 2022 and coincides with the targeted 50,000 refrigeration and 5,000 unitary air conditioning (A/C) units annually set for the fully developed EPR program in the next 5 years.

UTO both through this Project and with bi-lateral GIZ support have also completed a comprehensive assessment of ODS and HFC banks in the country along with projections of the associated availability of EOL refrigerants through to 2030. This work indicates the requirement for EOL refrigerant management will be dominated by the domestic and commercial refrigeration sectors, and unitary A/C sector. While some short-term requirements for management of CFCs exists these largely disappear in the next five years and the focus of the EPR system needs to be on HCFCs and HFCs.

A significant consequence of this is the need to expand the scope of qualification of destruction capability to HCFC and HFCs, something that would be required for technical reasons related to ensuring qualified environmental performance for the higher fluorine content involved in the case of the TECNIAMSA facility, and potentially future compliance with TEAP requirements. Likewise, it is also recommended that qualification of a cement kiln option for both HCFC and HFC refrigerants and HCFC based foam be considered to ensure a qualified option in accordance with TEAP requirements exists and a competitive commercial alternative for refrigerant destruction exists.

Colombia: Pilot Demonstration Project on ODS Waste Management and Disposal

Final Report on Project Results and their Application

1.0 Introduction

This document reports on the results to date of a Multilateral Fund for Implementation of the Montreal Protocol (MLF) funded Project in Colombia covering a pilot demonstration on management of end of life ozone depleting substances (EOL ODS). It has been prepared for submission to the Executive Committee of the MLF (EXCOM) as a final report on project results and their application upon completion of the Project's major milestone activities associated with qualifying national technical capability for EOL ODS destruction in accordance with Montreal Protocol requirements. Additionally, it outlines the country's continuing innovative work in applying these results in development of a sustainable EOL ODS management capability and Extended Producer Responsibility (EPR) system within a broader integrated national hazardous waste management framework. As such, it is also intended to document initial findings from the project as Colombia's contribution to the broader body of knowledge on this subject in terms of technical and economic conclusions and lessons learned for use and potential replication elsewhere. A complementary report on the project at its expected closure in 2019 will update these based on experience obtained with the initial implementation of the EPR system.

It has been prepared by the Ozone Technical Unit (UTO) in the Division of Sectorial and Urban Environmental Affairs of the Ministry of Environment and Sustainable Development (MADS), and the United Nations Development Programme (UNDP). MADS and specifically UTO are the executing entity for the MLF grant supporting the Project with UNDP acting as the MLF implementing agency. This EOL ODS destruction Project is one of twelve such projects in Article 5 countries being funded by MLF.

The approach taken to the report structure and content is to orient it to providing a summary description of the Project's background and context, its overall scope and objectives and the sequence of activities undertaken to date. The specific activities involved in the test burn program to demonstrate domestic ODS destruction capability are then described noting that this is the primary focus of this particular progress report. This includes summary information on the assembly of test EOL ODS, facilities modifications undertaken, and the design of the actual test program and its implementation. The results of these test burns are summarized and discussed relative to applicable standards and their implications respecting Project objectives and longer-term application to the national EPR program applicable to domestic refrigeration equipment. Finally, the current status of the EPR program applicable to domestic refrigeration equipment is summarized and its planned implementation discussed in the context of completing the MLF Project commitments and future sustainable operation including bilateral support through a National Appropriate Mitigation Action (NAMA) funded by the NAMA Facility. The document is supported by two substantive technical reports available from UTO. One prepared by TECNIAMSA, the company whose facilities were selected for the test burn demonstration program and provides details of the facility and modifications implemented[1]. The second, prepared by the national consultant who supervised the test burn program,

[1] TECNIAMSA, "Mosquera incineration facility – Technical description of facilities, process and modifications for test burn", March 2017

provides the detailed analytical results of the test program[2] and forms the basis of results summarized and discussed herein.

2.0 Project Background and Context

The originating rationale for MLF interest in the management of EOL ODS relates to the recognition of the importance of ODS banks and the potential opportunity of mitigating the emissions from these banks when the applications involving the use of ODS ceases. This is something that has become increasing problematic with the successful phase out of CFC consumption and now implementation of mandatory phase out of HCFC consumption under the Montreal Protocol. Understanding that EOL ODS would otherwise be subject to general release into the atmosphere at some point in a conventional waste management process, this waste is now seen as a regulated hazardous waste (HW) requiring environmentally sound management (ESM). In addition to the potential significant positive impact in accelerating combating ozone layer depletion, it was also recognized that effective destruction of many EOL ODS wastes could also significantly contribute to climate change mitigation by eliminating release of EOL ODS having significant high Global Warming Potential (GWP).

This priority was formally acknowledged by the Parties to the Montreal Protocol (Parties) in 2008 at their 20th meeting where the importance of acquiring more information on mitigating ODS emissions and on destroying ODS banks available at the end of their useful life is reflected in Decision XX/7[3]. This included requesting EXCOM to consider funding pilot demonstration projects that focused on assembled stocks of EOL ODS with high net global warming potential (GWP). Approved projects were to address the collection (without MLF funding), transport, storage and destruction of ODS with the results providing lessons learned, generation of experience about management and financing modalities; climate benefits; and leveraging co-financing opportunities. This request was followed up in 2009 with further direction to the EXCOM at the 21st Meeting of the Parties (Decision XXI/2)[4] which included requesting annual reports on the progress of such projects.

The above decisions at the 20th and 21st Meetings of the Parties also requested the Technical and Economic Assessment Panel (TEAP) to undertake continuing analysis of ODS banks and the environmentally sound destruction of EOL ODS. This included work related to updating Bank estimates globally, estimation of the potential availability of EOL ODS for environmentally sound management (ESM), possible mitigation impacts with respect to both ozone depletion and greenhouse gas release reduction, the cost effectiveness of mitigation, and applicable economic mechanisms that could be applied for purposes of financing destruction of EOL ODS Banks. At the 22nd Meeting of the Parties in 2010, Decision XXII/10[5] further requested the updating of available destruction technologies and development of criteria applicable to the verification of EOL ODS destruction. Most recently the Parties in Decision XXIX/4 have requested further updating of the list of approved destruction technologies and their assessment as to applicability to the destruction of HFCs now covered as controlled substances under the Kigali Amendment, a process that is currently being completed by TEAP.

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[2] Alexander Valencia Cruz, "Technical and operational support to the execution of activities related to the implementation of demonstration tests - pilot project on ODS (ozone-depleting substances) waste management" October, 2016

[3] http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/246

[4] http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/203

[5] http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/181

The initial consideration of pilot projects was undertaken by EXCOM at 57th meeting[6], in the context of the 2009-2011 consolidated MLF business plan (Decision 57/6). While preparation funding was approved for an initial six country specific pilot projects (Brazil, Ghana, Indonesia, Mexico, Philippines, Turkey), EXCOM requested the Secretariat to prepare a document containing criteria and guidelines for the selection of further ODS disposal projects, taking into account Decision XX/7 referenced above. At its 58th meeting[7], EXCOM approved the interim criteria and guidelines noted above[8] (Decision 58/18) for application to country specific proposals to be considered at the 59th EXCOM and subsequent meetings. The principle aspects of the criteria guidance relevant to the project undertaken in Colombia included: i) definitions of the collection, transport, destruction and storage facilities: ii) exclusion of primary collection activities from funding based on a perquisite that EOL ODS used in the project should be secured in advance; iii) application of a grant cost effectiveness threshold of <US$13.2/kg for EOL ODS eliminated; iv) annual progress reporting requirements; and v) provision for co-financing requirements.

In addition to above initiative and actions by the Parties to the Montreal Protocol and the MLF, the Parties also established a technical guidance framework applicable to the destruction of EOL ODS through TEAP which are to be applied to pilot/demonstration projects funded by the MLF. The formal adoption of an approved list of destruction technologies and performance standard requirements covering destruction efficiency and emission limits for such technologies dates from 2002 (Decision XIV/6)[9] with recognition of the guidance developed by the TEAP Task force in this area[10]. Since that time there has been periodic updating of an approved list of destruction technologies (Decision XXII/10) [11] and adoption of a Good House Keeping Standard applicable to destruction activities (Decision XV/9)[12]. In terms of relevance to this specific Project, destruction removal efficiency (DRE) and emission requirements applicable to both dilute and concentrated EOL ODS defined in Table 2.1 in the above referenced TEAP Task Force Report are particularly relevant in this work.

The ODS destruction pilot project for Colombia was submitted in 2009 by MADS to the 59th EXCOM meeting[13] and approved for preparation with funding of US$40,000 (Decision 59/20) as the seventh MLF pilot/demonstration project addressing the management of EOL ODS in Article 5 countries[14]. As documented in UNDP/UTO proposal and covering review and positive recommendation prepared by the MLF Secretariat[15], it was approved for implementation funding in 2012 at the 66th Meeting of EXCOM[16] (Decision 66/27) as proposed and clarified between the MLF Secretariat and UNDP for MLF funding of US$1,195,000, and the understanding that no further funding will be available to the country for ODS disposal projects in the future.

[6] UNEP/OzL.Pro/ExCom/57/69, http://www.multilateralfund.org/sites/57th/Document%20Library2/1/5769.pdf
[7] UNEP/OzL.Pro/ExCom/58/53, http://www.multilateralfund.org/sites/58th/Document%20Library2/1/5853.pdf
[8] UNEP/OzL.Pro/ExCom/58/19/Rev.1, http://www.multilateralfund.org/sites/58th/Document%20Library2/1/5819r1.pdf
[9] http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/548
[10] http://ozone.unep.org/sites/ozone/files/meeting-document/TEAP02V3b.pdf
[11] http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/25548
[12] http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/536
[13] UNEP/OzL.Pro/ExCom/59/59, http://www.multilateralfund.org/sites/59/Document%20Library2/1/5959.pdf
[14] Between 2009 and 2014, EXCOM approved 12 country specific projects for preparation and implementation funding as well as 3 Global/Regional projects on EOL ODS management.
[15] UNEP/OzL.Pro/ExCom/66/33, http://www.multilateralfund.org/66/English/1/6633.pdf
[16] UNEP/OzL.Pro/ExCom/66/54, http://www.multilateralfund.org/66/English/1/6654_and_c1_c2.pdf

3.0 Project Scope and Design

3.1 General Approach, Overall Scope and Objectives

The UNDP/UTO proposal submitted on behalf of the Government of Colombia and approved at the 66th EXCOM meeting as referenced above in Annex I of the MLF Secretariat decision document sets out the general approach, scope and design along with indicative costs, implementation priorities and modalities intended for the Project. In this overall section these aspects are described in more detail as implemented, including various areas where variation from what was originally proposed occurred and the reasons for that.

From the perspective of the Government, the Project proposal was made in the overall policy context of the evolving national policy framework being pursued by MADS related to the management of a range of environmentally sensitive waste streams and development of initiatives for the diversion of these waste from conventional disposal options, typically landfill or involving uncontrolled environmental release of contaminants. This was envisioned as developing capacity for ESM of these hazardous waste streams involving maximizing resource recovery and/or environmentally sound disposal/destruction.

This was being supported by introduction of a legal and legislative framework for this integrated approach to hazardous waste management. It started with establishment of a legal framework for hazardous waste in 2005 (National Policy for integrated management of Hazardous Waste[17] and Decree 4741, 2005[18]) and followed up in 2015 (Decree 1076, 2015[19]) which establishes the responsibility and obligations of a producer of a substance with hazardous characteristics for the ESM of the residues and containers/packaging. Initially, producers of only selected hazardous waste streams (pesticides, medicines, lead acid batteries) are subject to a mandatory requirement to put in place a "Return Management Plan for Post -Consumer Products". The intention is to pursue incrementally expanding this to other regulated hazardous wastes including EOL ODS and potentially EOL HFCs with the ratification of the Kigali Amendment. The feasibility of this would be substantially supported by being able to demonstrate cost effective domestic destruction capability through this Project. Likewise, it is closely linked to initiatives related to EPR programs applicable to the RAC sector and potentially including application to ODS and HFC importers.

One of the waste streams specifically being targeted under this policy approach is the general waste category of Waste Electrical and Electronic Equipment (WEEE), a major sub-component of which is end of life refrigeration and air-conditioning (RAC) equipment. The high priority attached to RAC equipment within this policy framework was and continues to be significantly motivated by the substantial progress made by the country in fulfilling its Montreal Protocol obligations, specifically achieving phase out of CFC consumption, now its aggressive initiation of HCFC consumption phase out, and in the future HFC phase

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[17]http://www.minambiente.gov.co/images/AsuntosambientalesySectorialyUrbana/pdf/sustancias_qu%C3%ADmicas_y_residuos_peligrosos/Politica_Residuos_peligrosos.pdf

[18]Decree 4741, 2005 by which the prevention and management of hazardous waste generated within the framework of integral management is partially regulated, http://www.corpocaldas.gov.co/publicaciones/1524/02-28/Decreto4741de2005.pdf

[19]Decree 1076, 2015 by means of which the Single Regulatory Decree of the Environment and Sustainable Development Sector is issued, http://www.minambiente.gov.co/index.php/normativa/81-normativa/2093

out under the Kigali Amendment. Law 1672 of 2013[20] provides the general framework for electric and electronic devices and the handling of their respective waste, then the National Policy for integrated management of WEEE launched in June 2017 and more recently Decree 284, February 15, 2018[21] established in more detail the responsibilities of the electric and electronic equipment producers. Domestic and commercial refrigerators and air conditioning equipment are included in the list of controlled EEE noting that in 2012 the capture of 2.6 million domestic refrigerators for environmentally sound management over the following decade was set as a national target[22]. This has stimulated the country to develop a robust basic capability among private sector service providers for processing WEEE including a basic capability for end of life RAC equipment including recovery for EOL ODS in both concentrated and dilute forms (i.e. foam).

Likewise, the parallel policy initiatives related to achieving enhanced energy efficiency through replacement of old RAC equipment reinforced this priority. Regarding the policies on energy efficiency, the Ministry of Mines and Energy adopted the Indicative Action Plan 2010-2015 to develop a programme for the rational and efficient use of energy and other forms of non-conventional energy (PROURE). Currently, the second phase of this plan includes the phase 2017-2022. The overall objective of PROURE is "to promote the rational and efficient use of energy and other forms of non-conventional energy, contributing to ensure a full and well-timed energy supply, competitiveness of the Colombian economy, consumer protection and promotion of the use of non-conventional energy sustainably". The replacement of old RAC equipment has been prioritized in PROURE's indicative action plan[23] that was approved by Resolution 41286 of December 30, 2016[24].

Based on the above policy priorities and initial development of a framework for establishing a sustainable EPR approach to managing RAC waste streams, the timing and focus of the MLF initiative on pilot demonstration EOL ODS management described in Section 2 above was recognized as having strong synergy with the Government's priorities as well as being consistent with its proven commitment as a Party to the Montreal Protocol. This synergy and specifically the identification of a critical gap related to selecting and qualifying EOL ODS destruction capability to support the overall ESM of these waste streams has served to define the design and scope of the Project as documented in the MLF proposal and in its subsequent implementation since that time.

The Project's stated primary objective is to put in place a sustainable, environmentally sound, and affordable capability for Colombia to destroy the "end of life" ODS that is anticipated to accumulate as a result of current national policy initiatives related to energy efficiency and waste management involving the replacement of domestic refrigerators. Other objectives originally identified were: i) integrate the management of EOL ODS into the countries overall hazardous waste management system; ii) to enhance synergies with initiatives related to meeting national obligations under the Stockholm Convention respecting the destruction of POPs stockpiles; iii) contribute to the technical knowledge base on destruction

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[20]Law 1672,2013 by which the guidelines for the adoption of a public policy of integral management of residues of electrical and electronic appliances (WEEE), and others provisions are dictated, http://www.minambiente.gov.co/images/normativa/leyes/2013/ley_1672_2013.pdf

[21]Decree 284, 2018 by which is added Decree 10476 of 2015, Sole Regulation of the Environment and Sustainable Development Sector, in relation to the Integrated Management of Electrical and Electronic Devices -RAEE and other provisions are dictated, http://www.minambiente.gov.co/index.php/normativa/decretos

[22]http://www1.upme.gov.co/DemandaEnergetica/MarcoNormatividad/plan.pdf

[23]http://www1.upme.gov.co/Paginas/Plan-de-Acci%C3%B3n-Indicativo-de-Eficiencia-Energ%C3%A9tica-PAI-PROURE-2017---2022.aspx

[24]http://www1.upme.gov.co/Documents/Resolucion_41286_de_2016_PROURE.pdf

and environmental performance of technologies accessible to developing countries; and iv) demonstrate how a developing country can develop national capability to manage EOL ODS for broader replication as appropriate.

The overall scope and design of the Project as proposed and implemented has three Components as follows:

- *Component 1 – EOL ODS Destruction Demonstration:* This is the main project component involving allocation of MLF funding (US$830,000) and the main focus of what is reported herein. It covers a comprehensive demonstration of the destruction step within the overall EOL ODS management process. It involves undertaking qualification test burns on a domestic commercial high temperature rotary incineration (HTI) facility employing modern rotary kiln and associated air pollution control (APC) technology in terms of the TEAP requirements as well as national regulatory requirements and other international reference standards. Initially it was planned to focus on available stocks of CFC-12, CFC-11, and anticipated stocks of CFC-based foam. Early in implementation this was also extended to HCFC-141b based foam, in part due to issues associated with obtaining sufficient verifiable quantities of CFC-11 foam as well as recognition that HCFC-141b foam is now dominating this EOL ODS waste stream. Conditional on its qualification, the Component also provides for use of this capability on a commercial basis in support of the parallel incremental introduction of the national EPR system for WEEE (from RAC sector) management by providing funds for destruction of EOL ODS generated by processing of the initially estimated 300,000 domestic refrigerators projected to be generated by it.
- *Component 2 -Technical Assistance:* In support of this and to facilitate the integration of management of end of life RAC equipment within the overall national WEEE management policy framework and specifically the development of an effective EPR system for RAC equipment, the Project also contained a technical assistance (TA) component with MLF funding of US$255,000. This is being used to support institutional and regulatory development, business planning and implementation activities for the EPR system, and public information/awareness activities.
- *Component 3 – Project Management/Monitoring/Evaluation:* A final component involving US$110,000 in MLF funding covers normal eligible national project staffing, administration and M&E costs.

A detailed breakdown of these components, allocated estimated costs, an indicative schedule, and associated co-financing is provided in Table 3 and Appendix 5 of the original proposal referenced above. A reconciliation with the actual MLF expenditures to date is provided in Section 3.9 below, along with an overall estimate of co-financing that has been attracted to this point in the project.

3.2 Project Implementation Chronology and Current Schedule Projections

As detailed in Appendix 6 of the original proposal, the Project was envisioned to be completed over slightly less than three years in a period from late 2012 (EXCOM approval) and mid-2015. However, early in the implementation process this was understood to have been overly optimistic. As reported to EXCOM annually as required, the practical reality is that the time period required both to undertake the destruction demonstration aspects of the project and then the transition through to a sustainable and self-funded EPR system has and continues to take longer than anticipated. EXCOM's appreciation of this reality has allowed extension of the Project in Colombia to June 2019 with submission of the final report to the last meeting of 2019 and a Project Completion Report no later than June 2020 [25]

[25] UNEP/OzL.Pro/ExCom/79/51, http://www.multilateralfund.org/79/English/1/7951.pdf

The actual chronology of the Project implementation to date and its projection through 2019 is illustrated in Appendix I and is summarized for this reporting period below:

- Q4/13 Supply of extraction/transfer equipment
- Q1/14 Assembly of HCFC-141b foam for 2014 destruction tests
- Q2/14 MLF funded facility modification
- Q2/14 2014 test burn design and planning
- Q2/14 Collection/consolidated storage of CFC-11 and CFC-12 stocks
- Q2/14 2014 test burn CFC-11, CFC-12 analysis
- Q3/14 2014 test burn
- Q4/14-Q3/15 Analysis/reporting of 2014 test burn results
- Q1/15 Assembly of CFC-11 foam for destruction tests
- Q2/15 Additional facility upgrading
- Q3/15 2015 short test burns on Cl and F feed sensitivity
- Q4/15 2016 test burn design and planning
- Q2/16 2016 test burn
- Q2-Q4/16 Analysis/reporting of 2016 test burn results
- Q4/16–Q1/17 Demonstration test of foam destruction in EAF furnace

The various reasons for the extended implementation period is elaborated in the following sections covering the various components and activities within them with the major ones being:

- Need to resolve initially unidentified regulatory issues related to originally selected HTI facilities
- Difficulties in accumulating verifiable quantities of CFC-based foam and need to develop a specific collection program to do so.
- The addition of HCFC-141b based foam to the menu of EOL ODS to be tested
- The necessity to undertake three test burn testing programs on a single facility instead of the originally contemplated separate CFC-11/CFC-12 and foam test burn programs on two separate HTI facilities for commercial, technical, and regulatory reasons
- The above final selection of a single HTI facility for demonstration testing increased scheduling constraints imposed by needing to accommodate priority commercial commitments at the facility.
- The more extensive learning curve related to test burn implementation and need to optimize the HTI facility's performance by addition of and scheduling an additional short test program and additional enterprise financed upgrades.
- Long delivery times for test results from the contracted analytical service provider.
- Addition of a demonstration of an alternative approach to destruction of ODS based foam from domestic refrigerators utilizing an electric arc furnace at a steel making process.
- The slower than anticipated development of the EPR program for domestic refrigerators and its transition from the current pilot voluntary approach to a regulatory mandated mandatory system.
- Delays in securing the needed transitional funding for the EPR program.

In summary, the current implementation status of the project is as follows:

- The demonstration destruction testing of the selected national HTI facility involving a series of three test burn programs is complete with positive results and conclusions reported herein.

- The collection and secure storage of EOL ODS refrigerants (CFCs, HCFCs and Blends) as well as initial volumes of HFC continues within the refrigeration service sector on a voluntary basis, and by WEEE service providers for eventual destruction under the developing EPR system.
- The limited manual extraction of ODS based foams (primarily HCFC-141b based) is undertaken by licenced WEEE service providers with an interim disposal option in cement kilns being used where commercial arrangements are viable.
- The voluntary EPR system for EOL domestic refrigerators under the direction of an industry association is developing incrementally with the operation active in 5 geographic areas, pending implementation of a mandatory system.
- Finalization of regulatory arrangements implementing the mandatory EPR system being made with anticipated effectiveness in 2019.
- Finalization of transitional financing arrangements under climate change initiatives for a refrigeration equipment replacement program being completed to cover up to 300,000 units starting in 2018.

3.3 Assembly of EOL ODS for Demonstration Test Burns

As indicated in the original proposal, a sufficient quantity of EOL ODS in the form of CFC-11 and CFC-12 had been collected or in the case of CFC-11 was scheduled for phase out in the MLF chiller project being implemented. Access to required quantities of CFC-11 foam was assumed based on anticipated generation from targeted domestic refrigeration equipment from the then contemplated rapid implementation of energy efficiency and EPR related programs. One underlying assumption made initially was that the large majority of the EOL ODS waste that would be generated and could be accessible in the medium term would be CFC-11 and CFC-12 both in concentrated form as extracted refrigerant and in dilute form as blowing agent in waste foam. Table 3.1 below summarizes the initial quantities of EOL ODS available or projected to be immediately available for the demonstration testing in the original proposal, along with a summary of what was available when test program EOL ODS was being assembled. Additionally, quantities currently held in secure storage for future destruction are provided.

Table 3.1: EOL ODS Available/Assembled for Demonstration Destruction Test Programs

<table>
<tr><th rowspan="2">EOL ODS Available</th><th colspan="4">Refrigerant (mt)</th><th rowspan="2">CFC-based Foam (mt)</th><th rowspan="2">HCFC based Foam (mt)</th></tr>
<tr><th>CFC-11</th><th>CFC-12</th><th>HCFCs*</th><th>HCFs**</th></tr>
<tr><td>2012 Proposal Estimates</td><td>8.120</td><td>5.674</td><td>n/a</td><td>n/a</td><td>Not quantified but sources identified</td><td>Not quantified but source identified</td></tr>
<tr><td>Available for test program</td><td>7.969</td><td>2.102</td><td>n/a</td><td>n/a</td><td>5.980</td><td>5.590</td></tr>
<tr><td>Available 2017</td><td>3.900</td><td>1.817</td><td>4.000</td><td>3.679</td><td>2.100</td><td>23.900</td></tr>
<tr><td>Expected to be collected from EPR system (next 5 years)</td><td></td><td>12.000</td><td>5.000</td><td>22.000</td><td>420.000</td><td>780.000</td></tr>
<tr><td>Estimated Banks (2017)</td><td colspan="2">88</td><td>4,111</td><td>4,997</td><td>Not available</td><td>Not available</td></tr>
</table>

EOL ODS Available	Refrigerant (mt)				CFC-based Foam (mt)	HCFC based Foam (mt)
	CFC-11	CFC-12	HCFCs*	HCFs**		
Estimated banks, potentially available per year,[26]	16		281	296	Not available	Not available

*HCFC-22, HCFC/HFC based blends

**HFC-134a including amounts available for reclaim/reuse

The implementation experience confirmed that sufficient EOL CFC-11 and CFC-12 was available as required for test burns based on their detailed design described below. The required CFC-11 was generated from the successful MLF funded chiller conversion project as completed through 2014. The base requirements for CFC-12 were already secured and added to through operation of ongoing refrigeration servicing activities, noting that the amounts collected remained quite modest. However, it was also noted that modest but growing accumulation of end of life HCFCs and HCFC based blends, and now HFCs has started to occur. In the case of refrigerant from domestic refrigerators, experience in the early stages of the voluntary EPR initiative has shown that CFC-12 capture is relatively modest (accounting for only 40% of units collected) and the majority of refrigerant recovered is now HFC-134a which is largely returned for reuse through reclaim facilities.

Experience respecting the availability of waste ODS based foams varied significantly from what was originally anticipated. The large majority of foam entering the regulated waste stream was in fact HCFC-141b based. This was largely being generated regularly in sufficient quantity to meet Project needs through the commercial manual dismantling of domestic and commercial refrigeration units by WEEE service providers on contract to various clients including local manufacturers, warranty units from importers, and replacement programs being undertaken by beverage manufacturers for older commercial units that they were voluntary replacing to eliminate ODS (Figure 3.1).

Figure 3.1: Recovery and storage of HCFC-141b based foam

Source: OCADE S.A.S.

Identifiable CFC-11 based foam was more difficult to obtain on a segregated basis. Initial attempts in 2013 to obtain reliable quantities from scrap yards feeding electric arc furnace (EAF) at steel plants were unsuccessful given issues related to the practicality of reliably identifying and

[26] ODS bank inventory for Colombia, draft report. GIZ, 2018.

segregating CFC and HCFC based foam. Eventually, the Project was able to coordinate with a targeted demonstration EOL domestic refrigerators management program supported by MADS, ANDI, the military, local authorities and the EAF steel maker DIACO which was undertaken on San Andres Island in 2014. This location had a high concentration of CFC-12/CFC-11 based units that could be reliably identified as such at source by labelling (Figure 3.2).

Figure 3.2: Recovery of CFC-11 based foam at San Andrés Island

Source: GERDAU- DIACO S.A.

3.4 Selection/Pre-Qualification of Disposal Options

As detailed in the original project proposal, preparation work on the project assessed a variety of strategic and technology specific options that could potentially be pursued for the environmentally sound destruction of both concentrated (CFC-11, CFC-12) and dilute (CFC-11/HCFC-141b foam) EOL ODS waste streams. The three strategic options considered and the conclusions drawn are described as follows:

i) *Establishment of new destruction facilities:* The establishment of new facilities, specifically those based on plasma arc technology both on a commercial scale for broader HW application and on a small scale was evaluated. Based on preliminary commercial proposals and experience elsewhere at that time, it was concluded that this would be relatively a high cost option. In the case of a larger scale commercial operation, this could potentially meet the cost effectiveness threshold but would require significant capitalization by a private sector partner which was not readily identifiable. The small units, while affordable in terms of initial capital investment, had high operating costs and ultimately poor cost effectiveness well above the specified threshold.

ii) *Export to already qualified facilities elsewhere:* The export option was found to be potentially cost effective although national experience and that seen in the MLF project in Ghana on small quantity transactions were approaching the MLF threshold, noting that where commercial quantities of halogenated waste could be assembled, the cost effectiveness for EOL ODS destruction under this option should be substantially lower. In addition, potential legal and legislative barriers related to import and export of hazardous waste could potentially apply in Colombia.

iii) *Co-disposal of EOL ODS in existing domestic commercial facilities:* This option was evaluated in recognition that Colombia was in the process of incrementally developing a relatively modern capacity for thermal oxidation destruction of hazardous waste using rotary kiln incineration facilities and potentially co-disposal of hazardous waste in industrial combustion processes, particularly cement kilns. Potentially qualified facilities were identified and evaluated in terms of availability, potential cost effectiveness, the national regulatory framework governing their licensing and operation, and prospects of meeting environmental and destruction efficiency standards. This work identified three rotary kiln facilities including two relatively new facilities with modern APC facilities, as well as several modern cement kilns. At the time this option also offered potential synergy with a GEF PCB elimination project that was also under preparation and was also likewise examining the use of domestic hazardous waste facilities and cement kilns.

At this stage of preparation, the election was made to pursue the option of qualifying existing domestic facilities. However, the cement kiln option was found not to be viable at the time due to low operator interest noting that this has since been revisited and is in fact now being used commercially for HCFC based foam but without any specific formal qualification. The three rotary kiln incineration facilities identified for potential qualification were modern HTI facilities operated by TECNIAMSA S.A in Galapa (Barranquilla), TECNIAMSA S.A in Mosquera (Bogota), as well as an older, less sophisticated facility operated by PROSARC S.A. in Mosquera. The conclusion based on qualifications completed or underway in accordance with the national regulations on incineration, was that the two TECNIAMSA facilities offered good potential for qualification in accordance with TEAP requirements for destruction of concentrated EOL ODS, while the PROSARC facility could potentially be qualified for destruction of foam. In terms of cost effectiveness, utilizing current commercial pricing this option appeared to be well within the specified threshold, substantially lower than development of new facility options, and competitive with export options. It was also shown that the country has a solid framework for the regulation of hazardous waste, and specific regulations requirements applied in terms of destruction removal efficiency and emissions are equivalent to the main referenced international standards and those applied in OECD countries, and furthermore generally exceed TEAP requirements.

Upon Project implementation, the selection of domestic facilities was further refined based on more detailed technical and regulatory assessment as well as more detailed commercial discussions with the owners. In this regard, it was decided to eliminate further consideration of PROSARC based on continuing regulatory compliance issues related to particulate and dioxin/furan (PCDD/F) emissions that would have precluded qualification either in terms of international or national standards. Commercial discussion with TECNIAMSA were undertaken during 2013 and 2014 on the basis of the detailed test burn design and agreed facility modifications (Section 3.5) resulting in a commercial agreement dated May 27, 2014. This provided for the disposal of up to 8 mt of CFC-11 liquid and 10 mt of HCFC-141b foam at Galapa, and 6 mt of CFC-12 gas and 10 mt of CFC-foam at Mosquera in two essentially parallel test burn programs targeting completion in the first part of 2015. An MLF funded payment in the initial amount of US$300,000 and final amount of US$281,696.15, was agreed to cover i) storage of consolidated EOL ODS as arranged by UTO under separate arrangements with hazardous waste service providers; ii) modifications required for feeding and fed measurement of CFC-11 and CFC-12 (foam would be handled in the existing weighting and feed system); iii) operational supervision of the test burn work: iv) contracting of sampling and analytical work as specified in the test burn design; and v) final reporting on the test burn program. Separate contracts valued at US$86,244.68were made with hazardous waste service providers for consolidation and delivery of already collected EOL ODS to TECNIAMSA.

However shortly after signing the agreement, TECNIAMSA encountered technical issues at the Galapa facility requiring renewed regulatory approvals that would substantially delay the test burn program planned at that facility. This resulted in a collective decision to focus qualification on the newer Mosquera facility, particularly noting that a major modernization of the APC system and addition of a second rotary kiln was being undertaken by the company which would both potentially offer better results. Additionally, it allowed TECNIAMSA to have greater flexibility scheduling now the two test burn programs around its commercial commitments.

3.5 TECNIAMSA Mosquera Facility Description

The TECNIAMSA Mosquera HTI incineration facility is part of the Sala Group (Grupo Sala)[27] who are one of Colombia's largest environmental services providers through 12 operating companies and providing a variety of sanitation, water treatment, solid waste management, and hazardous waste management services including operation of eight environmental technology parks around the country. TECNIMSA[28] is the main hazardous waste management company in the Sala Group, providing treatment, destruction and disposal of regulated HW from industrial, medical and oil/gas sectors. It operates with three integrated HW management facilities at Mosquera, Manizales and Galapa. The Mosquera facility operates on a 14.86-hectare site which, in addition to the two incineration units, also includes an engineered hazardous waste landfill and supporting storage, receiving, control room and laboratory facilities. The facility initially consisted of a single incineration unit constructed in 2010 but was expanded with a new parallel unit of the same size in 2014.

The HTI unit used in the test burn program was the original unit installed at Mosquera. While of modern design, by industry standards it is a relatively small unit having a nominal capacity of 1mt/hour and a nominal commercial annual capacity of approximately 7,000 mt/year which is generally lower than commercial HTI facilities qualified for halogenated HW streams. Its normal operation involves both solid and liquid hazardous waste typically in a 75/25 ratio with primary wastes received include bagged medical waste (30%), hydrocarbon wastes (25%) and general industrial hazardous waste (45 %).

Solid waste is fed using manually loaded 0.5 m^3 bins that are weighted (70-80 kg) prior to automated loading by an electromechanical elevator and dumping mechanism into a feed hopper in the burner end of the first stage rotary kiln. Liquid waste is injected at a dedicated port at the same end with a pump feed from tanks or containers located either in an enclosed area or outdoor tank staging area adjacent to the incineration building. The principle process components in the facility, inclusive of the primary and secondary combustion chambers and APC systems and supporting control and monitoring infrastructure are as follows:

- *Primary combustion chamber (rotary kiln)* typically operating in the temperature range of 900 to 1,200^{0}C with two burners and solids retention time of 100 minutes with release of combustion gases to the secondary combustion chamber and solid combustion residues (ash) to a bottom ash collector.
- *Secondary combustion chamber* receiving released combustion gas operating in the range of 1,250 to 1,300^{0}C with two burners and a 4 second resident time.
- *Quench unit and dry scrubber* accepts combustion gasses first into a direct quenching system that injects an alkali/water solution to lower temperature to about 250 ºC at the cyclone inlet after which the gases pass through a cyclone where particles larger than 5 microns are removed and acid gasses (SO_2 and HCl) are neutralized acid gas treatment system with generation of a recovered inert solid residual (sodium sulfate and calcium sulfate).
- *Dust Collector (Bag House)* provides a series of 420 filtration bags with filtration area of 620 m^2, rated 99% collective efficiency for 0.01micron particles, 240 °C maximum temperature and automatic clean/dry compressed air dust bag cleaning sequencing system for bottom collectors of removed particulate.

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[27] http://www.gruposala.com.co/es/
[28] http://www.tecniamsa.com.co/

- *Catalytic reactor* for dioxin and furan (PCDD/F) removal where gas from the bag house passes through a lateral flow reactor (LFR) which contains a catalyst enhancing high efficiency chemical treatment removing PCDD/F at relatively low temperatures.
- *Gas extraction fan and stack* receives and releases the final treated combustion gases with the extraction fan being controlled for flow volumes and a 23m high/1.2 m diameter stack equipped with access and platform structures for the operation of continuous and discontinuous sampling.
- *Continuous emission monitoring system (CEMS)* involving a modular system located in a dedicated room at the base of the stack receiving sampling inputs from the eight analyzer ports in the stack via heated sample lines for sample extraction with data collected and analyzed with i) an opacimeter for measuring PTS; ii) infrared spectroscopy gas analyzer for primary emission pollutants (CO, SO_2, HCL, HF, HCT, NO_x); ii) a pneumatic oxygen analyzer, with a measuring range from 0 to 25% per volume. The system is equipped with on-site calibration system[29] and data feed for real time alarm, display and recording in the main control room coincident with data on operating conditions.
- *Automatic Control System* for the combustion and post-combustion APC processes via the operation of burners and fans, thermocouples to measure temperature, transmission wiring, controllers and actuators for gas and air injection systems which also provides for data collection, storage and information processing in real time all connected to the central control room that has digital and graphics capability for observation and retention of all controlled and monitored parameters including the CEMS and as described below feed parameters during the test burn programs.

The facility is licenced in accordance with MADS Resolution 909/2008 which generally tracks requirements governing such facilities in the US and EU. It specifies: i) basic combustion operating conditions (primary and secondary combustion temperatures of >850^{0}C and >1,100^{0}C respectively and secondary combustion chamber minimum residence time of 2 seconds; ii) emission limits and destruction removal efficiency requirements; iii) annual and bi-annual test burn requirements; iv) operating condition recording and records; v) maintenance and inspection; and vi) safety/emergency response procedures. The facility specific licence is issued by the regional environmental authority and specifies the waste permitted for disposal who provide regular on-site monitoring. A more detailed description and photographic illustrations of the Mosquera facility are provided in the TECNIAMSA technical document referenced above. Appendix II provides photographs of various key components.

3.6 Test Burn Preparations

The design of the test burns undertaken as described in a following section was based on the established principle that well characterized target waste streams, in this case the EOL ODS noted above, would be destroyed in a controlled and monitored manner at the designated facility being qualified for accepting such wastes. This would be done with it operating in a steady stage condition matching commercial conditions that would apply in the future and be done over a period sufficient to demonstrate stable operation and allow representative sampling and analysis of emissions from all release points as well as being able to correlate these performance measurements with principle operating parameters and characterized waste feed rates for which the qualification would apply.

The perquisites for undertaking this in terms of preparing the selected facility for the test burn program were identified as i) availability of sufficient quantities of the characterized target EOL ODS (CFC-11,

[29] The upgraded CEMS system described here replaced the original system used in the initial 2014 test burn as an addition investment made by TECNIAMSA during the program.

CFC-12, CFC-11 based foam and HCFC-141b based foam); ii) availability of sufficient quantities of fully characterized baseline material which is a common commercial hazardous waste feed that is be designated for qualification purposes as the waste co-disposed with the EOL ODS; iii) implementation of selected facility modifications required to undertake the testing inclusive of instrumented feed system that control and measure feed rates of the baseline and EOL ODS into the incineration unit and any other operational or process modifications identified initially or during the course of the test program required to optimize the waste specific performance; and iv) availability of qualified sampling and analytical capacity to support the test burn.

Assembly of Baseline and EOL ODS Waste: During 2013 and 2014, a primary activity was the assembly of CFC-11, CFC-12, HCFC-141b foam and CFC-11 based foam. As described above, significant quantities of CFC-11 and CFC-12 were already available or being generated from completing CFC phase out projects. The initially conservatively estimated quantities required for two test burn runs based on an indicative chlorine feed level up to 1.25% was consolidated in bulk tanks and transferred to secure monitored storage at TECNIAMSA's Mosquera facility in accordance with a tracking, receiving and documentation protocol developed for the Project in line with national hazardous waste regulation and set out in the commercial agreement with the service providers involved and TECNIAMSA. In the case of HCFC-141b foam, this was packaged at the source by WEEE service provider partners in plastic bags, shipped to Mosquera in standard shipping containers, and stored in a secure area. Subsequently, this procedure was repeated for CFC-11 based foam sourced from the San Anders Island program described above. Table 3.2 below provides a summary of the consolidated inventory assembled and stored at Mosquera pending use in the test burn program.

Table 3.2: EOL ODS Received for Test Burns

EOL ODS	Consolidated Amount Received (kg)	Received from	Container Type	Date Received
CFC-11	594	LITO	Drums (2)	23/07/2014
	2,760	LITO	Drums (14)	12/08/2014
	3,300	LITO	Drums (17)	05/02/2015
CFC-12	202.5	LITO	Cylinders (5)	09/09/2014
	598.4	OCADE	Bulk cylinder (1)	09/09/2014
	430	OCADE	Bulk cylinder (1)	07/02/2015
	871	OCADE	Bulk cylinder (1)	07/02/2015
HCFC-141b foam	640	OCADE	Big bags	22/08/2014
	1,140	OCADE	Big bags	22/08/2014
	970	OCADE	Big bags	22/08/2014
	1,140	OCADE	Big bags	22/08/2014
	700	DIACO	Big bags	01/08/2014
	1,000	DIACO	Big bags	05/08/2014
CFC-11 Foam	5,980	DIACO	Containers (3)	08/2015

The baseline commercial waste selected for co-disposal was a hydrocarbon sludge waste stream that is regularly received by TECNIAMSA and generally available on demand at the Mosquera facility. It originates from oil production and distribution operations and supplied by clients with a reliable track record and good practice related to characterization and consistency based on past experience through normal company receiving and characterization protocols. It is generally found to be low in halogenated compounds, specifically chlorine, thus facilitating co-disposal of optimum amounts of EOL ODS. As was TECNIMSA's practice this was mixed in a 40/60 ratio with inert mineral material to formulate the incineration feed in order to optimize combustion.

Characterization of Baseline and EOL ODS: For purposes of initiating the test burn design and specifically determining target feed rates, the theoretical amounts of Chlorine (Cl) and Fluorine (F) contained in pure forms of CFC-11, CFC-12 and HCFC-141b were used, recognizing that these elements would be the likely determinates for air emission performance parameters and effectively dictate the maximum feed rates of the respective EOL ODS. Table 3.3 below provides the results of these calculations.

Table 3.3: Theoretical content of Cl and F in the EOL ODS chemicals

EOL ODS	**CFC-11**		**CFC-12**		**HCFC-141b**	
Chemical Name	Triclorofluoromethane		Diclorodifluoromethane		1,1-Dicloro-1-fluoroethane	
	CCl_3F		CCl_2F_2		CH_3CFCl_2	
Molecular weight	137.35		120.9		116.9	
Cl content	77%	106.35	59%	70.9	61%	70.9
F Content	14%	19	31%	38	16%	19
C content	9%	12	10%	12	21%	24
H Content	0	0	0	0	3%	3

At the initiation of each test burn the selected CFC-11 and CFC-12 containers or, in the case of foam, random samples from storage shipping containers being used were sampled and analyzed for the respective chemical's purity, and in the case of CFC-11 and 12 any potential cross contamination. For the baseline a general analytical characterization for chlorine content and in some cases heavy metals was undertaken. The results of this characterization on actual feed during the test burn runs is provided in the detailed analytical report referenced above. These results indicated the following overall results and conclusions:

- The chlorine content for the baseline waste was generally low with test burn run averages of between 0.012 and 0.015% and a maximum of 0.019% suggesting that this should not be a variable affecting test burn performance results
- The purity of CFC-11 was effectively 100% for the 2014 test program but varied from 80% to 97% for the 2016 test program. Likewise, the purity of CFC-12 was >99% for all samples except one that was 80% CFC-12/with 20% CFC-11 during the 2014 test program. This suggests that in practice an assumption of high purity is prudent for determination of feed rates but some lower purity in commercial material seen in the future can be expected.

MLF financed facility modifications: The facility modifications that were contemplated within the scope of the MLF project involved modest incremental investment related to the development of feed systems for CFC-11 and CFC-12. This covered the transfer from consolidated containers to the existing liquids feed port in the burner end of the rotary kiln as well as the required automated flow control and measure requirements applicable to this and to providing digital data transfer to the main control room for real time correlation with operating conditions and CEMS data[30]. Separate CFC-11 and CFC-12 feed systems were installed in a separate building located adjacent to the feeding points for the rotary kiln. Access for bulk

[30] EOL ODS foam required no incremental investment as the existing manual loading of bins into the existing weighting and electromechanical system for bulk solid waste was used and feed data across the scale was manually recorded.

containers was provided by a sliding half wall door and, when operating, the closed building was held under positive pressure vented through overhead piping to the kiln such that no fugitive emission from the system were released. The containers were placed on a digital scale. For CFC-11, as shown in Figure 3.3, that was injected as a liquid the primary equipment consisted of a liquid dosing transfer pump, flow meter, custom dedicated and spray nozzle fitting. For CFC-12, as shown in Figure 3.4 that was injected as a gas the primary equipment consisted of a gas flow meter, instrumented control valve and evacuation pump. Additionally, a heated jacket system for the CFC-12 tank was utilized so temperature could be maintained consistently as the liquid in the tank discharged as a gas. Both systems utilized an over head ½" stainless steel transfer pipe from the feed building across to the incinerator feed port, as shown in Figure 3.5 as well as the necessary digital data collection and transfer instrumentation to feed the control room. A final modification included in the MLF scope involved modifications to the alkali dosing system applied between the secondary combustion chamber and dry scrubber to accommodate higher chlorine waste feed.

Figure 3.3 CFC-11 feed system

Source: TECNIAMSA S.A.

Figure 3.4 CFC-12 feed system

Source: TECNIAMSA S.A.

Figure 3.5 Feed house vent and feed lines and Incinerator feed port

Source: TECNIAMSA S.A.

Additional facility modifications: In addition to the above throughout the test program TECNIAMSA undertook a number of significant process upgrades that were at least in part a result of the learning curve associated with the test burn program and which significantly increased the originally projected co-financing. These modifications include:

- Re-calibrating and upgrading of the CEMS system after the 2014 test program
- Major repairs and upgrading of the bag house
- Improved PCDD/F emission treatment
- Enhanced monitoring/sampling access
- Reconstruction and modernization of control room

Identification of qualified sampling and analytical capacity: A critical perquisite to support the test burn program is the availability of qualified capability in undertaken the sampling program and associated chemical analysis set out in the test burn scope, design and applicable regulatory standards. For this work a national service provider (ADA & CO LTDA)[31] was contracted on a turn key basis, inclusive of sub-contracting the analytical work with internationally certified laboratories in Canada and the US.

3.7 Test Burn Reference Performance Standards and Sampling Methods

For purposes of meeting the Project's objective of demonstrating environmental sound destruction of the targeted EOL ODS waste streams as set out by the Montreal Protocol, the required performance standards involve demonstrating compliance with destruction efficiency and emission release limits specified in the TEAP standards referenced above. Additionally, the destruction also needs to be appropriately permitted in Colombia under national requirements, namely MADS Resolution 909/2008 governing incineration facilities generally in Colombia. Table 3.4 below sets out these limits which effectively define what is required to be sampled and analyzed for this work during the test burn program. Also illustrated are two EU reference standards applicable to incineration performance used during the development of the test burn program noting that the EC Incineration directive has since been rolled into a general air emission directive

[31] Experienced national firm undertaking air, water and soil monitoring of industrial facilities, including regular regulatory test burn and monitoring at licensed incineration facilities including past test burns at TECNIAMSA

that encompasses waste combustion facilities. By way of comment this table, it illustrates that generally the national regulations in Colombia for general air emission limits is equivalent and, in some cases, more restrictive than those applicable in the EU if used as a bench mark. The TEAP air emission limits are significantly less rigorous than either national or EU requirements. With respect to destruction efficiency (DE) and destruction removal efficiency (DRE) these are not applied in the EU regulations. However, DRE which accounts for air releases only at a limit of 99.99% is widely applied internationally in Canada, US and Japan as well as in international guidance documents applicable to POPs wastes (Basel Convention[32] and GEFSTAP[33]). Both TEAP and national regulations are less rigorous when compared against this. The latter international standards also apply guidance for DE of > 99. 99% and for purposes of a test burn program this is used to provide a measure of destruction efficiency accounting for releases from all sources (including solid and waste water).

The parameters listed in the performance standards in Table 3.4 generally define what was required for stack emission sampling and analysis. The selection of methods to by which this was implemented is generally dictated by those approved for use in the MADS "Protocol for Control and Surveillance of Atmospheric Contamination Generated by Stationary Sources"[34]. This essentially adopts US EPA standard methods (CFR - 40 part 60) that are widely applied in undertaking test burn and environmental monitoring generally. Table 3.5 below summarizes the parameters sampled/analyzed for air emissions the analytical methods used and test burn repetitions. For the 2014 test program only chlorine was measured with estimated net EOL ODS calculated. The actual EOL ODS was analysed for the 2016 test run. Additionally, daily sampling of solid residual from the rotary kiln bottom ash, solids recovered from the cyclone, back house and catalytic treatment unit were manually collected for analysis of originating EOL ODS, PCCD/F and Mercury, undertaken on composite samples of each. Analytical methods applied were USEPA Method 8260b for ODS, USEPA Method 8290a for PCCD/F and USEPA Method 7471b for Mercury.

Table 3.4: Reference Incinerator Environmental Performance Standards for Relevant Air Emissions

Performance Parameter	Colombia Regulation 909	TEAP Task Force Report (2002)[35] Decision XV/9[36]	EC Incineration Directive[37]	EC IPPC BREF[38]
Particulates (mg/Nm^3)	10 (Day Av.) 20 (Hr. Av.)	50	10(Day Av.) 30(8Hr. Av.)	1-5(Daily Av) 0.1 – 20 (1/2Hr. Av.)
SO_x (mg/Nm^3)	50 (Day Av.) 200 (Hr. Av.)	n/a	50(Day Av.) 200(8Hr. Av.)	1 – 40(Daily Av) 1-150(1/2Hr. Av.)

[32] General Technical Guidelines on the Environmentally Sound Management of Wastes Consisting of, Containing or Contaminated with Persistent Organic Pollutants (2015) http://www.basel.int/Implementation/Publications/LatestTechnicalGuidelines/tabid/5875/Default.aspx
[33] Selection of Persistent Organic Pollutant Disposal Technology for the Global Environmental Facility, GEF STAP, Nov. 2011, https://www.thegef.org/sites/default/files/publications/POPs_Disposal_Final_low_1.pdf
[34] This Protocol establishes the procedures for evaluating emissions as provided in Article72 of Regulation 909/2008
[35] TEAP Task Force Report on ODS Destruction Technologies (2002) – Table 2.1 Page 30,data assumed to be Hourly averages daily in the absence of it being specified http://ozone.unep.org/Assessment_Panels/TEAP/Reports/Other_Task_Force/TEAP02V3b.pdf
[36] Handbook of the Montreal Protocol, 8th Edition (2009), Section 3.1,Page 457, http://www.unep.ch/ozone/Publications/MP_Handbook/MP-Handbook-2009.pdf
[37] Directive 2000/76/EC on Incineration of Waste – Hazardous waste incineration daily averages: http://www.central2013.eu/fileadmin/user_upload/Downloads/Document_Centre/OP_Resources/Incineration_Directive_2000_76.pdf
[38] EC IPPC BREF, August 2006- – Hazardous waste incineration daily averages:, ftp://ftp.jrc.es/pub/eippcb/doc/wi_bref_0806.pdf

Performance Parameter	Colombia Regulation 909	TEAP Task Force Report (2002)[35] Decision XV/9[36]	EC Incineration Directive[37]	EC IPPC BREF[38]
HCl (mg/Nm^3)	10 (Day Av.) 40 (Hr. Av.)	100	10(Day Av.) 60(8Hr. Av.)	1 – 8(Day Av.) 1-50 (8Hr. Av.)
HF (mg/Nm^3)	1(Day Av.) 4 (Hr. Av.)	5	1(Day Av.) 4(8Hr. Av.)	<1(Day Av.) <2 (8Hr. Av.)
HBr/Br_2 (mg/Nm^3)	n/a	5	n/a	n/a
NO_x (mg/Nm^3)	200 (Day Av.) 400 (Hr. Av.)	n/a	200(Day Av.) 400(8Hr. Av.)	120-180(Day Av.) 30-350(8Hr. Av.)
CO (mg/Nm^3)	50 (Day Av.) 100 (Hr. Av.)	100	50 (Day Av.)	1-10(Day Av.) 1-20(8Hr. Av.)
Total HC (HCT) (mg/Nm^3)	10 (Day Av.) 20 (Day Av.)	n/a	10(Day Av.) 20(8Hr. Av.)	1-10(Day Av.) 1-20(8Hr. Av.)
Hg (mg/Nm^3)	0.03 (Day Av.) 0.05 (Day Av.)	n/a	0.05(8 Hr. Av) 0.1 (1/2 Hr. Av.)	0.001-0.02(Day Av.) 0.001-0.03(8Hr. Av.) <0.05 Non-continuous
Cd + Ti	0.05	n/a	0.05(8 Hr. Av) 0.1 (1/2 Hr. Av.)	0.005-0.05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	0.5	n/a	0.1(8Hr. Av.) 0.5(1/2 Hr. Av	0.005-0.5 Non-continuous
Dioxin/Furan (ng-ITEQ/Nm^3)	0.1	0.2 (Conc.) 0.5 (Dilute)	0.1 (2-8 Hr. Av.)	0.01 – 0.1 Non-continuous
HCl Removal Efficiency (%)	99	n/a	n/a	n/a
DE (%)	n/a	n/a	n/a	n/a
DRE (%)	99.99	99.99 (Conc.) 95.0 (Dilute)	n/a	n/a

n/a – not applied

Table 3.5: Air Emission Methods used During the Test Burn Programs

Pollutant	Methods	Test Burn Repetitions
Particulate matter (PM) and sulfur dioxide (SO_2)	EPA 5 and 8	Three repetitions simultaneously
Nitrogen oxides (NO_X)	EPA 7	16 samples as follows: -4 samples in the first PM repetition (EPA 5) -4 samples in the second PM repetition (EPA 5) -4 samples in the first Dioxins repetition (EPA 23) -4 samples in the second Dioxins repetition (EPA 23)
Halides (HCl y HF)	EPA 26A	Three repetitions
Heavy Metals	EPA 29	Two repetitions
Carbon Monoxide (CO)	EPA 10	Three repetitions
Total Organic Compounds (TOC) including Benzene, Toluene, and Xylene as hydrocarbons	EPA 0030*	Two repetitions, each one with 3 samples
Dioxins and Furans	EPA 23	Two repetitions and a blank

* Colombian regulation does not yet approve this method, but unlike the approved method, Method 0030 allows identification of ODS in emissions.

3.8 Test Burn Program Plan and Schedules

As indicated previously the EOL ODS destruction demonstration program was originally intended to involve three separate incineration facilities. However, the one ultimately designated to handle foam was judged to have major compliance issues with nationally regulated emissions and was dropped. Additionally, regulatory issues developed at TECNIMSA's Galapa facility and additionally delays in assembling CFC based foam developed. As a consequence, the final program plans involved doing two test program runs at the TECNIAMSA facility, with the first using CFC-11, CFC-12 and HCFC-141b foam, and the second scheduled when commercially feasible and CFC-11 based foam was available. It was also understood that this allowed results from the first to be obtained and analyzed thus allowing adjustments and lessons learned to be applied in undertaking the second test program runs.

As implemented and described in more detail in the reporting of test burn results, the latter had a significant impact on the subsequent program plan and schedule. More specifically, the marginal results from the initial 2014 test burn program undertaken at relatively high waste feed rates and associated high Cl and F levels resulted in the need for adjustments in subsequent tests to achieve acceptable results. This included the adding of an interim short test program at variable Cl and F levels to optimize feed rates for use in the subsequent test burn runs. It also allowed time for TECNIMSA to make necessary adjustments to facilities and operating changes, the most significant were upgrading bag house integrity, adjusting O_2 control, upgrading PCDD/F treatment practice, and replacing the CEMS system so it could more reliably monitor key emission performance parameters. The following provides a summary description of each of the test burn program runs and schedules as implemented.

2014 Test Burn Program: The initial 2014 test program was conducted over a 12-day period between Aug 29 and September 11, 2014 with a test sequence of i) baseline hydrocarbon sludge (B/L); ii) B/L plus HCFC-141b based foam (assumed to contain 9% HCFC-141b); iii) CFC-11; and iv) CFC-12. Each waste stream test run was undertaken over a 3-day period with each daily continuous monitoring period test lasting at least 11 hours (typically 7:00-18:00 day shift) during which the air and solid waste repetitive sampling was undertaken. The remaining period during each day involved continuous operation either on the target waste stream or normal commercial waste plus short maintenance shut downs as required. This sequencing ensured at least three 8-hour continuous steady state test runs each day as required for average emission sampling per the selected methods. The air sampling for HCl, HF, NO_x, and CO were typically sampled for all three test days with PCDD/F and heavy metals sampled on two test days and particulate (MP) and SO_2 at least one day. Solid residuals were sampled daily at each release point and 2-5kg samples were taken at the end of each waste test run. For the B/L test run waste feed rate of 800 kg/hour was used and for the HCFC-141b based foam, CFC-11 and CFC-12 test burn runs B/L feed rates were 720, 787 and 774 kg/hour respectively. Table 3.6 provides a summary of the daily feed rates and analytically determined average chlorine daily Cl and F content for the four test runs. Table 3.7 summarizes the overall average EOL ODS destruction productivity in terms of average hourly amounts destroyed and totals for each test run, along with average chlorine and fluorine.

Table 3.6: Waste Feed Rates and Chlorine/Fluorine Content for 2014 Test Program Runs

Test Burn Run Date	Baseline Daily Average Feed Rate kg/hr	EOLODS Daily Average Feed Rate			Daily Average Chlorine Content	Daily Average Fluorine Content
		kg/hr	l/hr	m^3/hr		
Baseline Test Burn Run						
29/08/2014	800	n/a	n/a	n/a	0.01918%	n/a
30/08/2014	800	n/a	n/a	n/a	0.01918%	n/a
31/08/2014	800	n/a	n/a	n/a	0.01873%	n/a
HCFC-141b Foam Test Burn Run						
01/09/2014	720	80	n/a	n/a	0.56392%	0.14468%
02/09/2014	720	80	n/a	n/a	0.64981%	0.16727%
03/09/2014	720	80	n/a	n/a	0,63903%	0.16443%
CFC-11 Test Burn Run						
05/09/2014	787	n/a	18	n/a	2.41848%	0.43643%
06/09/2014	787	n/a	18	n/a	2.59314%	0.46820%
07/09/2014	787	n/a	18	n/a	2.83294%	0.51181%
CFC-12 Test Burn Run						
09/09/2014	774	n/a	n/a	3.3	1.28577%	0.68429%
10/09/2014	774	n/a	n/a	3.3	1.11736%	0.59401%
11/09/2014	774	n/a	n/a	3.3	1.21436%	0.64601%

Table 3.7: Overall EOL ODS Productivity and Corresponding Chlorine/Fluorine Content for the 2014 Test Burn Program

HCFC-141b foam		CFC-11		CFC-12	
Average kg/hr	**Total (kg)**	**Average kg/hr**	**Total (kg)**	**Average kg/hr**	**Total (kg)**
80	5,590.00	25.8	2,192	17.1	626
Av. Cl %	**Av. F%**	**Av. Cl %**	**Av. F%**	**Av. Cl %**	**Av. F%**
0.61759	0.15879	2.61485	0.47215	1.20583	0.64144

2015 Short Test Program: As will be discussed in more detail in the results section below, the results from the 2014 test burn program indicated that the relatively high feed rates used for the EOL ODS test burn runs and associated relatively high chlorine and fluorine content in the feed resulted in compliance issues associated with HCl and HF releases which exceeded both TEAP and national limits. Following upgrading of APC equipment and recalibration of the CEMS system to ensure reliability of emission monitoring, particularly HCl and HF, a series of 5 short test burn runs were undertaken in the period September 28th to September 30th, 2015. Each of these tests consisted of 1 to 2-hour test burn runs on CFC-11 with a progression of calculated chlorine feed levels namely 0.25 %, 0,5%, 0,75%, 1.0% and 1.25% (based on analysis of CFC-11 feed material selected). Each test was separated by a period of normal commercial operation. CFC-11 was selected based on it being the most halogenated EOL ODS waste being evaluated in the program. For each test, continuous HCl and HF emission readings were taken using the upgraded CEMS with a current calibration. Table 3.8 below outlines the short test burn sequence over the three days.

Table 3.8: 2015 Short Test Burn Test Schedule

September 28/15		September 29/15		September 30/15	
Time Period	**Activity**	**Time Period**	**Activity**	**Time Period**	**Activity**
6:00-8:00	Stabilization	6:00-8:00	Stabilization	6:00-8:00	Stabilization
7:00-8:00	Measuring equipment installation	7:00-8:00	Measuring equipment installation	7:00-8:00	Measuring equipment installation
8:00-11:00	CFC-11 test run – 0.25% Cl	8:00-11:00	CFC-11 test run – 0.75% Cl	8:00-11:00	CFC-11 test run – 1.25% Cl
11:00-13:00	Stabilization – Check Data	11:00-13:00	Stabilization – Check Data	11:00-13:00	Stabilization – Check Data
13:00-16:00	CFC-11 test run – 0.50% Cl	13:00-16:00	CFC-11 test run – 1.0% Cl	13:00-17:00	Check CEMS Data, ODS Feed Rate, Baseline
16:00-17:00	Check CEMS Data, ODS Feed Rate, Baseline	16:00-17:00	Check CEMS Data, ODS Feed Rate, Baseline		

2016 Test Burn Program: The final full test program was conducted over the period between May 2 and 14, 2016 covering 12 actual test days with a test sequence of i) baseline hydrocarbon sludge (B/L); ii) B/L plus CFC-11 based foam (assumed to contain 7% CFC-11); iii) CFC-11; and iv) CFC-12. Each waste stream test run was undertaken over a 3-day period with over at least 8 hours continuous operation during each day shift during which the air and solid waste repetitive sampling was undertaken. The remaining period during each day involved continuous operation either on the target waste stream or brief periods of normal commercial waste and short maintenance shut downs as required. This sequencing ensured at least three 8-hour continuous steady state test runs each day as required for average emission sampling per the selected methods. The air sampling for each test run was applied as follows: i) Day 1 - HCl, HF, NO_x, SO_2, Cl_2, PM, Hg, and heavy metals; ii) Day 2 – PCDD/F, CFC-11, CFC-12, CFC-13, HCl, HF, NOx, CO, Cl_2, Hg, and heavy metals; iii) Day 3 – PCCD/F, CFC-11, CFC-12, CFC-13, HCl, HF, CO, NOx, TOC, and Cl_2. Solid residuals were sampled daily at each release point at the end of the day. A B/L waste feed rate of 720 kg/hour was used for all test runs. Table 3.9 provides a summary of the daily feed rates and analytically determined average chlorine daily Cl and F content for the four test runs. Table 3.10 summarizes the overall average EOL ODS destruction productivity in terms of average hourly amounts destroyed and totals for each test run, along with average chlorine and fluorine. Finally, Table 3.11 summarizes the EOL ODS quantities destroyed during the three runs of test burns.

Table 3.9: Waste Feed Rates and Chlorine/Fluorine Content for 2016 Test Program Runs

Test Burn Run Date	Baseline Daily Average Feed Rate kg/hr	EOLODS Daily Average Feed Rate			Daily Average Chlorine Content	Daily Average Fluorine Content
		kg/hr	l/hr	m^3/hr		
Baseline Test Burn Run						
02/05/2016	720	n/a	n/a	n/a	0.01461%	n/a
03/05/2016	720	n/a	n/a	n/a	0.01461%	n/a
04/05/2016	720	n/a	n/a	n/a	0.01461%	n/a
CFC-11 Foam Test Burn Run						
05/05/2016	720	75	n/a	n/a	0.01636%	0.00037%

Test Burn Run Date	Baseline Daily Average Feed Rate kg/hr	EOLODS Daily Average Feed Rate			Daily Average Chlorine Content	Daily Average Fluorine Content
		kg/hr	l/hr	m^3/hr		
06/05/2016	720	75	n/a	n/a	0.01631%	0.00034%
07/05/2016	720	75	n/a	n/a	0.01797%	0.00067%
CFC-11 Test Burn Run						
09/05/2016	720	4.7	3.2	n/a	0.56119%	0.10031%
10/05/2016	720	4.7	3.2	n/a	0.54998%	0.09827%
11/05/2016	720	5.2	3.5	n/a	0.51672%	0.09222%
CFC-12 Test Burn Run						
12/05/2016	720	3.2	629	0.629	0.17326%	0.08896%
13/05/2016	720	3.3	629	0.629	0.21229%	0.10988%
14/05/2016	720	3.3	629	0.629	0.15035%	0.07668%

Table 3.10: Overall EOL ODS Productivity and Corresponding Chlorine/Fluorine Content for the 2016 Test Burn Program

CFC-11 foam		CFC-11		CFC-12	
Average kg/hr	**Total (kg)**	**Average kg/hr**	**Total (kg)**	**Average kg/hr**	**Total (kg)**
75	5,980	4.87	389	3.3	159
Av. Cl %	**Av. F%**	**Av. Cl %**	**Av. F%**	**Av. Cl %**	**Av. F%**
0.01688	0.00046	0.54263	0.09693	0.17863	0.09184

Table 3.11: EOL ODS received and destroyed during Test Burns

ODS	Received at TECNIAMSA 2014 (kg)	Incinerated 2014 (kg)	Received at TECNIAMSA 2015 (kg)	Incinerated 2015 (kg)	Incinerated 2016 (kg)	Total received (kg)	Total incinerated (kg)	Remaining (kg)
CFC-11	3.354	2.192	3.300	173	389	6.654	2.754	3.900
CFC-12	801	626	1.301	0	159	2.102	785	1.317
CFC-11 based PU foam	0	0	5.980	0	5.980	5.980	5.980	0
HCFC-141b based PU foam	5.590	5.590	0	0	0	5.590	5.590	0

3.9 Project Costs

Table 3.12 below provides a comparison of the original project cost estimate (MLF funding and indicative co-financing) as approved and the current actual disbursed MLF costs and their projections through to project closure. In terms of MLF funding, as of the end of 2017 all MLF funds were disbursed (US$861,201) or committed (US$333,799). The remaining undisbursed funds are associated with the MLF contribution to the destruction of EOL ODS (US$245,000) from the initial stage of the EPR program to be co-financed by the industry and the NAMA program with the remaining funds supporting continuing related technical assistance and logistic support for capture of EOL ODS. For Component 1 covering the completed demonstration test burns this work has been completed US$105,320 below the estimate, notwithstanding the extended schedule and addition of the 2015 short test program. A significant factor in this positive cost performance for the actual test burn programs work is the major financial commitments made by TECNIAMSA that include additional capital investments in facility upgrading for improved emission performance and its monitoring, co-financing of analytical cost, in-kind costs associated with labour and consumables, and forgone opportunity costs associated with business interruption. A general overall estimate provided by the company would indicate these costs exceed US$147,804. It was clear that given the learning curve involved in this program, a significant factor in its ultimate success was the commitment of the company and the financial resources it provided. In broader terms relevant to EOL ODS destruction activities globally, such commitment may be seen as important in undertaking facility specific qualification of facilities generally in this application.

Table 3.12: Comparison of Approved Project Framework Cost Estimate and Actual Disbursed/Projected Costs

Component/Sub-Component/Activity	Cost Estimate (US$)			MLF Funds (US$)[39]			Co-Financing (until 2017) (US$)
	MLF	Co-Financing	Total	Disbursed	Committed	Total	
Component 1: ODS Destruction Demonstration	**830,000**	**1,235,000**	**2,065,000**	**419,680**	**305,000**	**724,680**	**248,146**
1.1 Consolidation/storage/characterization/transport of CFC-11 and CFC-12 EOL ODS	100,000	50,000	150,000	74,945	25,000	99,945	80,342
1.2 Manual processing of refrigerators at scrap yards to produce 10-15t of CFC-11 foam	100,000	-	100,000	63,039	35,000	98,039	20,000
1.3 Test Burn demonstrations for CFC-11 and CFC-12 at a selected HW Incinerators	250,000	165,000	415,000	221,696	-	221,696	147,804
1.4 Test Burn demonstration for CFC-11 containing foam at two selected Industrial/HW Incineration Facilities	135,000	80,000	215,000	60,000	-	60,000	
1.5 Destruction of EPR program start up volumes of CFC-12 and CFC-11 containing foams (Based on 300,000 units, 34 t CFC-12, 65 t CFC-11 in 1,228 t of foam)	245,000	940,000	1,185,000	-	245,000	245,000	Not available at this moment
Component 2.0 Technical Assistance	**255,000**	**150,000**	**405,000**	**287,342**	**28,799**	**316,141**	**702,319**
2.1 Legal and regulatory institutional TA	50,000	25,000	75,000	37,283	13,099	50,382	15,000
2.2 Technical/business planning support for EOL ODS Management under the EPR system	75,000	100,000	175,000	89,867		89,867	504,278
2.3 Public Consultation and Information	50,000	25,000	75,000	22,533	5,200	27,733	183,041
2.4 Technical Oversight and Overall Project Technical Report (international expert)	80,000	-	80,000	137,659	10,500	148,159	-
Component 3.0 Project Management/Monitoring/Evaluation	**110,000**	**170,000**	**280,000**	**154,180**		**154,180**	**147,893**
3.1 National Project Coordinator	60,000	60,000	120,000	121,910		121,910	72,500
3.2 Project office administration	-	60,000	60,000	-		-	21,600
3.3 Misc. contract services and travel	20,000	20,000	40,000	25,892		25,892	5,000
3.4 M&E costs	30,000	30,000	60,000	6,378		6,378	48,793
Totals	**1,195,000**	**1,555,000**	**2,750,000**	**861,201**	**333,799**	**1,195,000**	**1,098,358**

[39] UNDP Combined Delivery Report by activity - CDR, project 68669 output 83728, for 2013, 2014, 2015, 2016 and 2017

4.0 Test Burn Results and Analysis

This section provides the results of the three test burn programs described above along with an interpretive analysis of each relative to what it demonstrates in terms of the TECNIAMSA facility's ability to meet the applicable regulatory and Montreal Protocol (TEAP) standards that would apply (Section 3.7). The section concludes with a general discussion on the application of the demonstrated capability as a domestic option for destruction of EOL ODS generated by the envisioned long term EPR program for environmentally sound management of ODS banks becoming available in the future. Associated with this discussion, further measures are identified that may be considered to improve the utility as well as an updated analysis of other options based on current experience elsewhere is provided.

4.1 Results and Analysis - 2014 Test Burn Program

The principle measured and calculated technical and environmental performance results obtained for the 2014 test burn program for each of the test burn runs as applicable are presented in Tables 4.1 and 4.2 below, Table 4.1 provides the air emission results and Table 4.2 provides destruction removal efficiency results for the target EOL ODS and HCl respectively based on air release which in the case of EOL ODS is equated to destruction removal efficiency (DRE). No ODS analysis was successfully undertaken on solid residues hence overall destruction efficiency (DE) was not determined. All test runs were run with the design and basic regulated operating parameters for the facility as specified in Sections 3.5 and 3.6 above which based on continuous monitoring record of these parameters were generally consistent without significant variation. In particular, attention was paid to maintaining primary and secondary combustion chamber temperatures above 850^0C and $1,200^0$C respectively.

Overall the results indicate that, at the relatively high target waste chlorine content feed rates used (2.6% Cl for CFC-11 and1.2% Cl for CFC-12), the overall results showed significant compliance issues as measured against both TEAP and national performance requirements. In terms of general air emission performance requirements, non-compliance, seemingly unrelated to EOL ODS waste streams, were noted for particulate (MP) against both TEAP and national standards, and against national standards for mercury (Hg) and in one case for total heavy metals. In all these cases, this appears related to the inherent performance of the facility when processing the baseline material and suggest some basic issues related to facility itself and its commercial waste feed that need to be addressed in any event. While in compliance, performance related to PCDD/F emissions is marginal, but interestingly not apparently affected by the presence of the halogenated EOL ODS waste streams, noting that these emissions were highest for the baseline. However, substantive compliance issues in respect to both TEAP and national requirements for HCl and HF emissions were observed when CF-11 and 12 was being feed to the facility and the HCl removal efficiency required in national regulations was not achieved. This suggests chlorine and potentially fluorine content appear to be the controlling parameters in determining the achievable feed rates of EOL ODS. On the positive side, the estimated DRE for the concentrated EOL ODS is substantially better than the required DRE levels in applicable standards indicating that the EOL ODS was effectively destroyed consistent with the intended objective.

Operationally, a number of issues were identified that in-part contributed to the mixed results of the 2014 test program as noted in the following require attention prior to and during subsequent test programs:

- The CEMS system which should have given an immediate indication of the compliance issues associated with particulate, HCl and HF was found not to be functioning properly and did not reflect the stack sampling and analysis. This suggested a calibration issue with the CEMS and was flagged as an issue to be addressed.

- Issues related to seals in the combustion system were found and associated with excess air and less than optimum O_2 levels something that in part may explain the high particulate emissions.
- Issues were also identified with respect to the maintenance of the dust collection (bag house) system in terms of regular cleaning and general maintenance which would have contributed to the high particulate emissions.
- Issues associated with high Hg emissions were initially assumed to be associated with the baseline. However, check analysis removed this as a possible source and the potential of this originating in medical waste streams and being deposited, then released over time in refractory linings was identified.

4.2 Results and Analysis of the 2015 Short Test Burn Program

The main issues respecting EOL ODS destruction performance determined in the 2014 test program was the sensitivity of the facility to Cl and F feed content and its impact on HCl and HF air emission performance. To address this issue, the 2015 short test program was designed to evaluate HCl and HF performance as a function of Cl content using CFC-11 feed. CFC-11 as opposed to CFC-12 was chosen based on its higher Cl content. Table 4.3 shows the short test results for HCl, HF and particulate at the five target chlorine levels (0.25%, 0.50%, 0.75%, 1.00% and 1.25%). These show that the emissions of HCl and HF are well within compliance requirements and relatively constant below 0.75% target chlorine but increase rapidly to excessive levels for 1.00% and 1.25% target chlorine, suggesting the facility essentially has a threshold above which it can not deal with HCl and HF generated in the combustion process. As a conclusion, a feed limitation of <0.75% was determined to be a prudent maximum target for future test burns and commercial application to EOL ODS. The results also indicated that non-compliance with respect to particulate was still associated with the facility although as in the 2014 test run this appears unrelated to EOL ODS feed.

4.3 Results and Analysis – 2016 Test Burn Program

The 2016 test program was undertaken taking into account the results of the 2015 short tests and the various monitoring and facility maintenance issues identified in the previous test runs. A conservative target chorine feed content was selected, namely 0.54% chlorine for the CFC-11 test run and 0.18% chlorine for the CFC-12. Prior to the test run maintenance measures included the seals on the combustion units, inspection and maintenance of the bag house prior to and during the test run and a replacement of the rotary kiln refractory and upgrading/full calibration of the CEMs system.

Tables 4.4 and 4.5 provide the results. Table 4.4 indicates complete compliance with TEAP requirements and substantive compliance with national regulatory requirements related to air emissions. In the case of the latter, the exceptions are individual high measurements for NO_X and Hg in the CFC-11 foam test run, both of which were deemed by the sampling and analytical consultant as anomalous. The other compliance issue noted were exceedances in PCDD/F levels above the national regulatory requirement in the base line and CFC-11 foam test runs. With respect to destruction efficiencies, Table 4.5 shows that the tests were compliant with the national HCl removal efficiency requirement except for one baseline number that was slightly below 99%, and substantively compliant in terms of DRE for EOL ODS. Analysis of the solid residues completed showed no detectable ODS so DRE can be equated with DE.

The overall conclusion is that at these chlorine levels and feed rates the facility has qualified for the destruction of the tested EOL ODS (CFC-11, CFC-12, CFC-11 based foam and HCFC-141b based foam) with the only qualification being to flag the marginal PCDD/F performance as potentially requiring future additional measures.

Table 4.1: Compliance Requirements and Direct Air Emission Measurements - 2014 Test Burn

Exceeds TEAP and Resolution 909

Exceeds Resolution 909

Test	Repetition	PM (mg/m^3)	SO2 (mg/m^3)	NOx (mg/m^3)	CO (mg/m^3)	TOC (mg/m^3)	HCT (mg/m^3)	Hg (mg/m^3)	(Cd+Ti) (mg/m^3)	Metal Summation (mg/m^3)	HCl (mg/m^3)	HF (mg/m^3)	Dioxins and Furans (ng-TEQ / m^3)
TEAP/MP		50	n/a	n/a	100	n/a	n/a	n/a	n/a	n/a	100	5	0.2 (Conc.) 0.5 (dilute)
Resolution 909/2008 (Hr. Av)		20	200	400	100		20	0.05	0.05	0.5	40	4	0.1
1 Baseline	1	67.90	3.80	93.70	9.90	0.05	0.04	0.01	0.0033	0.15	4.60	0.62	0.12
	2	75.40	3.50	59.80	5.30	0.06	0.05	0.08	0.0017	0.11	1.33	0.00	0.09
	3	104.00	5.30		4.30						3.42	0.71	
	Average	**82.43**	**4.20**	**76.75**	**6.50**	**0.05**	**0.04**	**0.09**	**0.0025**	**0.13**	**3.12**	**0.44**	**0.10**
2 HCFC-141b Foam	1	73.30	1.10	113.70	40.10	0.03	0.02	0.08	0.0028	0.50	10.77	0.72	0.08
	2	77.20	3.70	95.80	9.10	0.02	0.01	0.05	0.0019	0.12	1.90	0.06	0.05
	3	67.30	3.30		6.30						1.26	0.06	
	Average	**72.60**	**2.70**	**104.75**	**18.50**	**0.02**	**0.02**	**0.06**	**0.0024**	**0.31**	**4.64**	**0.28**	**0.07**
3 CFC-11	1	41.30	111.30	63.10	2.50	0.04	0.02	0.30	0.0204	4.54	747.10	302.60	0.12
	2	36.00	96.40	77.40	3.20	0.04	0.02	0.10	0.0023	0.30	1455.90	388.60	0.09
	3	37.00	96.00		4.40						2806.90	373.80	
	Average	**38.10**	**101.23**	**70.25**	**3.37**	**0.04**	**0.02**	**0.20**	**0.0114**	**2.42**	**1,669.97**	**355.00**	**0.01**
4 CFC-12	1	53.60	22.30	51.00	5.50	0.04	0.02	0.05	0.0023	0.25	9.31	5.94	0.03
	2	79.80	12.90	71.90	6.80	0.09	0.03	0.03	0.0066	0.18	0.11	4.50	0.08
	3	74.90	14.30		4.90						304.44	114.98	
	Average	**69.43**	**16.50**	**61.45**	**5.73**	**0.06**	**0.02**	**0.04**	**0.0045**	**0.21**	**104.62**	**41.81**	**0.05**

Table 4.2: Summary of Measured Calculation Data for HCl and ODS Removal Efficiencies- 2014 Test Burn Program

Exceeds TEAP and Resolution 909

Exceeds Resolution 909

Test/Repetition		Date	Measured Feed Parameters				Measured Emission Parameters				Removal Efficiency (%)	
			Cl (g/hr.)	HCl (g/hr.)	HCl (mg/m^3)	ODS (g/hr.)	Stack Air Flow (m^3/hr.)	HCL (g/hr.)	HCl (mg/m3)	ODS (g/hr)	HCl	ODS
1 Baseline	R1	29/08/2014	131.80	135.51	4.60	-	12,840	59.06	4.60	-	56%	-
	R2	31/08/2014	177.78	182.78	1.33	-	14,160	18.88	1.33	-	90%	-
	R3	31/08/2014	172.53	177.39	3.42	-	13,680	46.83	3.42	-	74%	-
2 HCFC-141b Foam	R1	1/09/2014	137.94	141.83	10.77	-	12,960	139.59	10.77	-	2%	-
	R2	2/09/2014	98.01	100.77	1.90	-	12,900	24.54	1.90	-	76%	-
	R3	3/09/2014	106.24	109.23	1.25	-	11,820	14.87	1.26	-	86%	-
3 CFC-11	R1	5/09/2014	21,448.01	22,052.18	747	26,754	12,660	9,458.29	747.10	8.45E-07	57%	99.9999999968%
	R2	6/09/2014	21,917.03	22,534,41	1,455.9	26,607	11,400	16,597.26	1,455.90	2.24E-07	26%	99.9999999992%
	R3	7/09/2014	21,843.43	22,458.74	2,806.9	_	13,260	37,219.49	2,806.90	–	*	_
4 CFC-12	R1	9/09/2014	9,529.52	9,797.96	9.31	0.5680	13,080	121.79	9.31	5.93E-08	99%	99.9999895599%
	R2	10/09/2014	9,531.94	9,800.44	0.11	0.5680	12,720	1.41	0.11	2.62E-06	100%	99.9995387324%
	R3	11/09/2014	9,514.57	9,782.59	304.44	_	12,960	3,945.54	304.44	–	60%	_

* Removal value is negative. Emission values surpass feeding values, suggesting an error during the stack measurement

Table 4.3: Impact on Varying Chlorine Feed Content – 2015 Short test Burns on CFC-11

Exceeds TEAP and Resolution 909

Exceeds Resolution 909

Test/Target Cl Feed %	Time	Measured Feed Parameters					Measured Emission Parameters						Removal Efficiency (%)	
		CFC-11 Feeding (kg)	Cl (kg)	HCl (kg)	Fluoride (kg)	HF (kg)	HCl		HF		PM		HCl Removal Efficiency	HF Removal Efficiency
							mg/m³	kg/h	mg/m³	kg/h	mg/m³	kg/h		
1 0.25%	14:45 - 15:53	3.23	1.43	1.47	0.26	0.27	0.77	0.0080	0	0	145.20	1.46	**99.45%**	100%
	16:52 - 17:57	3.45	1.52	1.56	0.28	0.29	4.50	0.0420	1.91	0.20	233.30	2.18	**97.31%**	31%
	Average	3.34	1.47	1.52	0.27	0.28	2.63	0.0250	0.95	0.10	189.30	1.82	**98.35%**	65%
2 0.50%	9:30 - 10:35	7.37	3.25	3.34	0.59	0.62	9.08	0.07	1.06	0.0084	146.60	1.16	**97.90%**	99%
	11:30 - 12:35	7.03	3.10	3.19	0.56	0.59	8.47	0.07	0.49	0.0038	218.92	1.72	**97.80%**	99%
	Average	7.20	3.18	3.27	0.58	0.61	8.77	0.07	0.77	0.0061	182.82	1.44	**97.85%**	99%
3 0.75%	14:23 - 15:30	7.00	3.09	3.18	0.56	0.59	9.24	0.07	0	0.0000	152.14	1.10	**97.79%**	100%
	16:15 - 17:20	7.58	3.34	3.44	0.61	0.64	10.54	0.07	0.94	0.0064	336.31	2.29	**97.96%**	99%
	Average	7.29	3.22	3.31	0.58	0.62	9.89	0.07	0.47	0.0032	244.23	1.70	**97.88%**	99%
4 1.00%	9:10 - 9:50	5.27	2.33	2.39	0.42	0.45								
	18:48 - 19:08	3.64	2.71	2.79	0.49	0.52	90.59	0.78	28.43	0.246	146.11	1.26	**84.91%**	74%
	Sum	8.91	5.04	5.18	0.92	0.96								
5 1.25%	19:55 - 21:00	19.45	14.48	14.90	2.63	2.77	365.10	3.23	71.47	0.63	157.4	1.39	**78.32%**	77%

Table 4.4: Compliance Requirements and Direct Air Emission Measurements - 2016 Test Burn

Exceeds TEAP and Resolution 909

Exceeds Resolution 909

Test	Repetition	PM (mg/m^3)	SO_2 (mg/m^3)	NOx (mg/m^3)	CO (mg/m^3)	TOC (mg/m^3)	HCT (mg/m^3)	Hg (mg/m^3)	(Cd+Ti) (mg/m^3)	Metal Summation (mg/m^3)	HCl (mg/m^3)	HF (mg/m^3)	Dioxins and Furans (ng-TEQ / m^3)
TEAP/MP		50	n/a	n/a	100	n/a	n/a	n/a	n/a	n/a	100	5	0.2 (Conc.) 0.5 (dilute)
Resolution 909/2008 (Hr. Av)		20	200	400	100		20	0.05	0.05	0.5	40	4	0.1
1 Baseline	1	2.40	3.60	128.80	1.57	0.02	0.33	0.03	0.00	0.06	0.24	0.64	0.10
	2	8.40	2.50	107.50	6.08	0.20	13.05	0.01	0.00	0.09	0.34	0.23	0.26
	3	6.40	1.30								0.01	0.01	
	Average	**5.73**	**2.47**	**118.15**	**3.82**	**0.11**	**6.69**	**0.02**	**0.00**	**0.08**	**0.20**	**0.29**	**0.18**
2 CFC-11 Foam	1	8.70	1.10	1,700.60	8.82	0.02	0.35	0.03	0.00	0.08	0.18	0.93	0.26
	2	5.70	1.00	154.60	9.40			0.22	0.00	0.07	0.45	1.60	0.63
	3	6.20	1.90						0.00		0.35	1.26	
	Average	**6.87**	**1.33**	**927.60**	**9.11**	**0.02**	**0.35**	**0.12**	**0.00**	**0.07**	**0.33**	**1.27**	**0.45**
3 CFC-11	1	10.10	9.10	75.70	1.06	0.25	5.00	0.03	0.03	0.08	0.56	0.31	0.09
	2	10.20	10.70	134.30		0.07	1.28	0.03	0.01	0.15	1.08	0.60	0.02
	3	9.00	10.60								1.14	0.73	
	Average	**9.77**	**10.13**	**105.00**	**1.06**	**0.16**	**3.14**	**0.03**	**0.02**	**0.11**	**0.92**	**0.55**	**0.06**
4 CFC-12	1	3.50	2.80	428.10	1.25	0.02	0.07	0.02	0.00	0.06	0.56	0.71	0.07
	2	2.70	4.30	155.60	1.98			0.03	0.00	0.10	0.20	0.13	0.14
	3	3.60	3.90						0.00	0.05	0.22	0.16	
	Average	**3.27**	**3.67**	**291.85**	**1.62**	**0.02**	**0.07**	**0.03**	**0.00**	**0.07**	**0.33**	**0.34**	**0.10**

Table 4.5: Summary of Measured Calculation Data for HCI and ODS Removal Efficiencies- 2016 Test Burn Program

Exceeds TEAP and Resolution 909

Exceeds Resolution 909

Test/Repetition		Date	Measured Feed Parameters				Measured Emission Parameters				Removal Efficiency (%)	
			Cl (g/hr.)	HCl (g/hr.)	HCl (mg/ m^3)	ODS (g/hr.)	Stack Air Flow (m3/hr)	HCl (g/hr)	HCl (mg/m3)	ODS (g/hr)	HCl	ODS
1 Baseline	R1	2/05/2016	117.34	120.65		-		1.1		-	99.09	-
	R2	3/05/2016	120.85	124.26		-		2		-	98.39	-
	R3	4/05/2016	114.57	117.80		-		0.1		-	99.92	-
2 HCFC-141b Foam	R1	5/05/2016	633.33	651.19		-		1		-	99.85	-
	R2	7/05/2016	840.03	863.72		-		3		-	99.65	-
	R3	7/05/2016	1,185.39	1,218.82		-		2		-	99.84	-
3 CFC-11	R1	9/05/2016	4,127.72	4,244.16		5,474.67		3		0.00000001	99.93	99.999999999817
	R2	10/05/2016	5,474.57	5,629.00		7,253.53		6.4		0.00000001	99.89	99.999999999862
	R3	11/05/2016	4,476.18	4,602.44		6,611.00		6.3		0.00000001	99.86	99.999999999849
4 CFC-12	R1	12/05/2016	1,109.29	1,140.58		1,818.00		3.6		0.00000002	99.68	99.9999999989
	R2	14/05/2016	952.97	979.85		1,542.00		1.3		0.00000002	99.87	99.9999999987
	R3	14/05/2016	978.69	1,006.29		1,611.53		3		0.00000002	99.70	99.9999999988

4.4 Productivity, Destruction Cost and Recommended Future Optimization of Capability

On the basis of having demonstrated that the TECNIAMSA facility is qualified in principle for the destruction of EOL ODS, specifically CFC-11 and HCFC-141b based foam and CFC-11 and CFC-12 chemicals up to some limit of chlorine feed content, this section discusses the practical application of this conclusion to the routine commercial capability to utilize this facility as is anticipated to present itself in the implementation of the overall EPR based system contemplated in Colombia in managing domestic and other RAC equipment. The central issues related to the practicality of applying this domestic capability relates to the constraints on productivity and through that unit costs that apply as a result of dependence on achieving compliance air emission requirements with chlorine and likely fluorine content.

Demonstrated productivity for CFC-11 and CFC-12 chemicals: The limiting demonstrated chlorine feed content appears to be not greater than 0.75% based on the short tests on CFC-11. This limit equates to a maximum potential destruction productivity of approximately 6.5 kg/hour, noting that to apply this level, additional full-scale test burns would be prudent. However, it must be assumed that the productivity will be limited by an ultimate licensing decision to formally permit CFC-11 and CFC-12 to be destroyed commercially and this would likely be based on the current 2016 compliant test burn results at around 0.5% Cl for CFC-11 and 0.2% Cl for CFC-12. In this case, the commercial productivity would be approximately 5 kg/hr of CFC-11 and 3 kg/hr of CFC-12 (Tables 3.9 and 3.10). Translating this into total annual capacity[40] that might be offered by the facility on a commercial basis, capacities of 25.6 mt/year of CFC-11 or 15 mt/year of CFC-12 with a maximum up side that might be achieved if additional compliant test burns were undertaken at the 0.75% chorine content of 33.3 mt/year of CFC-11 and 19.5 mt/year of CFC-12. In assessing the utility of the above productivity, the facility has capacity to support the currently modest generation of EOL CFC-11 and CFC-12. It also supports the potential to qualify for destruction of the amounts of EOL HCFCs that are currently being generated and/or are in storage and in the future EOL HFCs occurring as a result of the Kigali Amendment's implementation[41]. However, given the higher fluorine content of these chemicals additional test burns to determine feed limits and productivity would be both prudent and required to meet pending extension of TEAP qualification requirements to HFCs. Likewise, if the contemplated EPR system achieves the collection of CFCs, HCFCs and a portion of the HFCs predicted in Table 3.1 above over the next five years, capacity exists to destroy the originally contemplated 35 mt of CFC-12 or as may be the case HCFCs, HFCs or blends as it is generated in that period using available MLF funding. It should also be noted that the above productivity is for a single unit at Mosquera and potential exists to employ the second unit subject to its qualification.

Demonstrated productivity for ODS based foam: The limiting factor in terms of ODS based foam productivity as determined by the test burn program is not chlorine content but rather the physical practicality of manual feeding bulk foam with a suitable baseline material. This was determined to be 75-80 kg/hr for purposes of the test burn programs which translates into a demonstrated capacity range of 400 mt/year of foam. Applying the original PD indicative assumption of 4 kg of foam generated after manual processing of an average domestic refrigerator, and a 7% and 9% ODS blowing agent content for CFC-11 and HCFC-141b foam respectively, the facility offers a potential EOL ODS destruction capacity of 28 mt/year of CFC-11 or 36 mt/year of HCFC-141b blowing agent. Applied to the targeted initial 300,000 units nominally targeted to be generated initially in the EPR program over the next five years this just meets

[40] Based on an assumed 16 hour/day, 320 day/year operational dedication.

[41] It would likely be required for licensing that test burns be undertaken on specific pure HCFC and HFC refrigerants as well as associated blends

the requirement of 1,200 mt of foam that theoretically could be generated (Table 3.1). It should be noted that this indicative analysis does not account for the obvious potential for optimization of capacity by addressing some of the logistical constraints governing the current manual feeding system. In the first instance, it should be feasible to increase the rate of current feeding. If this was a substantial waste stream as might be achieved in a more fully developed EPR system, justification could exist for automating the feed system including size reduction and lost capture, something that TECNIMSA has indicated it would consider investing in.

Indicative Unit Costs: In the course of concluding discussions on test burn results, TECNIAMSA confirmed its commitment to continuing to pursue this market in partnership with MADS/UTO and private sector EPR system proponents as such a system develops. To this end and as elaborated below the company has formally provided commitments to a program of continuous improvement related to environmental performance and has provided indicative commercial pricing for ODS containing foam, and ODS chemicals in gaseous and liquid form. These prices are US$5.20/kg for foam, US$5.98/kg for liquid (CFC-11), and US$6.20 for gas (CFC-12). In the case of liquid and gas, this pricing is higher that initially anticipated due to feed-rate constraints. However, it remains well below the MLF specified cost effectiveness threshold and is likely viable for refrigerant destruction as part of the EPR system when operational. However, the pricing for foam appears problematic. Assuming a 7% CFC-11 content in foam (ODP impact) the effective EOL ODS destructions would be approximately US$75/kg which implies poor cost effectiveness and not likely a viable option unless dramatic reductions in unit price occurred in an optimized system for its destruction. For HCFC-141b foam that in reality likely represents the majority of material that would be available in the near and medium terms a cost effectiveness based on a 9% content level would be approximatelyUS$59/kg but with substantially lower ODP reduction impact.

Future Optimization Potential: The above work identifies a number of areas for optimizing the linked technical performance, destruction productivity and destruction costs. The principle technical performance issues faced by the TECNIAMSA facility are the limitations on air emission performance, specifically related to HCl, HF, PCDD/F and Hg. HCl and HF have the effect of limiting the Cl and potentially F content of the waste feed and consequently the feed rate of EOL ODS chemicals and ultimately unit destruction costs. Technical upgrading of the APC system to increase the ability to accommodate these acid gas products of combustion is a continuing priority in the company's investment program. Additionally, the side testing during the 2016 Test Burn program showed that the calibrated CEMS system demonstrated effective real time correlation of HCl and HF emission performance which could be utilized to maximize the feed rate to its limit below the compliance level thus optimizing productivity and reducing unit costs in commercial operation. In the case of PCDD/F, the test burn results generally show that, while generally compliant with national requirements, these emissions consistently approach that limit regardless of chlorine feed rates. TECNIAMSA recognizes this as an inherent issue for the facility generally and have included added APC equipment intended to reduce this in their current investment program. In the case of Hg, this is recognized as an issue associated with its general commercial waste stream, particularly medical waste and is being prioritized with efforts to better educate and police waste generators. A final area of attention related to both PCDD/F and Hg is the potential addition of continuous monitoring systems for these emissions which are now on the market and finding application in commercial EU HTI facilities. As in the case of HCl and HF these systems would allow these emissions to be controlled in real time and thus optimizing feed control.

4.5 Updated Analysis of Other Potential EOL ODS Destruction Options

The overall general conclusion from the test burn programs documented above are that Colombia has the basic domestic technical capability to destroy the primary target EOL ODS wastes, namely CFC-11 and CFC-12 chemicals and CFC-11 and HCFC-141b foam, in accordance with TEAP requirements and, with some manageable qualifications related to national regulatory requirements. The principle limitations associated with this conclusion relate to the relatively low productivity of the destruction and the higher than originally assumed unit costs. In the case of CFC-11 and CFC-12 these limitations will not necessarily preclude the utility of this destruction option to support the destruction requirements of a national EPR program as envisioned in the near and medium terms, particularly noting the potential to optimize performance and productivity. However, it is apparent that for cost and productivity reasons this option will not likely be viable for eliminating foam when judged either in terms of direct cost effectiveness or global environmental benefit. In light of these conclusions, it is reasonable to re-visit the original 2012 technology selection options based on more current experience and experience observed in other countries and particularly MLF ODS destruction demonstration projects. With respect to the latter, Appendix III provides a summary of the status of these projects based on a recent EXCOM status reports and direct contacts made by project team consultants.

With respect to the originally considered options (Section 3.4), the option of developing a purpose-built capability specifically in the form of a small plasma arc capability remains impractical. A number of MLF and GEF projects that initially considered this option did not pursue it upon implementation. In the one documented case where it was pursued (Ecuador) a unit was purchased and installed but ultimately proved to be unaffordable to operate. In any event, these units lack the capacity to support the anticipated volumes from the Colombian EPR program. The more practical option of developing a commercial scale plasma arc hazardous waste destruction facility would be a technically viable option. Work currently being undertaken by TEAP in updating approved ODS destruction technologies indicates that a number of commercial argon plasma arc facilities (Australia, Japan, US, Mexico) are in operation as is at least one commercial scale nitrogen plasma arc facility in China. Similar facilities are also reported to be planned for the Russian Federation and Canada. While this remains a relatively high cost option, information applicable to the MLF demonstration work in Mexico indicates destruction costs of US$9/kg which approaches competitiveness with the current costs estimated in this work. As far as application in Colombia, it is concluded that developing such a facility would depend on a wider waste market to attract the capital investment required.

However, the option of exporting EOL ODS chemicals remains an option at least theoretically. As indicated in Appendix III this remains a common option in three of the completed MLF funded projects, albeit for relatively small quantities and is the approach apparently being adopted by five other projects, at least one of which involved a linkages to GEF POPs export projects. In terms of cost, this option appears to be the most cost effective when a critical mass exists as is the case when combined with a POPs project. Current market survey data based on recent tenders on GEF/UNDP POPs projects indicate that a likely destruction cost alone in the range of US$1.0-2.0/kg for HTI destruction and US$9/kg for commercial plasma arc[42] with an additional of approximately US$1.0/kg to cover export/import transaction and transportation cost might would apply. In the one identified case where export from the Balkans to HTI facilities in the EU occurred in modest but reasonable quantities, commercial prices in the range of 1.64 to 2.15 Euro/kg for

[42] Based on quoted destruction costs at a domestic commercial plasma arc facility demonstrated in the MLF project in Mexico.

destruction and 0.36 to 0.66 Euro/kg for transportation were reported[43]. However, for small quantities the export/import transaction costs would be significantly higher. Applied to the situation in Colombia, this would only be an option if the EPR system elected to store accumulating recovered EOL ODS chemicals until some economically acceptable volume were available for a bulk export. Additionally, specific national regulatory barriers to export of hazardous waste would have to be addressed.

In terms of other domestic options for EOL ODS chemicals, the use of cement kilns is being pursued in a significant number of MLF and other projects elsewhere. Appendix III indicates that in total 6 projects involve utilization of cement kilns two of which are considered completed, although limited technical performance and cost information on only one is available. The one where information is available in Mexico reports that direct destruction cost for this option were US$7.0/kg which approaches the indicative unit cost quoted by TECNIAMSA. Technically, formal test burns in CFC-12 and HCFC-22 indicated a DRE compliant with TEAP requirement and national regulations. As such, this might be considered a backup option in Colombia assuming interest by a domestic facility partner could be attracted and the required technical performance testing were undertaken. As noted below, the use of a domestic cement kiln for PCB oil and contaminated soil is being pursued in Colombia MADS in its GEF POPs project, instead of an original interest in partnering with the current MLF ODS project in qualification of TECNIAMSA. More broadly, MADS has positive interest in development of expanded waste derived fuel use in cement kilns as part of its overall integrated waste management strategy, and particularly in diverting foam waste generally from landfills. Apart from potential economic issues, the only barriers to pursuing this option are firstly that cement kilns are not formally approved by TEAP for destruction of dilute ODS, and to date the absence of any formal destruction demonstrations on ODS foam in such facilities.

All of the above discussion focuses on the destruction of EOL ODS chemicals and the question of destruction of dilute EOL ODS, namely foam, remains problematic given the poor economic viability of using TECNIAMSA in this application. Early recognition of this during the test burn program led UTO to pursue a parallel option independent of the MLF program in association with the EPR system development and an electric arc steel making plant (GERDAU - DIACO). This company is a primary consumer of scrap steel from RAC equipment and would represent a major market for this recyclable by-product stream from processing of such equipment in the developing EPR system. An evaluation program was developed whereby the option of compacting stripped refrigeration units without removal of the foam and using these directly as feed for electric arc steel making. This program has progressed to the point of having run two test lots at DIACO's Tuta plant from July 23 to 30 and from November 1 to 4, 2017. These involved a baseline test run at a scrap feed rate of 49 mt/hour and then repeating it with an additional charge involving an average of 819 kg/hr of compacted intact refrigerator cabinets that can be assumed to have utilized mixed CFC-11 and HCFC-141b blowing agent. In each case a complete range of air emissions as specified in Resolution 909 were sampled and analyzed in three separate sampling/analysis tests.

For the first test run, the results showed general compliance within the limits set out in the national regulations with the exception of a small exceedance for particulate with the refrigerator charge and PCDD/F emissions somewhat higher than the regulatory limits for both the baseline and refrigerator charge runs. The second test run indicated compliance with particulate limits but PCCD/F emissions remained marginally higher that the TEAP requirements. The company is currently examining design and APC modifications to address this and will undertake additional testing in 2018/19. Subject to this work, a

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[43] Source: http://www.multilateralfund.org/80/Document%20Library1/1/8012.pdf, Demonstration of a Regional Strategy for ODS Waste Management and Disposal in the ECA Region, EUR/DES/69/DEM/14 – UNIDO.

commercial arrangement between DIACO and the EPR system administrators is being discussed where DIACO would take collected and stripped refrigeration cabinets for processing in this manner in exchange for a dedication of this scrap stream, effectively eliminating the cost of foam destruction and providing some reasonable level of associated retained EOL ODS destruction. This could provide a practical and cost effective interim solution to dealing with ODS based foam as the EPR system develops, recognizing that losses can be expected although these are likely of a similar magnitude as those associated with manual separation and processing that would be involved in incineration options. In longer term, an option involving investment in an automated processing system now available commercially and utilized where significant assured volumes from a mature EPR system are available as might be the case when a mature ERP system was operating.

4.6 Synergies with Stockholm Convention Initiatives

A specific objective stated in the original Project document was to enhance synergies with initiatives related to meeting national obligations under the Stockholm Convention respecting the destruction of POPs stockpiles. In case of Colombia the initial intention was to coordinate the EOL destruction demonstration work with implementation of a parallel GEF/UNDP POPs Focal Area project entitled "Development of National Capacity for Environmentally Sound Management of PCBs and their Disposal"[44] that was approved in 2013. The intention was to involve the MADS team involved with the PCB work in the demonstration work at TECNIAMSA undertaken in this Project and assess the results in relation to the potential to qualify the facility for PCBs, both concentrated PCB based oil and PCB cross contaminated mineral oil noting both are halogenated chemicals. This cooperation was undertaken for the 2014 test burn program. However, when it became apparent that the facility's capacity for higher chlorine content feed rates would be limited, TECNIAMSA indicated a concern about considering this POPs waste stream, particularly considering the facilities productivity limitations and the relatively large estimated volumes of such wastes that might be involved. The PCB project has since initiated consideration of utilization of domestic cement kilns and other alternatives.

5.0 Development of a National Extended Producer Responsibility Based System

As introduced in Section 3 above, in parallel with undertaking the test burn program, MADS and specifically UTO has been coordinating the development of a national EPR system for RAC equipment generally and specifically for domestic refrigeration equipment. This is being done within the overall regulatory[45] and policy framework[46] of the national initiative on integrated WEEE management which effectively sets the regulatory framework for implementation of a mandatory EPR system applied to all WEEE including RAC equipment. The current implementation work generally focuses on various WEEE sub-sectors. For the RAC sub-sector this is based on the piloting and incremental development of a voluntary EPR system undertaken in part with support of this MLF Project, and now its transition to mandatory large-scale application. It has also involved planning and development of financial instruments and other funding support mechanisms in addition to direct EPR financial responsibility to be ultimately assumed by manufacturers and importers, noting a cooperative obligation is also applied to distributors and

[44] https://www.thegef.org/sites/default/files/project_documents/8-24-2011%2520ID4417%2520PIF%2520revised_0.pdf
[45] Law 1672 of July 19, 2013. http://www.minambiente.gov.co/images/normativa/leyes/2013/ley_1672_2013.pdf
46 "Política Nacional para la Gestión Integral de Residuos de Aparatos Eléctricos y Electrónicos (RAEE)", Ministerio de Ambiente y Desarrollo Sostenible, 2017.

retailers. These financial instruments include those linked to climate change mitigation through energy efficiency incentives, which will also extend the long-term focus beyond EOL ODS to replacement of equipment utilizing other high GWP chemicals, specifically HFCs consistent with the Kigali Amendment. This section describes the progress and current EPR program direction including the linkage to the MLF project's final objective upon completion, namely the capture and processing of 300,000 domestic refrigerators including supporting the environmentally sound destruction of the EOL ODS generated.

5.1 EPR System Structure and Development to Date

Starting in 2013 with the promulgation of the above referenced national law, MADS through UTO initiated the development of a series of partnerships with industry stakeholders directed specifically to the capture and processing of EOL domestic refrigeration equipment. The principle industry partner is the National Business Association of Colombia (ANDI) and, within it, the Chamber of Home Appliances. In 2014 with UTO's assistance and technical assistance resources from the MLF project as well as participating domestic refrigerator manufacturers and importers, the Corporación RED VERDE was established within ANDI to serve as the operational entity for the EPR system with the participation of UTO. The other partnerships brought together were a number of commercial hazardous waste management services providers involved in WEEE management and end users of recovered materials from these waste streams, particularly the EAF steel making sector as noted in Section 4 above.

Since its establishment RED VERDE has undertaken a range of development activities including: i) establishment of ten collection stations in six major cities (Bogotá, Medellín, Pereira, Barranquilla, Cali and Bucaramanga); ii) undertaken regular collection campaigns : iii) conducted an extensive /public awareness program promoting ESM of refrigeration equipment; vi) established commercial contracts with licenced WEEE service providers to collect and process domestic refrigerators, and since 2017, washing machines, air conditioners and microwave ovens.

Additionally, RED VERDE has been working with UTO and the Climate Change Division of MADS and the Ministry of Mines and Energy in the formulation of a National Appropriate Mitigation Action for the domestic refrigeration sector (NAMA). This NAMA will promote the national replacement program for domestic refrigerators.

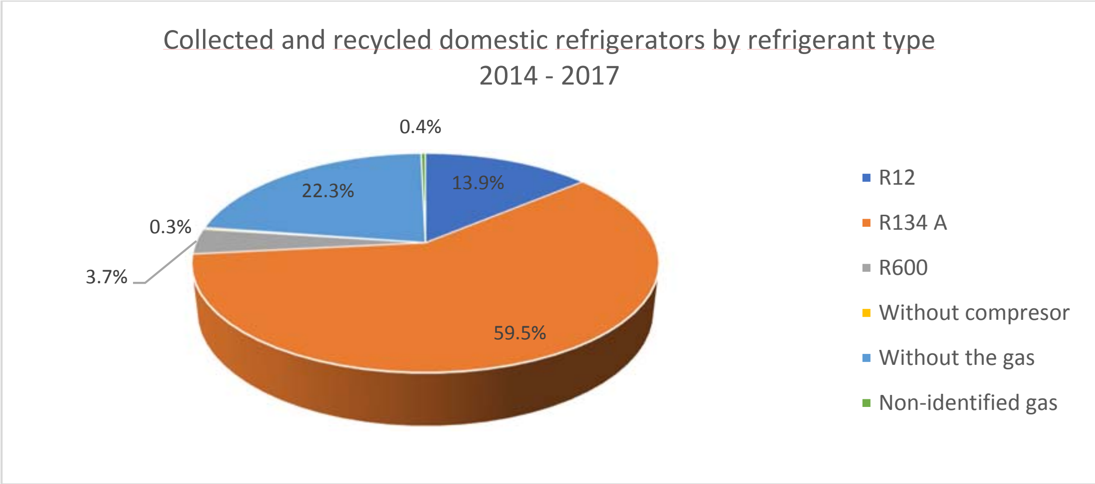
Table 5.1 below provides a summary of appliance collection by year. To date, 3,638 domestic refrigerators have been collected for processing, and as shown in Figure 5.1, 13.9% being CFC-12 based, 59.5% being HFC -134a based and 3.7% being R- 600a based.

Table 5.1: Annual collection 2014-17 by appliance type

Appliance	2014	2015	2016	2017	Total
Refrigerator	41	1,264	1,158	1,175	3,638
Washing machine			30	185	215
Air conditioner				193	193
Microwave oven				333	333
Others				6	6
Total	**41**	**1,264**	**1,188**	**1,892**	**4,385**

Source: RED VERDE, 2017

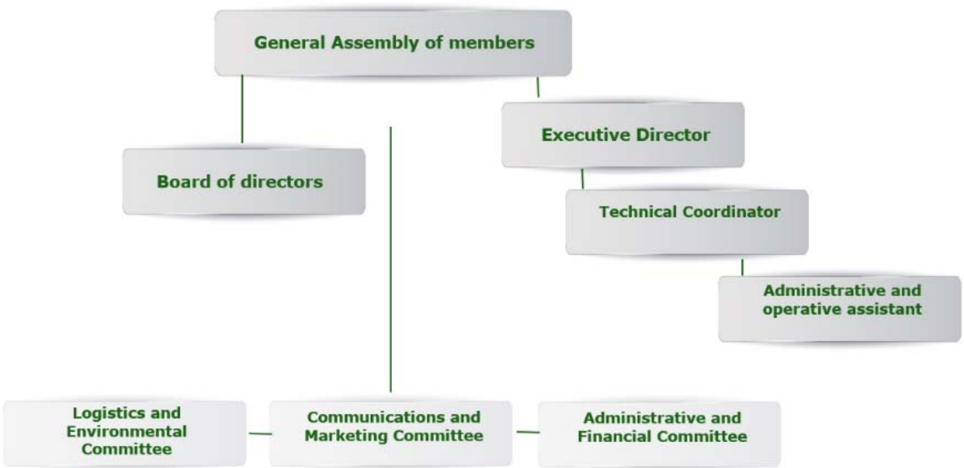
Figure 5.1: Domestic refrigerators collection by refrigerant type, 2014 - 2017



Source: RED VERDE, 2017

Red Verde has two kinds of producer members: i) Founding members and ii) Adherent members, being those members who subsequently have entered after the constitution of the Corporation. These members and all the support partners are organized under the structure shown in Figure 5.2.

Figure 5.2: Red Verde´s organizational structure



Source: RED VERDE, 2017

The administrative head office of RED VERDE works in Bogotá D.C., where a team of three people is directly working for the Corporation, with the support of the administrative services that ANDI provides. The team is composed of:

- Executive Director acting as the legal representative of the Corporation, appointed by the Board of Directors and employed by ANDI.
- Technical coordinator.
- Administrative/operating assistant.

ANDI support is shared by the six Corporations affiliated to ANDI and in charge of different EPR type systems (one of those, is Red Verde):

As each producer member and support partner has specialized teams in topics such as communications, marketing, logistics, environmental management, and general and financial management, three committees exist in order to guide and support all the needed actions for Red Verde operation.

The eight associated members have a participation percentage inside the Corporation according to their market share. The distribution of costs for the operation of Red Verde, as well as the contribution scheme are explained below.

Currently, the budget is mainly divided in administrative (including communication and marketing items) and operating costs, as set out in Table 5.2.

Table 5.2: Distribution of Red Verde´s budget

Item	Activities	2014	2015	2016	2017	Proposed 2018
Administrative costs	Services Retorna Group – Transversal services Maintenance Travel expenses Legal expenses Other expenses Depreciation and amortization Staff Furniture	42,17%	60%	59%	64%	63,30%
Communication and marketing	Advertising and design agency Advertising and design agency Production of advertising material and campaigns Free press Social networks Education program	35,67%	23,94%	28,36%	22,70%	21,60%
Operational costs	Transport Environmental recycling services IT Platform Operational coordination	18,78%	11,46%	7,64%	5,50%	12,10%
Unforeseen	Others	3,37%	4,76%	4,76%	4,80%	2,90%
Budget (USD)		$ 136.976	$ 183.990	$ 148.716	$ 211.249	$ 232.095
Budget (COP)		$ 280.356.219	$ 459.421.750	$ 493.707.723	$ 616.671.532	$ 697.769.209
Exchange rate, April		$ 2.046,75	$ 2.496,99	$ 3.319,80	$ 2.919	$ 3.006

Source: RED VERDE, 2017

The costs of the budget items are distributed between the associated members considering a fixed part and a variable part, as shown in Table 5.3.

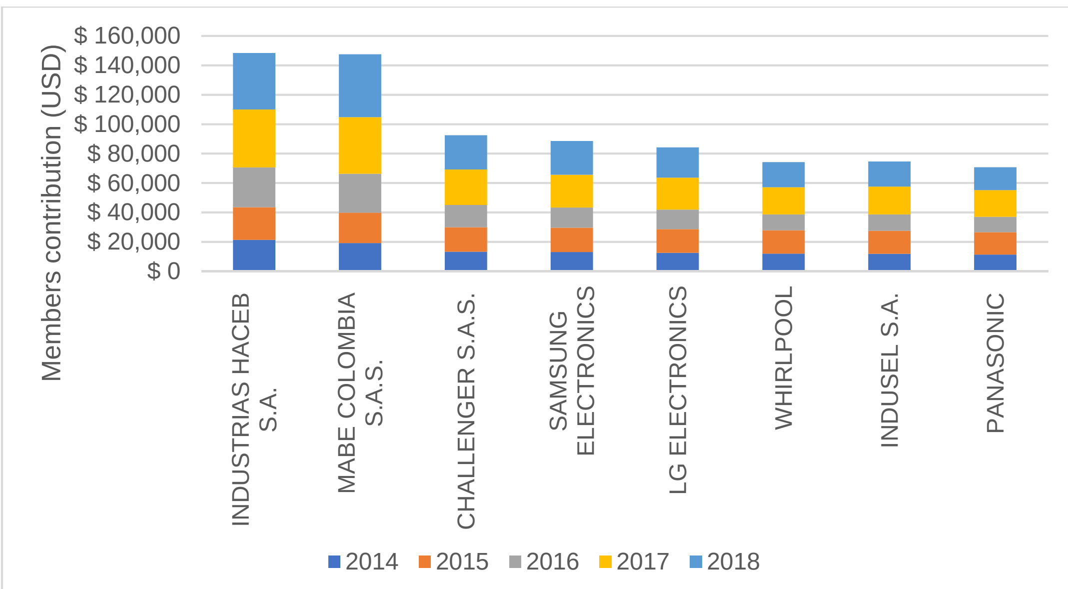
Table 5.1: Distribution of Red Verde´s budget into fixed and variable parts

	Fixed	Variable
Items	Administrative costs	Operational costs
	Furniture	Communication and marketing
	Unforeseen	
Costs 2017	72%	28%

Source: RED VERDE, 2017

Considering the eight companies which support Red Verde and the percentages of the market share of the members per year, the financial contribution of each member since 2014 is summarized in the figure 5.3.

Figure 5.3: Historical contribution of Red Verde's members



Source: RED VERDE, 2017

Besides the member contributions, UTO has contributed in the framework of MLF Project funding as shown in Table 5.4.

Additionally, the GEF/UNDP POPs project under MADS assigns cooperation funds in order to promote research activities focused on the analysis of alternatives for the persistent organic compounds treatment, present in the e-Waste managed by RED VERDE.

In addition to the above, RED VERDE has been developing experience and data that would form the basis for a long term sustainable business model for the EPR system. This identifies a cost structure that would be sustained by an EPR funding for the capture, processing of end of life equipment including destruction of EOL ODS. Figure 5.4 provides an illustration of the sequence of operations envisioned to be covered by the system and Table 5.5 shows pro-forma costs applicable per unit collected and dismantled based on current contractual arrangements, recovered market revenues and current disposal options.

Table 5.4: UTO/MLF Contributions to RED VERDE

UNDP/MADS Agreement	General activities	Counterpart (USD)
Agreement 0 - 2013	Previous activities: survey on final disposal of domestic refrigerators and consultancy for domestic refrigerators EPR scheme design	$ 35,000
Agreement 1 - 2014	-RED VERDE Launching -RED VERDE Administration and Information Platform - Dissemination and awareness campaigns and material for end users	$ 30,000
Agreement 2 - 2016	- Controlled burning test for refrigerator cabinets or doors at EAF steel producer. - Analysis of foams (physic-chemical). - Estimation (generation) and recycling alternative studies for foams. - Dissemination and awareness campaigns and material for end users	$ 40,000
TOTAL		$ 105,000

Source: RED VERDE/UTO, 2017

Figure 5.4: Sequence of RED VERDE´s operations

Source: RED VERDE, 2017

Table 5.5: Pro-forma costs applicable per unit collected (US$)

Activity	Description	Cost by Management Scenario		
		Disassembly by WEEE service Provider		Partial Disassembly by WEEE service provider plus /EAF processing of intact cabinets and doors
		Foam Disposal by HTI	Foam Disposal by Cement Kiln	
Transport	End user to WEEE processing	**8.5**	**8.5**	**8.5**
Revenue recovery from waste	Ferrous scrap	4	4	2
	Alumium	0.6	0.6	0.6
	Copper	2.2	2.2	2.2
	Plastics	0.8	0.8	0.5
	Net Revenue	**7.6**	**7.6**	**5.3**
Treatment/ Disposal	Manual dismantling	**5.2**	**5.2**	**4.0**
	Oil (HW SP)	0.1	0.1	0.1
	Foam (HTI)	35	4.5	0
	ODS (HTI)	1	1	1
	Misc. (Solid waste (LF)	0.3	0.3	0.3
Direct net cost per unit		**41.6**	**11.1**	**5.4**
EPR Program Administration (*)		**1,2**	**1.2**	**1.2**
Net Total Unit Cost Estimate		**42.8**	**12.3**	**6.4**

(*) Based on actual development and collection of the EPR program applied to an annual collection rate of 120,000 units/year
Source: RED VERDE&UTO, 2017

The above results indicate that the key determining factor in the cost of a the envisioned self-sustaining EPR system will be disposal costs applied to foam removed from collected refrigeration units. Clearly, the cost associated with the option of destroying ODS based foam with at a national HTI facility, while technically and environmentally feasible as demonstrated in the current work, is excessively expensive and unlikely to be affordable to either industrial participants or consumers. An option that is reasonably affordable on a per unit basis would be the option of sending the intact doors and cabinets to an EAF steelmaking facility, noting that this is not yet qualified by pending resolution of emission issues to be consistent with TEAP requirements and potentially inclusion of this option as an approved TEAP technology at some point would be recommended to maintain compliance with MP requirements. The third option would be destruction of foam at a cement kiln which technically and environmentally should be equivalent to the HTI option and is in fact used currently on a modest scale, albeit without formal qualification or official TEAP destruction technology approval. The relatively low cost/unit that is reported for these disposal arrangements (approximately US$0.65/kg) is the basis of the above projected unit cost. Assuming these destruction costs are verified as applicable to a fully operational EPR system, this is could be considered if compliance with TEAP requirements were sought albeit at a cost premium and a program to qualify a cement kiln were undertaken.

5.2 Supporting Bilateral Initiatives

In association with this work, a substantial supporting bilateral technical assistance initiative has been undertaken by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) as part of a multi-country project over the period 2013-2018, funded by the German Government entitled "Management and Destruction of ODS Banks". This is supporting integrated waste management of ODS and equipment containing ODS globally and has produced a number of useful generic outputs utilized in Colombia including guidance documents on global ODS bank management, and developing ODS inventories, key policy and regulatory measures required and guidance on manual dismantling of RAC equipment. In Colombia, MADS/UTO has acted as the primary coordinating beneficiary for this work with the involvement of other government institutions, RED VERDE, and commercial HW and WEEE management service providers in the period 2015 to 2018. The principle outputs of this work have been a number of practical training programs and the current work involving development of a country specific road map for ODS banks management supporting the development of EPR program. The latter includes an updated estimate of current ODS banks in the country and strategy guidance on the development of the EPR system building on the present MLF project as described in the following.

In terms of ODS banks inventory work being done by MADS/UTO, this is reported in two linked documents, one entitled "Survey of ODS and ODS Alternatives in Colombia"[47] and "ODS bank inventory for Colombia"[48]. These documents were prepared with GIZ assistance and partially supported through UTO with MLF funding all as part of the above GIZ "Global ODS Banks Management and Destruction" project. The results of this work are summarized in the following.

The ODS banks inventory focuses on chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) used as refrigerant and for foam in the RAC sector. Additionally, hydrofluorocarbons (HFC) are included in the inventory in recognition of this being a future focus for bank management.

The estimation of ODS banks in Colombia was done for each RAC subsector, based and the various systems they contain and expressed in units (mt) to be most relevant to future planning and design of recycling, reclaim and destruction infrastructure capacity required for overall ODS and future HFC bank management.

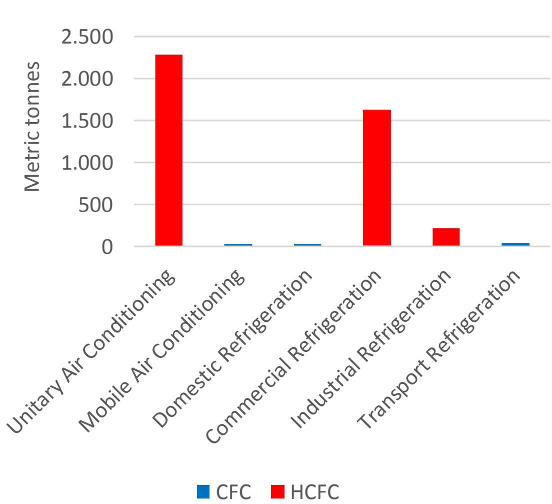
Future projections until year 2030 have been undertaken to assess the future potential availability of EOL ODS and HFCs. This is particularly relevant when it comes to an economic feasibility assessment associated with decision making respecting future infrastructure and ensuring sustainable mechanisms to capture, re-use and ultimately destruction capacity.

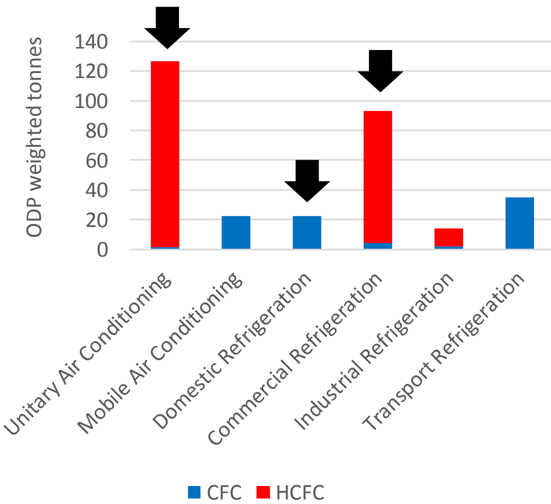
A significant finding in the "Survey of ODS banks inventory in Colombia", that was conducted by MADS/UTO and GIZ, noted to date (Figure 5.5) is that ODS Banks in the RAC sector are dominated by three sub-sectors, unitary air conditioning, commercial refrigeration and domestic refrigeration. In total ODS volume in the currently estimated ODS Bank, the air conditioning and commercial refrigeration applications dominate and is predominately HCFC (approximately 3,000 mt) refrigerants. However, in ODP terms, domestic refrigeration which is CFC based remains significant despite the relatively small ODS volumes remaining (approximately 200 mt). Having said that the available CFC bank is rapidly

[47] "Survey of ODS and ODS Alternatives in Colombia" GIZ/MADS-UTO, January 2017
[48] "ODS Bank Inventory for Colombia", GIZ, draft report, December 2017.

disappearing and becomes less of a factor in EOL ODS related decision making beyond the next few years as will be illustrated below.

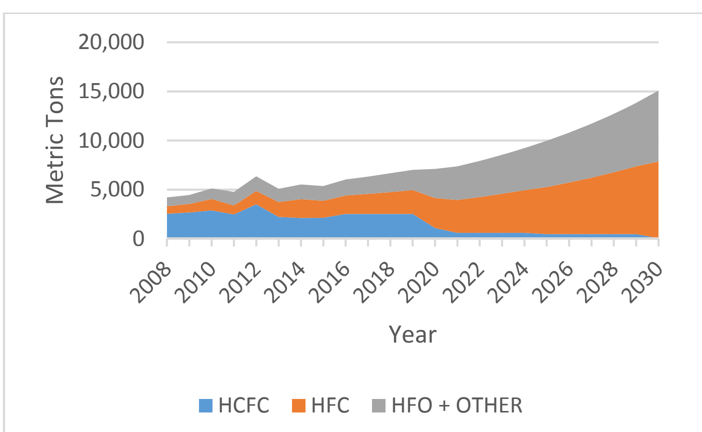
Figure 5.5: Estimated ODS bank of the refrigeration and air conditioning sectors in metric tonnes (left) and ODP weighted tonnes (right), split by CFC and HCFC.[49]





This is of significance in terms of looking to the future demands that will placed on any the EPR system and ODS destruction requirements as it scales up. Clearly it requires capability to address CFC-12 refrigerant and needs to prioritize its capture and elimination in the near term before what remains is lost. However, in both the near and medium term the principle priority and major expenditures will be directed to dealing with the significant volumes of HCFCs (HCFC-22 and blends). Although not quantified here, banks of HFCs will become a priority as well in term of environmentally sound management with the implementation of the Kigali Amendment and a transfer of focus in terms of global environmental benefit to GWP rather than ODP impact mitigation. As an illustration of this, Figure 5.6 below shows the recent and projected HCFC and HFC consumption through to 2030.

Figure 5.6: Consumption of HCFC, HFC and other refrigerants in Colombia (UTO 2017a)

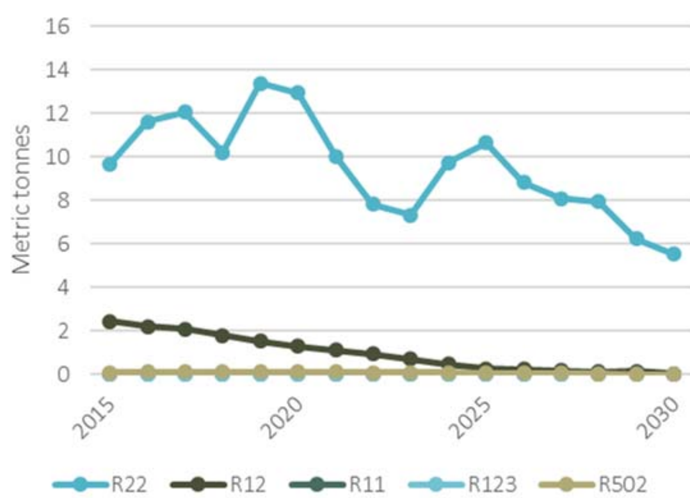


Source: Inventory of ODS banks in Colombia, draft report. GIZ, 2017

49 "Survey of ODS and ODS Alternatives in Colombia" GIZ/MADS-UTO, January 2017

The UTO/GIZ inventory work referenced above has developed a time related estimate of CFCs and HCFCs for these three key sectors for the period 2015-2030 that would be theoretically and practically available from the estimated bank available for EOL management and destruction. The maximum achievable estimates consider all RAC equipment which would be decommissioned and enter the waste stream (assuming a 100% collection rate). The second estimate in each case provides a minimum scenario that assumes a 5% collection rate and recovery rate more characteristic of global experience. For the three sectors, the manageable amounts of HCFC-22 will increase until the year 2020 then decrease afterwards. In contrast the window of opportunity to destroy CFCs is closing rapidly such that CFC-11 and CFC-12 will not be available after 2025 in any significant amounts. When assuming the minimum collection and recovery rate of 5% (lower bound), the estimates indicate that only around 12 mt of HCFC- 22 are currently available for management and 2 mt of CFC-12 chemical for destruction with quantities of HCFC-22 available being roughly maintained at this level annually until 2020 and then declining to 6 mt in 2030. CFC-12 continues to decline and effectively unavailable after 2025. This is illustrated graphically in Figure 5.7 below over the period 2015 to 2030.

Figure 5.7: Estimated Availability of EOL ODS from the RAC Sector at an assumed Minimum Bank Capture Rate of 5% (GIZ, 2017)



Looking forward, Colombia has been selected for a NAMA Support Project (NSP) entitled "Colombian NAMA for the domestic refrigeration sector" involving grant funding of EUR 9,006,000 to be implemented over the period 2018-2022. MADS is the implementation partner and, within it, joint responsibility is assigned to UTO and the Climate Change Division. GIZ will act as the delivery agency. With the overall goal of transforming the domestic refrigeration sector toward green technologies, the NSP identifies five primary areas of intervention linked to key outputs that are to be supported by the NAMA, namely; i) establishment of the required supporting policy framework for this transformation; ii) providing the required technical and financial support for domestic manufacturers for the design and production of climate friendly and energy efficient refrigerators; iii) support for accelerated market introduction of these products through an incentivized replacement programme; iv) technical and investment support for expanded national capacity for environmentally sound processing of replaced equipment; and iv) institutional support for robust monitoring and verification. The NSP is structured with two overall parts in terms of implementation focus and funding. There is a technical cooperation component that provides technical assistance, training and implementation resources for policy/regulatory development, and capacity upgrading for manufacturers, the EPR system development and WEEE service sector. The financial component provides support financing capacity largely through national financial institutions included a national development bank to leverage required investments within manufacturers and in the WEEE service sector, as well as a mechanism to incentivize the replacement programme. In practical terms relevant to the MLF project, the NSP anticipates the complete conversion of the manufacturing sector to low GWP refrigerant, elimination of new HFC based domestic refrigeration equipment from the market, accelerated replacement of 300,000 CFC/HFC (60%-40%) based units, and capacity within the domestic WEEE and hazardous waste management sector to handle the volumes generated by a sustainable EPR system operated by RED Verde in an environmentally sound manner.

This information along with the experience from the voluntary RED VERDE pilot program and the results of this MLF project, is guiding the finalization of the Colombia road map which is developing detailed recommendations in four areas: i) strengthening the supporting legal and regulatory framework; ii) identifying and implementing a sustainable financing mechanism, iii) further development of recycling and destruction infrastructure; and iv) scaling up the collection mechanism. When completed, this road map should provide a tool for the overall transition of the current voluntary EPR system to a scaled up mandatory one and assist in integrating other financial instruments under development.

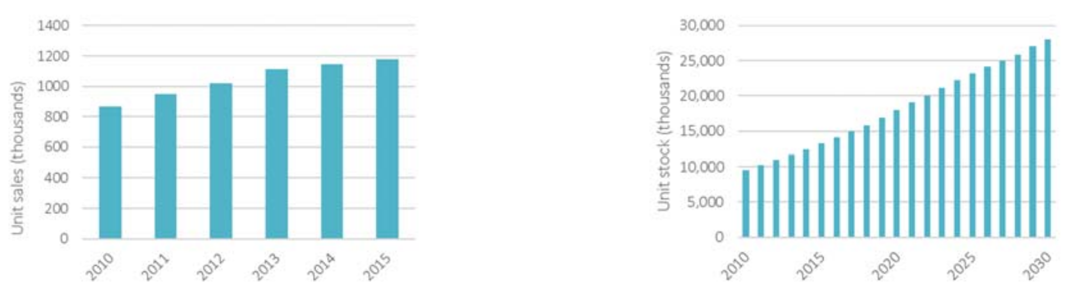
5.3 Projected EOL ODS Banks and Management Availability

Analysis specifically for a number of sectors was undertaken in the 2017 GIZ/UTO bank and inventory work referenced above specifically related to the projected size of EOL ODS banks and availability for management thru to 2030. The results for the three principle sectors noted above (domestic refrigeration, commercial refrigeration and unitary air conditioning) are summarized in this section. This information will be a key input into planning and scaling the EPR system and associated infrastructure and other resource requirements.

5.3.1 Projected EOL ODS Banks and Management Availability – Domestic Refrigeration

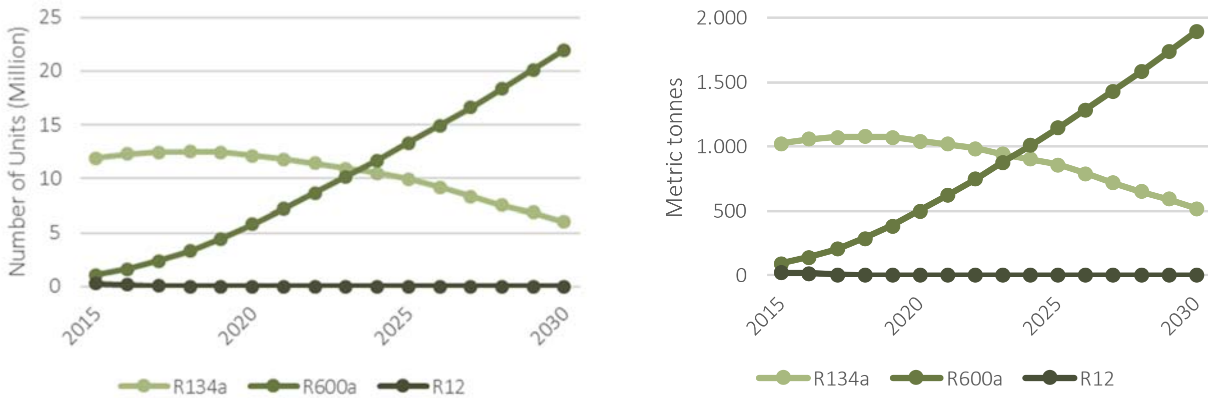
Domestic refrigeration is the fastest growing subsector in Colombia, with sales and total stock figures. Around one million refrigerators are sold per year on average (over the last 5 years), the current stock in use is 13.2 million units, and projected to increase to 28 million units by 2030 as illustrated in Figure 5.8 below.

Figure 5.8: Domestic Refrigerator sales in the last 5 years and projected stock in use through 2030 (GIZ, 2017)



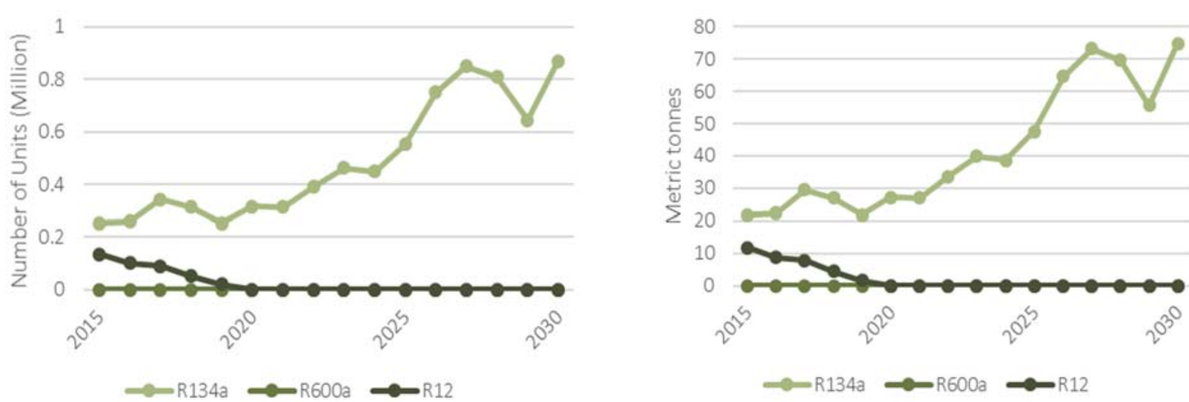
The dominate refrigerant in use is HFC-134a. While this will be continuously replaced by R-600a it is not projected to be eliminated until 2030 in the absence of accelerated phase out measures consistent with the Kigali Amendment. The current bank is peaking at just over 1,000 tonnes of HFC-134a, with 100 tonnes of R-600a and 23 tonnes of CFC-12 (Figure 5.9)

Figure: 5.9: Bank of domestic refrigerators by refrigerant and by amount of refrigerant until 2030 (GIZ, 2017)



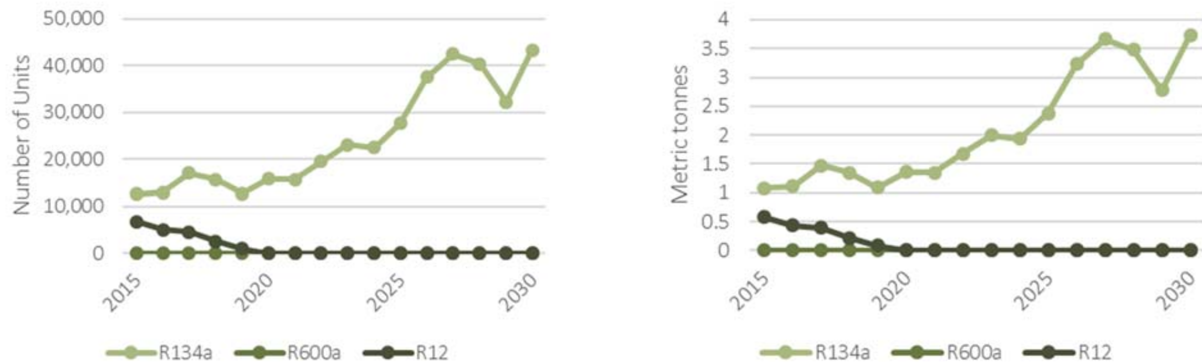
Around 140,000 CFC-12 based refrigerators and 300,000 HFC-134a based units are estimated to be potentially currently available for management which translates in about 9 tonnes of CFC-12 and 30 tonnes of HFC-134a. The calculations indicate that all CFC-based refrigerators will have disappeared after 2020 based on an assumed average life time of 20 years. The number of HFC-134a units being potentially available for management is projected to increase until 2030, significant numbers of R-600a units are not projected to be available for management in this time frame (Figure 5.10).

Figure: 5.10: Projected end-of-life Domestic Refrigeration Units and Quantities of Refrigerant Potentially Available for Recovery until 2030 (GIZ 2017)



Noting that the above projections are based on the highest recovery rate, a lower bound recovery rate of 5% estimates dramatically lower amounts of refrigerators and associated refrigerant as illustrated below in Figure 5.11.

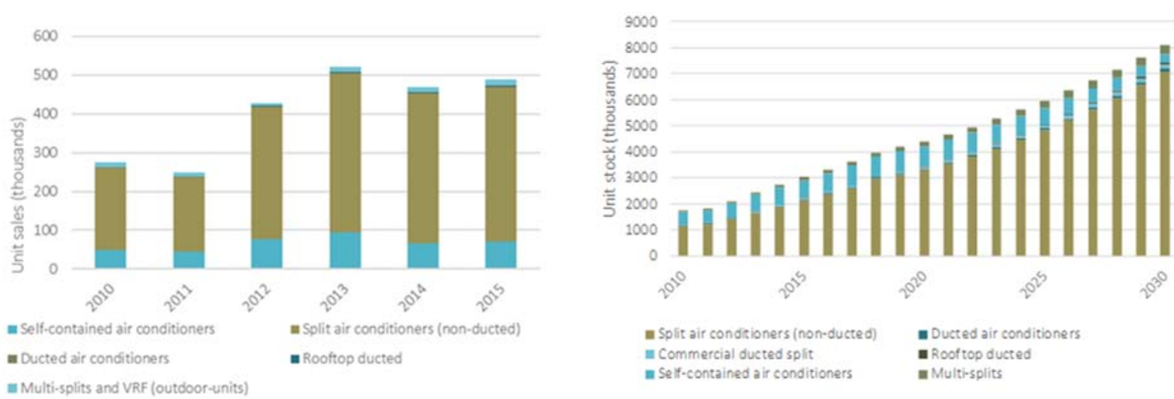
Figure: 5.11: Number of EOL domestic refrigerators and corresponding amounts of refrigerant available for management assuming a 5% collection/recovery rate (GIZ, 2017)



5.3.2 Projected EOL ODS banks and management availability - Unitary Air conditioning

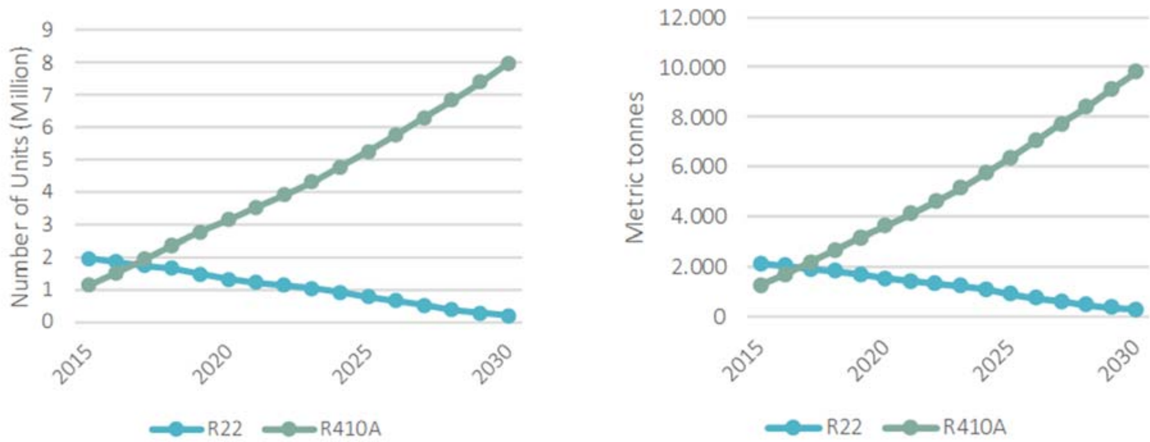
The air conditioning sector has been growing at 10% on average across the various systems over the last 5 years with unitary air conditioning, particularly non-ducted/split system type units, being is the dominant sub-sector with over 3 million air conditioning (AC) units currently in operation. It is expected to reach 8.2 million units by 2030. These projects are illustrated in Figure 5.12 below.

Figure 5.12: Unitary A/C system sales in the last 5 years and projected stock in use through 2030 (GIZ, 2017)



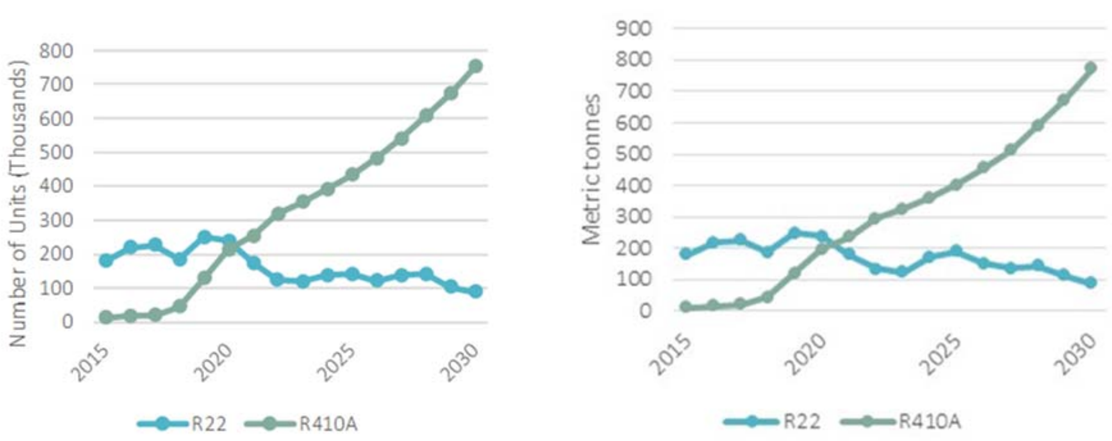
The dominate refrigerant in use has been HCFC-22 but this is rapidly being replaced by R-410A blends as illustrated in figure 5.13 below. The 2017 bank of HCFC-22 and R-410A is about equal in terms of units and refrigerant (2 million units/2,000 mt for each respectively) but by 2030 HCFC-22 units and the associated banks in service is projected to have disappeared, something that underlines this as a priority for action if it is to be addressed.

Figure: 5.13: Bank of Unitary A/C units by refrigerant and by amount of refrigerant until 2030 (GIZ, 2017)



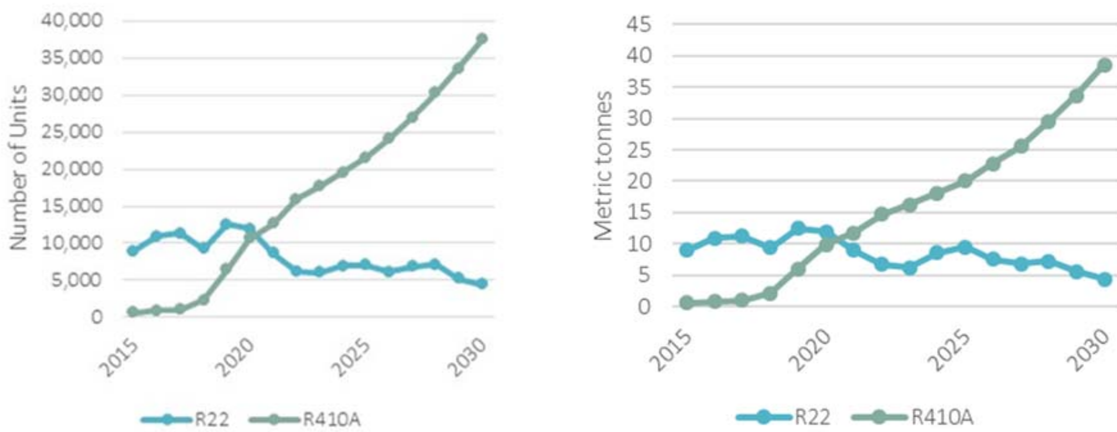
Around 200,000 HCFC-22 based units and 130,000 R-410A based units are estimated to be potentially currently available for management which translates in about 200 tonnes of HCFC-22 and 30 tonnes of R-410A. The calculations indicate that for most of the period, HCFC-22 units will relatively stable (between 100,000-200,000 units, and 100-200 mt of refrigerant). However, there will be a rapid increase in R-410A units extending beyond 2030 (estimated 750,000 units and 800 mt of refrigerant in 2030). This is illustrated in Figure 5.14.

Figure: 5.14: Projected end-of-life Unitary A/C Units and Quantities of Refrigerant Potentially Available for Recovery until 2030 (GIZ, 2017)



Noting that the above projections are based on the highest recovery rate, a lower bound recovery rate of 5% estimates dramatically lower amounts of units and associated refrigerant as illustrated below in Figure 5.15.

Figure: 5.15: Number of EOL unitary A/C units and corresponding amounts of refrigerant available for management assuming a 5% collection/recovery rate (GIZ,2017)



5.3.3 Projected EOL ODS banks and management availability – Commercial Refrigeration

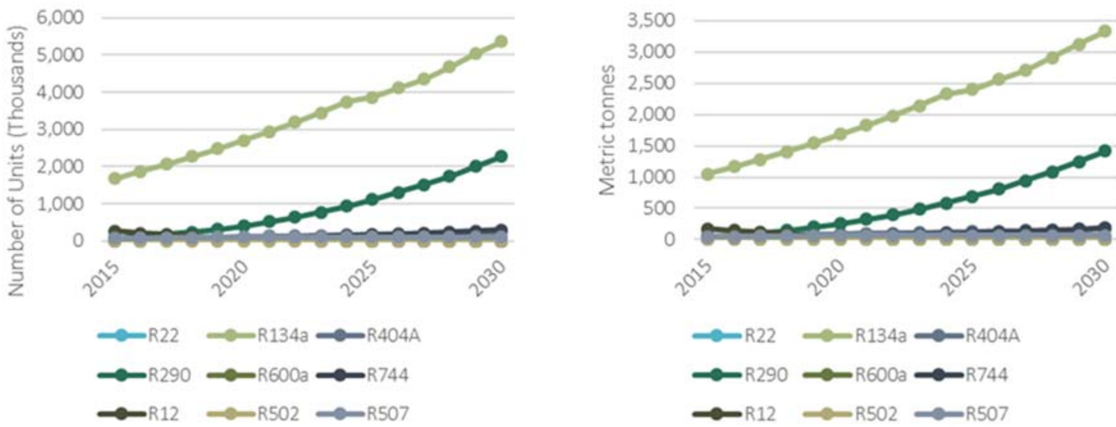
The data available for the commercial refrigeration sub-sector is somewhat fragmented and distributed between stand-alone units, condensing units and centralized systems. For purposes of the current work related to development of the EPR system, the primary interest at least initially would be on stand-alone units. The following summarizes the EOL ODS bank and management availability estimates for this case. Estimates for the whole sector are provided in referenced GIZ report.

The current sales figures of commercial refrigeration equipment are estimated to be between 250,000 and 300,000 units per year and are heavily dominated by stand-alone units. This is expected to result in the current stock of approximately 3 million units to almost 8.3 million units by 2030 (Figure 5.16).

Figure 5.16: Commercial Refrigeration sales in the last 5 years and projected stock in use through 2030 (GIZ, 2017)

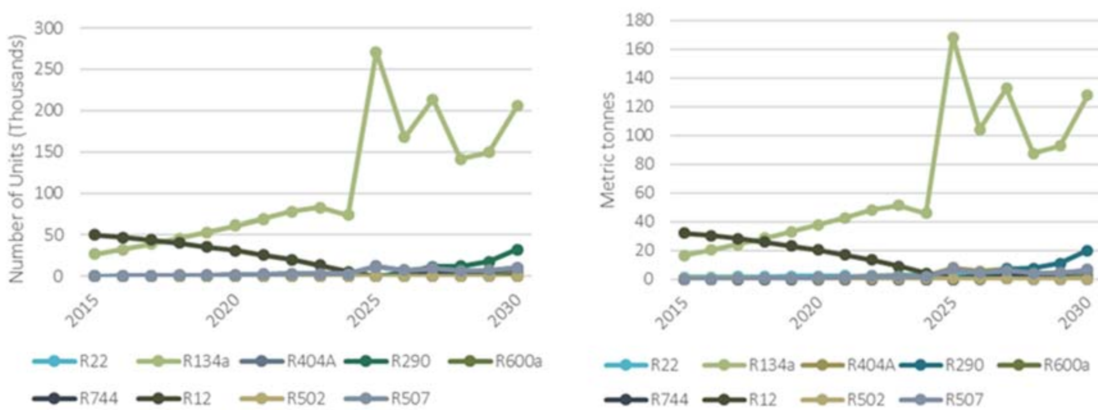
While a variety of different refrigerants is used in the sector is now dominated by HFC-134a with a remnant stock of CFC-12 and HCFC-22 based equipment. Into the future through 2030 HCFC-134a equipment is predicted account for virtually all of in-service equipment with this refrigerant bank almost tripling by 2030 when it is estimated to be 3,330 mt. Likewise, the bank of R404A based units and refrigerant becomes significant beginning in 2020.

Figure 5.17: Bank of commercial refrigeration units by refrigerant and by amount of refrigerant until 2030 (GIZ, 2017)



The above trends are reflected in the amounts of EOL ODS available for management as illustrated in Figure 5.18. While a modest availability of CFC-12 and HCFC-22 currently exists this largely disappears by 2020 after which HFC-134a is projected to be the predominant refrigerant potentially requiring management.

Figure 5.18: Projected end-of-life commercial refrigeration units and quantities of refrigerant potentially available for recovery until 2030 (GIZ, 2017)



5.4 Additional Financial Mechanisms

Several national policy initiatives are under development that may serve to provide financial incentives for the retirement of ODS and HFC based RAC equipment and could be integrated with the EPR system and financial support mechanism provided by the NSP. Those identified are:

- Fund for Non-Conventional Energy and Efficient Energy Management (FENOGE) established under the Law 1715 of 2014 that regulates the integration of non-conventional national energy system to renewable energy has been identified with the Ministry of Mines and Energy as appropriate for the funding of programmes and projects aimed at improving energy efficiency, particularly for low income consumers through introduction of equipment such as green refrigerators that promote sustainable energy use.

- Measures related to VAT rebates. Decree 2143 of December 2017, which establishes the procedure for the application of the differential sales tax of five (5%) percent on sales tax for the acquisition of environmentally friendly refrigerators (ODS/HFC free). The objective of the Decree is to promote the replacement of old refrigerators that have a high energy consumption and additionally contain refrigerant gases that destroy the ozone layer and contribute to global warming. With the environmental benefits that this measure will bring, it will contribute to the fulfillment of the commitments of Colombia for the reduction of twenty percent (20%) of its greenhouse gas emissions to the atmosphere targeted for the year 2030 and accelerate implementation of the Montreal Protocol. This tax benefit covers low income households and those refrigerators whose cost is equal to or less than about 950,000 COP. The consumer must deliver his used fridge to the producer, either directly or through third parties authorized by the same producer to act on their behalf.

5.5 EPR System Development Plan 2018-2022

Based on the work to date on developing the EPR program and the outputs from the MLF project, the intention is that over the next 5 years, the system will be applied to priority RAC sector products (domestic refrigerators, commercial refrigeration equipment, and unitary AC equipment) and will transform from its current voluntary pilot scale to a fully functioning mandatory system having sustainable financing and providing domestic environmentally sound processing of RAC equipment. An indicative target of capturing 50,000 refrigeration and 5,000 A/C units annually by 2022 is in place.

The system will operate under the overall direction of RED VERDE, established within ANDI and supervised by a representative stakeholder board including producer funders, institutional and bi-lateral funders, MADS, and ANLA (National Environmental Licenses Authority). RED VERDE will contract with licensed service providers for collect including operation of a network of geographically appropriate collection facilities, the manual processing of units including separation and secure storage of targeted hazardous components (oil, refrigerant, ODS based foam) and for environmentally sound disposal. At present, ODS and HFC chemicals are envisioned to be either managed in the present (and expanded) reclaim capacity associated with the refrigeration servicing sector or be directed to qualified destruction facilities. Based on the results from this MLF project, chemicals will be directed to TECNIMANSA (subject to expanded qualification for HCFC and HFC chemicals) and in the case of foam to utilize the developing arrangements with GERDAU/DIACO for direct feeding to EAF steel making operations or cement kiln, subject to formal qualification. The potential is also identified to move to automated processing of refrigeration units such that blowing agents are captured for destruction and recyclable components are recovered for re-sale. A reliable threshold supply of at least 150,000 units per year is estimated to justify this option, notwithstanding the significant capital investment that would be involved.

The basic financing for the EPR system operation will be provided by the producers as is now mandated as mandatory under current legislation. The anticipated significant acceleration in capture and collection is assumed to be stimulated by the incentives created under the NSP and the VAT reduction measures described above and the various national financial incentives that are expected to come into effect. The financing of the needed capacity additions for the WEEE and refrigeration service sector will be a combination of their own means and the support being provided by the financial support and associated concessionary green lending provided under the NSP. In this transition period as the EPR system moves to full sustainability and self-sufficiency, the remaining funding support from this MLF project remains a key component both in terms of practical level support UTO provides to Red Verde’s work, particularly related to public awareness, and facilitating integration with the NSP and implementation of the GIZ road map, but also funding of the destruction of CFC and HCFC refrigerant and PUR foam recovered as the system ramps up.

6.0 Discussion of Lessons Learned, Replicability, and Future Work

This section provides a general discussion of this Project's results in the context of the ongoing developments in Colombia and more broadly the overall MLF demonstration program, both in terms of contributions related to replicability and potential future MLF program initiatives in this area.

Overall, the Colombian EOL ODS demonstration project to date has shown that qualified domestic capability is available to support the environmentally sound capture and destruction of EOL ODS, specifically the primary EOL CFC chemicals (CFC-11 and CFC-12) as well as CFC and HCFC based foams. This demonstration applies to the infrastructure and technical capacity within an established refrigeration servicing sector, an expanding specialized commercial waste management capability dealing with the WEEE sector and commercial HTI rotary kiln incineration facilities. Likewise, the initial development stage of putting in place a cost effective and sustainable EPR system based on an industry administered partnership has also been demonstrated. Both these aspects, as developed to date, represent significant achievements relative to the Project's objectives and should have immediate value to the broader MLF and Montreal Protocol community for purposes of dissemination and potentially replication.

However, it is also recognized that the effort in Colombia to have in place a fully sustainable and comprehensive system to manage EOL ODS and future EOL chemicals under the MP remains a work in progress, something that will take several more years to achieve. The following discusses some of the principle issues and tasks that are identified as being required to achieve this, a discussion that may also inform initiatives by others as well as future program decisions under the MLF.

Perhaps the most significant issue that comes out of this Project overall is the fact that the practical availability of EOL ODS and ability to capture it for management is inherently problematic in practice given the nature of the waste stream. Experience where reasonable capture relative to theoretically available banks is achieved shows that this must be supported by strong national policy commitment and supporting legislation and regulation as well as constructed institutions, economic instruments and public awareness to support its capture for purposes of destruction. In the case of Colombia, there was relatively early recognition of this and the parallel process of systematically undertaking incremental development of these aspects along with development and demonstration of physical capability has occurred. This was based around setting the ground work to implementation of a mandatory EPR system that is now moving toward a sustainable model capable of achieving meaningful capture rates.

Associated with the above is the need to recognize that this process is time consuming and even in countries with advanced institutions, financial capability and unquestioned policy commitment this will take a relatively long time. This has been and continues to be in the current experience in Colombia and explains the longer than initially anticipated Project implementation period. The lesson learned from this and the complexity of having the appropriate policy, regulatory, sustaining financial, and institutional capacity in place is this should be factored into future initiatives in this area, rather than necessarily having dominate focus on developing and qualifying physical capability for capture and destruction.

Another major lesson learned to come out of the current Project is that the overall MLF program initiated a decade ago and focused on CFCs is now outdated in terms of the EOL chemicals that any system in the future will have to deal with. While over the next 5-7 years some EOL CFCs will require management, the reality is that these chemicals are is rapidly disappearing and most remaining may not appear before an effective system to capture and destroy it in significant amounts is generally in place. The window of opportunity to capture the initially targeted high ODP reduction EOL ODS is rapidly closing. While Colombia continues to address this in the near term by targeting EPR initiatives to lower income households for domestic refrigeration equipment recovery, this is will be a relatively short-term measure. The medium and longer-term priority for the mature EPR system in full operation will in fact be HCFC and HFC based refrigerants where the availability of a large bank of material can now be projected, and where the rational for environmentally sound management shifts from ODS release reduction to eliminating release of potent greenhouse gases.

A significant consequence of this change in priorities respecting EOL chemicals, is that the original scope of MLF demonstration projects being focused on the destruction of EOL CFCs has left a gap in what the availability of qualified destruction technologies and particularly that applied to facilities qualified for national use in countries such as Colombia. This gap has recently been recognized at the 29th Meeting of the Parties to the Montreal Protocol as reflected in XXIX/4[50] which requested TEAP to review the current list of approved technologies as to applicability to the destruction of HFCs now controlled under the Kigali Amendment. The TEAP has constituted a Task Force for this purpose and has submitted a report for consideration by the Open-Ended Working Group. While provisional at this time, the recommendations indicate that technologies currently approved for ODS destruction that might be applicable to HFC destruction or have a high potential for HFC destruction. This may have significance for to Colombia if rotary kiln incineration is recommended as only having high potential. The Task Force also noted that consistent with experience in this work, there is variability in rotary kiln emission performance between individual facilities and it is recommended that consideration should be given to qualification testing on the subject chemical. Additionally, it also noted that rotary kilns like a number of other technologies may be subject to issues both related environmental performance, productivity, and maintenance due to the higher fluorine content and resulting acid gas (HF) generation. This latter issue would be consistent with observations made in relation to the current results reported for this Project and could be material in qualifying the TECNIMSA facility for HFC destruction.

Based on the above, a prudent step that is recommended by this Project to be undertaken in Colombia is conducting additional qualification testing of the TECNIMSA facility with both HCFCs and HFCs. This would be most appropriately done for HCFC-22 and HFC-134a as the principal EOL chemical refrigerants anticipated in the future and perhaps for completeness one or more likely HFC blends. It would be anticipated that demonstration test results would be similar to those for CFCs on the TECNIMSA facility in terms of DRE and most emissions with the exception of HF given the apparent sensitivity to this seen in the present work. Screening of the impact of higher fluorine content at various feed rates could be readily done utilizing the current well calibrated CEMS system. A more complete test burn program involving a modest investment could also be undertaken and could serve as useful input to t future requests by the Parties for technical assessment of destruction technologies.

A final technical issue related to expanded technical qualification potentially required to support destruction capability in Colombia relates to the destruction of ODS based foam. As described in Section 4 above, test burn demonstrations have been completed on CFC-11 and HCFC-141b based foam in the TECNIMSA HTI rotary kiln facility. However, the cost of this option would be prohibitively expensive in terms of affordability to the EPR system. With some qualifications, the use of an arrangement with a domestic EAF

[50] http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/42073

steel maker would provide an affordable option, although it is unlikely that a demonstration of the required DRE specified in Montreal Protocol Decisions for dilute EOL ODS waste streams could be practically demonstrated even though it would likely be generally equivalent to other options. Similarly, a somewhat more expensive, but still potentially affordable option that is now in use would be the use of cement kilns. Neither of these options is currently approved by Montreal Protocol Decisions for dilute waste streams such as foams. Nevertheless, the absence of such an approval might be seen as an oversight in the case of cement kilns which would logically be equal in performance of a dilute EOL ODS waste stream to currently approved options of rotary kilns and municipal incinerators. Perhaps a useful additional initiative in Colombia would be to undertake a formal cement kiln demonstration test on ODS based foam in partnership with a major operator which has an interest. Extending this to representative ODS and HFC chemicals might also be useful with a view to ensuring full conformity with MP requirements of the EPR system, particularly if the destruction of foam is to be financed with remaining MLF funding. Extending this to include representative HCFC and HFC chemicals may also be of value as a potentially competitive backstop to the rotary kiln option. In both instances, this could also serve a broader purpose of providing input to any future technical assessments of destruction technologies under the Montreal Protocol.

In evaluating the general issue of foam destruction, it is also worth noting that there is limited global environmental benefit in the destruction of foam that is likely to be available and that the requirement, at least for the refrigeration sector targeted in the EPR program is relatively short term. The subject ODS based waste stream is a mixture of that using CFC-11 and HCFC-141b blowing agents, now heavily dominated by relative low ODP/modest GWP HCFC-141b. Over a relatively short period it would likely all decline given the complete conversion to cyclopentane in both domestic and imported equipment. For this reason, it may be appropriate to view this as broader waste management issue to be addressed in the context of a waste resource and energy strategy within the already existing national framework related to integrated waste management, something that is anticipated to be a priority within the GEF-7 Chemicals Management Focal area.

7.0 Conclusions and Recommendations

The following summarizes the principle conclusions that can be drawn from this work to date and applicable recommendations that can be made at this point with respect to its completion and long-term application of its results.

1. *Basic national capability for the collection and assembly of EOL ODS* for environmentally sound destruction exists in Colombia based on the well-established refrigeration servicing and developing WEEE management sectors, such that it should have the critical mass to support this aspect of the EOL management process on a commercial basis as it develops.
2. *National capability for the cost-effective destruction of EOL ODS chemicals* in the form of CFCs has been demonstrated in a commercial HTI rotary kiln at a hazardous waste facility as being qualified relative to the technical and environmental performance requirements of the Montreal Protocol (TEAP) and should have capacity to handle anticipated projected national demands for these services.
3. *Availability of EOL ODS chemicals for collection and destruction* remains the principle practical limitation to effectively utilizing this capability to reduce EOL ODS releases.
4. *Increasing the capture of EOL ODS for environmentally sound processing* to a level that would ultimately be meaningful in terms of global environmental benefit will be dependent on the aggressive implementation of the current policy and regulatory measures, and the establishment of sustainable

financing mechanisms based primarily on a mandatory Extended Producer Responsibility (EPR) system.

5. *Establishing an effective EPR system model* based on an industry based institutional approach (RED VERDE) is a significant and replicable output of this project to date that offers good prospects of scaling up to a fully developed system that is affordable in terms of incremental costs to both producers and consumers within a mandatory EPR model.
6. *The time and financial support required to develop an effective national EOL ODS management capability* should not be underestimated in countries such as Colombia noting the experience with this project relative to the Project's initial expectations and likewise will require sustaining financial support management, both national and international, over an extended period.
7. *The EOL chemicals, particularly refrigerants, that require environmentally sound management in a mature EPR system is rapidly changing to HCFCs and HFCs* as a consequence of the time frames required to develop the system as is seem in available EOL ODS bank projections. CFCs, particularly high impact CFC-12, will not be available in significant quantities while demand for elimination of HCFCs, particularly HCFC-22, and then HFCs, particularly HFC-134a, will significantly increase and be the main focus of the EPR system and particularly qualified destruction capability.
8. *Additional destruction facility qualification demonstrations are required on HCFCs and HFCs to support the requirements of the EPR system* as it develops in the next five years, particularly noting the pending recommendations of TEAP Task Force work respecting the applicability of previously approved ODS destruction technologies for HFCs as mandated under Decision XXIX/4.
9. *There needs to be consideration of qualifying cost-effective methods of managing foams containing ODS blowing agents* (particularly HCFC-141b) at least in the near term when these waste streams are generated. This Project offers insight into two practical options that might be readily available in Article 5 countries, namely cement kilns and EAF furnace facilities, both of which would require additional demonstration work with industrial partners.
10. *Colombia should successfully be able to have a sustainable comprehensive EPR system in place for EOL chemicals covered by the Montreal Protocol within five (5) years* when a critical scale for domestic refrigerators is achieved and its expansion to the unitary A/C and commercial refrigeration sectors will be well advanced, particularly noting commitments available for substantial bi-lateral international support obtained and the implementation of national financial and regulatory support mechanisms.

Appendix I: Project Implementation Timelines Component/Sub-Component/Activity 2013-18

Project Component/Sub-Component/Activity	2013				2014				2015				2016				2017				2018		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Component 1: ODS Destruction Demonstration																							
1.1 Consolidation/storage/characterization/transport of EOL ODS for Destruction Demonstrations																							
1.1.1 Supply of extraction/transfer equipment &ODS analyzers																							
1.1.2 Supply of bulk cylinders																							
1.1.3 Collection/transport of distributed CFC- 11 stocks																							
1.1.4 Collection/transport of distributed CFC- 12 stocks																							
1.1.5 Consolidation/storage of CFC-11 stocks																							
1,1,6 Consolidation/storage of CFC-12 stocks																							
1.1.7 Verification analysis of consolidated CFC-11/CFC-12																							
1.1.8 Transportation to incineration facility																							
1.1.9 Documentation and reporting																							
1.2 Manual processing of refrigeration equipment CFC-11 and HCFC-141b containing foam																							
1.2.1 Test burn foam separation, and storage – HCFC-141b																							
Test burn foam separation and storage – CFC-11																							
1.2.2 Transportation – HCFC-141b foam																							
Transportation – CFC-11 foam																							
1.2.3 Site screening of extracted foam.																							
1.2.4 EOL ODS content analysis																							
1.3 Test Burn Demonstrations for EOL ODS at selected HW incinerator facility																							
1.3.1 Test burn planning and design																							
1.3.2 Minor facility modifications																							
1.3.3 Baseline feed selection/characterization																							
1.3.4 Test Burn #1 – HCFC-141b foam, CFC-11, CFC-12																							
1.3.5 Analysis if Test Burn #1 results																							
1.3.6 Additional Facility modification/upgrading																							
1.3.7 Test burn #2 – Short Tests on CFC-11																							
1.3.8 Analysis of Test Burn #2 results																							
1.3.9 Test Burn #3 – CFC-11 foam, CFC-11, CFC-12																							
1.310 Analysis of Test Burn #3 results																							
1.3.11Test burn supervision																							
1.4 Demonstration destruction test for ODS based Foam in Electric Arc Furnace																							
1.4.1 Demonstration test planning and design																							

Project Component/Sub-Component/Activity	2013				2014				2015				2016				2017				2018		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
1.4.2 Demonstration testing																			■	■			
1.4.3 Analysis of results																			■	■	■		
1.4.4 Demonstration test supervision																			■	■			
1.5 Destruction of EPR Program Start up volumes of EOL ODS																							
1.5.1 EOL ODS collection, extraction, consolidation and transport								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.5.2 EOL ODS Refrigerant destruction																							
1.5.3 EOL ODS based foam destruction																			■	■			
Component 2.0 Technical Assistance																							
2.1 Legal and regulatory institutional TA																							
2.1.1 Regulations through which Law 1672 of 2013 on WEEE management (including RAC equipment) is regulated: Decree 284, February 15, 2018 and other resolution.			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2.1.2 Regulation by which CFC, HCFC and HFC waste will be included as part of the waste listed in Article 102 of Resolution 909 of 2008 as wastes that can be destroyed at HW - HTI facilities.																■	■	■	■	■	■	■	■
2.1.3 Tax reform in 2016 (Law 1819 of 2016 - Art. 185) establishing the differential VAT (5%) for the domestic refrigerators of the replacement program. Regulation of the measure in Decree 2143 of December 19, 2017.														■	■	■	■	■	■	■			
2.1.4 Technical guidelines for the integrated management of substances controlled by the Montreal Protocol including guidelines for ODS incineration at HTI																		■	■	■	■	■	■
2.2 Technical/business planning support for EOL ODS management under the EPR system																							
2.2.1 Design of an EPR system for EOL domestic refrigerators			■	■	■	■	■	■															
2.2.2 Legal conformation of RED VERDE as an EPR scheme.						■	■	■															
2.2.3 RED VERDE operates in Bogotá									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2.2.4 RED VERDE expands its operation to other geographic regions															■	■	■	■	■	■	■	■	■
2.2.5 RED VERDE expands its operation to other appliances as AC																			■	■	■	■	■
2.2.6 Formulation and approval of the National Appropriate Mitigation Action (NAMA) for the domestic refrigeration sector, including a replacement program				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
2.2.7 Implementation of NAMA activities																						■	■
2.3 Public Consultation and Information																							
2.3.1 Initial survey dedicated to consumers on EOL domestic refrigerators management			■	■																			

2.3.2 Consumers awareness rising with regards to the environmental benefits and responsibilities of ESM of EOL domestic refrigerators
2.3.3 RED VERDE's visibility
2.3.4 Clear communication of the different Red Verde strategies to producers, importers, distributors, stores.
2.4 Technical Oversight and Overall Project Technical Report
2.4.1 Oversight and technical advice on the overall project implementation (international expert)
2.4.2 Technical reports to MLF
Component 3.0 Project Management/Monitoring/Evaluation
3.1 Coordination of project's activities
3.2 Periodic reports to UNDP and MADS

Appendix II: Photographic Illustrations of the TECNIAMSA Facility and Process Components

Photo 1. Primary combustion chamber (rotary kiln)

Photo 2. Secondary combustion chamber

Photo 3. Automatic Control System for the combustion and post-combustion APC processes

Photo 4. Quench unit and dry scrubber

Photo 5. Gas Extraction Fan

Photo 6. Continuous emission monitoring system (CEMS)

Photo 7. Stack

Appendix III
Survey of National EOL ODS Destruction Demonstration Projects

Country	Approval	MLF	IA	Destruction Option	Implementation Status/Remarks
Algeria	2014	250,000	UNIDO	Cement kiln	Status unknown
	2014	375,059	France		
Brazil	2012/ 2014	1,490,600	UNDP	National HW facilities – HTI, Plasma Arc Initial parallel development of two de-manufacturing plants	Project restructured to focus on competitive selection of HW disposal facility Implementation restarted based on commercial HTI facility
China	2012	1,227,885	UNIDO	Existing HTI/plasma arc facilities	Under implementation Destroyed 88 mt CFC-12 (Sept 2017)
China	2012	900,000	Japan		
Colombia	2012	1.195,000	UNDP	National HW HTI facility for CFCs/HCFC EAF steel furnace/cement kilns for foams Integrated with existing refrigeration servicing system and HW service providers. EPR funding and energy efficiency incentives being phased in to sustain system	HTI test burns completed to qualify domestic HTI facility 2016 Trials on refrigerator components containing foam in EAF completed in 2017 Integrated with expanding ERP financed RAC equipment collection - 5 cities Planned Processing of 300,000 refrigerator units
Cuba	2010	525,500	UNDP	CFC-12 in cement kilns	Complete Destruction quantities and performance testing results not yet reported
Georgia	2013	55,264	UNDP	Export to EU HTI facilities	Complete – 2.13 mt CFC-12 destroyed Export combined with GEF POPs project
Ghana	2011	198,000	UNDP	Initial intent to purchase ISADA unit (dropped), Export to EU HTI facility	Complete - 2.2 mt CFC-12, 5.2m t MB destroyed Export combined with GEF POPs project disposal

Country	Approval	Grant	IA	Destruction Option	Implementation Status/Remarks
Lebanon	2014	123,475	UNIDO	Export to EU HTI facility	No information
Mexico	2011	927,915	UNIDO	Domestic plasma arc facility and cement kiln	Completing - 113 mt CFC-12 destroyed Report successful demonstrations on commercial plasma arc facility and cement kiln
	2011	500,000	France		
Nepal	2009	157,200	UNEP	Export to HTI facility	Completed – 10 t CFC-12
Nigeria	2012	811,724	UNIDO	Export to HTI facility	Under implementation. Limited amount of EOL ODS captured
Turkey	2012	1,076,250	UNIDO	Initial intent to export to commercial plasma arc facility (potentially qualify national HTI unit in future)	Currently being restructured due to EOL ODS availability and export barriers
E. Europe	2013	274,480	UNIDO	Export to HTI facility	Completed 33mt EOL ODS destroyed
E. Europe	2013	75,000	UNEP	Export to HTI facility	
Other MLF Projects Outside the Formal Program					
Ecuador	2008	500,000	UNIDO	Initial purchase of ASADA unit but not utilized Currently developing cement kiln option	Continuing implementation Positive test burns on CFC-12 reported with 2.5 mt CFC-12 destroyed,
Trinidad Tobago	2015	Unknown	UNDP	ASADA unit initially planned Bow pursuing a cement kiln option	Under development
Costa Rica	Unknown	Unknown	Unknown	Cement kiln	Under development
GEF CEIT Projects					
Belarus	2018	N/A	UNDP	Export to HTI facility or development of a domestic plasma arc facility	Potential opportunity to combine with POPs project

PILOT DEMONSTRATION PROJECT ON ODS MANAGEMENT AND DISPOSAL IN NIGERIA

Draft Final Report

Federal Ministry of Environment, Nigeria and UNIDO
23 April 2018

1. Introduction

The Federal Republic of Nigeria was provided with financial assistance from the Multilateral Fund for the implementation of the Montreal Protocol on substances that deplete the Ozone Layer. Following Decision XX/7 of the Meeting of the Parties, the Executive Committee decided at its 58th Meeting in July 2009 (Dec. 58/19) to fund a limited number of demonstration projects for the disposal of obsolete and unwanted Ozone Depleting Substances. Consequently, at its 67th meeting, a pilot project for ODS waste management and destruction in Nigeria at the amount of US $911,724, plus agency support costs of US $68,379 was approved for implementation by UNIDO in its capacity as an implementing agency of the Montreal Protocol.

2. Objectives

The project aimed to establish a model to show the best way to manage the unwanted ODS banks in Nigeria. The preparatory phase of the project identified existing stocks of ODS collected by Oil Companies from their installations in Nigeria and stocks collected from the chillers (under AFROC project) in Nigeria with the funding from the MLF. The initial plan of the project was to seek subsequent carbon market co - financing from CAR (Climate Action Reserve) after destruction in the United States. The aim was also to provide capacity building activities for operators in the waste management sector and end-users on the proper handling and management of waste ODS before and leading up to their disposal.

3. Activities Implemented

a) Inception Workshop

The inception workshop took place in November 2013. The project was introduced to the audience made up of government agencies, end-users, servicing companies and waste management companies. Participants were also introduced to the various types of destruction technologies and best available techniques for safe disposal of ODS wastes.

b) Aggregation Activities

A local contractor was hired to aggregate waste ODS in the country. This activity started off in early 2014 with a technical workshop by international experts to train technicians on safe collection, transportation and storage of ODS wastes including testing, correct labeling and documentation procedures.

i. Capacity Building Workshop

A capacity building workshop for ODS Collection and Aggregation was held in June 2014. The attendees at this workshop were employees from the selected local contractor for aggregation, staff of Federal Ministry of Environment, National Ozone Unit and other relevant organizations such as Nigeria customs, National Agency for Food and Drug Administration Control (NAFDAC) and Nigerian Association of Refrigeration and Air conditioning Practitioners (NARAP).

The topics covered in the capacity building workshop are as follows:

- Ozone Layer depletion and Montreal Protocol
- National obligation and response
- Demonstration project for disposal of unwanted ODS in Nigeria
- Carbon market co-financing and Climate action Reserves (CAR) protocol
- Plan for collection, storage and transportation of ODS for disposal
- Record keeping and database development
- Safe handling, transport and storage of ODS
- Case study: Nepal ODS disposal project

The training gave a good foundation to the participants on the background of the project, roles of various partners and the requirements for safe handling, labelling, transport and storage of ODS wastes.

Picture 1: Participants at the Capacity Building Workshop- June 2014

ii. Aggregation of Stocks

Companies and end-users that had been identified during the preparatory phase were contacted to enquire about their stocks of ODS. In many cases there were no replies so the contractor had to visit most companies. Stocks of ODS reported in most cases were not found. There were many reasons given. Some of the oil companies had disposed of the stocks themselves; some other companies had sold them while some claimed no knowledge of any stocks. This is probably due to change of management. In some cases, stocks reported as CFC-12 were actually halons.

The total ODS collected is shown below.

Location	**Source**	**Type**	**Amount/kg**
Lagos	2 Chiller Plants	CFC-12	399.5
Port-Harcourt and Lagos Ports	NAFDAC seizures	CFC-12	1099.29
Total Amounts		**CFC-12**	**1,499 kg**

In addition to the CFC-12 collected, stocks of halons were either sighted or in some cases requested for collection. Since these were not eligible for the project, they were not collected. The amount of halons readily available for collection was estimated around 4 tonnes including those already at the ozone village. However, not all halons identified are in this estimate. All ODS collected were tested and weighed before aggregation and documented. All stocks were found to be CFC-12 with varying levels of contamination.

The collection activities were halted as no new stocks of CFC-12 were found and new inquiries repeatedly turned out to be halons. Most of these halons are in the hands of government agencies in the defense and power production sectors.

c) Policy and Legislation

i. Overview of Previous ODS and Waste Management Legislation

Since becoming a party to the Montreal Protocol, Nigeria has come up with several policies and legislations, the implementation of which has led to the successful phase out of CFCs as on 1st January, 2010. The National Environmental Standards and Regulations Enforcement Agency (NESREA) published 24 separate sectoral regulations governing the environment since 2009 alone. The regulations most directly related to ozone depleting substances and their disposal, are set out below:

- National Environmental (Ozone Layer Protection) Regulations 2009: These regulations place a total ban on CFCs and some control measures on others including HCFCs entering the country. They have the following salient features:-
  - Section 2 prohibits the release of ODS into the atmosphere. Sub-section 2(3) specifies that

  "No person shall dispose of equipment or fire extinguishing equipment that contains an ozone-depleting substance without first ensuring that the ozone-depleting substance is recovered".

  This regulation served as the driver for collection of ODS in industry after most of the CFC-based equipment were converted.
  - Sections 13 and 14 deal with import and export permits including granting export permits for disposal of ODS.
  - Section 20 sets out requirements for application and approval of the set-up of an ODS destruction facility within the country.
- National Environmental (Sanitation and Waste Control) Regulations 2009: These regulations govern both municipal and industrial sanitation and waste management.
  - Section 1.28 specifies that importers of different listed products including refrigerators should undertake product stewardship including buy-back of End-of-Life products for recycling. This means that equipment importers have a vested interest in investing in a refrigerator replacement, recycling and disposal scheme in Nigeria.
- The Harmful Wastes Act: This is the main legislation governing the handling, transportation, export and import of hazardous wastes in Nigeria. It prohibits the carrying out of all these activities without lawful authority.

ii. Project Activities related to Policy and Legislation

Two workshops on the amendment of the Ozone regulations were held. The first workshop had the following objectives:

- Identify the gaps in the ODS Regulation;
- Inform stakeholders about planned introduction of the mandatory destruction of unwanted ODS and product stewardship in ODS containing equipment;
- Share experiences and ideas for review of regulations;

The second workshop had the following objectives:
- Share draft changes to the regulations;
- Share stakeholders' views on the changes;
- Make further amendments to the draft.

The draft was then reviewed by UNIDO and returned back to the government for signature and gazetting.

The new ozone regulations, 2016 make provisions for mandatory destruction of wastes, guidelines for destruction facilities including emission limits, extends responsibility of end-of-life waste equipment to producers/suppliers, etc. Extended Producer Responsibility (EPR) regulations are now in place for the electronic/electrical sectors. This means that for new refrigerators, future recovery of refrigerants at their end-of-life should be the responsibility of the private sector. Training sessions on e-waste collection and management were carried out through the EPR development process and well-attended by government agencies and private sector. The Ozone regulations were streamlined with the EPR regulations to ensure that no gaps were left.

d) Final ODS Destruction Process

Officials from the Federal Ministry of Environment Nigeria and UNIDO inspected 4 disposal facilities and invited 2 of them to bid for the disposal of wastes CFCs. The company selected has a proven track record of hazardous waste management for multinational companies and experience of managing CFC wastes specifically from collection to recycling.

i. Haulage

The collected stocks of ODS waste were tested for purity at the storage facility before loading. They were then transported safely to the waste destruction facility in Port Harcourt, Nigeria after the relevant permits from the government were obtained.

ii. Reception

At the waste destruction facility, the wastes were inspected and tested again to verify that the actual consignment matched the consignment records. The cylinders were weighed and recorded accordingly. The cylinders were then stored in the waste storage building pending test-burn and final destruction.

iii. Rotary Kiln Incineration Process

The destruction process employed by the contracted facility is rotary kiln incineration. The ODS is fed into a high temperature two chambered incinerator and destroyed through thermal oxidation. The incinerator operates between 1000 and 1500°C temperature. It is designed to eliminate Incomplete Combustion Products such as furans and dioxins (salt flux). The ODS is fed into the incinerator (rotary kiln) through a feeding system (from the ODS container or cylinder through an air-line in to the burner for combustion) with automated flow controls and a system interlock (for emergency waste cut-offs).

iv. Incineration Integrity Assurance

- The incineration process is highly efficient and effective and achieves 99.99% Destruction
- Removal Efficiency achieved through the following technology:
- High Temperature Two chamber burning system: Totally destroys the ODS and Combustion byproducts.
- Two seconds Residency Time: It ensures flue gas is sustained at about 1000-1500°C for at-least two seconds for complete breakdown of all the toxic substances.
- Acid gas treatment: Acid gas scrubbers are used to remove halogen acid gases through lime slurry injection for neutralization.
- Heavy metals Removal: Heavy metals are adsorbed on injected active carbon powder, which is collected by filtration of the particles.
- Particulate Matter/dust Control: Particulate is collected by a highly effective particle filtration system that can reduce the matter to less than 2.02 g/GJ (grams per energy content of the incinerated waste)
- Continuous monitoring System: For emission rates measurements and composition analysis. This is an integration of two Differential Optical Absorption Spectroscopy Analyzers (UV + FTIR) for measurements of gas concentrations, in combination with other instruments providing e.g. flue gas flow rates, concentrations and PM unit counter for particulates concentrations. The following data is captured on the monitor for recording;
  - SO_2
  - CO/CO_2
  - NO_x
  - HCl/Cl_2
  - HF
  - Particulates
  - Polychlorinated dibenzofurans (PCDFs)
  - Polychlorinated dibenzodioxins (PCDDs)

Picture 2: View of Rotary kiln incinerator and Scrubber System

The disposal process is ongoing. Wastes are being disposed of on a batch basis and the draft report will be updated as soon as disposal is concluded.

4. Financial Status

Approved	Obligated	Disbursed	Balance of Funds
911,724	44,487	219,288	647,948

The above table shows the status of funds approved for the project. This table will be updated once destruction is complete and all outstanding payments are made. The balance of funds will be returned to the Multilateral Fund.

5. Monitoring and Verification

The labelling, documentation and testing procedures carried out were done according to the ODS collection protocols accepted by the carbon markets. Information was recorded about the source of ODS, type of system, location, etc. The ODS were always weighed and tested for quality in the presence of another person. Data on the ODS collected was uploaded unto an online database accessible by UNIDO.

6. Conclusions and Lessons Learned

a) The capacity building efforts for waste collection, labelling, storage and destruction were very beneficial as they enlightened the waste management sector about the requirements for ODS disposal and even disposal of other hazardous wastes. Visits to companies in the sector showed that the awareness was still there and some companies had even taken steps to upgrade their facilities to accept ODS wastes.

b) Data collected during the preparatory phase may have been correct but during the time that elapsed between collection of data and approval of the project, actions were taken by waste owners that affected the project. For future projects, perhaps transfer of ownership could be initiated pending project approval.
c) Since only the destruction of wastes was eligible for funding, it restricted the choices available for the management and disposal strategy. It would be beneficial if for future disposal projects, both collection and destruction are eligible and instead a cost-effectiveness threshold is applied to reduce total costs borne by the Multilateral Fund. This would give countries greater flexibility in designing projects that fit their national circumstance.
d) Halon wastes were more readily available in the country but unfortunately were not eligible for inclusion in the project. There appears to be little demand for recycled halons within the country as well so these wastes will continue to build up.
e) It is important that the final destruction is being done in the country as neighbouring countries with small amounts of waste stocks have indicated interest in the outcome of the project so that they can have a nearby destination for their wastes. The capacity to fabricate mobile destruction solutions also exists within the country.

Final Report

TUR/DES/66/DEM/99 - UNIDO

DEMONSTRATION PROJECT FOR DISPOSAL OF UNWANTED OZONE DEPLETING SUBSTANCES (ODS) IN TURKEY

PRESENTED TO THE
81ST MEETING OF THE EXECUTIVE COMMITTEE
OF THE MULTILATERAL FUND FOR THE IMPLEMENTATION
OF THE MONTREAL PROTOCOL

April 2018

Executive summary

As implementing agency of the Multilateral Fund for the implementation of Montreal Protocol on ozone depleting substances, UNIDO developed and carried several ODS destruction programmes.

The 66th ExCom of the MLF approved the demonstration project for disposal of unwanted ozone depleting substances (ODS) in Turkey at the funding level of USD 1,076.250.

Preliminary project expenditure is US$ 598,354 USD.

The objective of the project was to establish a sustainable and integrated business model for an efficient waste management system of ODSs, by institutional measures that will organize the existing recovery and collection systems in the country into an integrated and efficient collection validation and valuation system.

The project aimed to cover the disposal of chlorofluorocarbon (CFC-12) from the domestic refrigerator sector of Turkey. The expected amount of ODS waste to be destroyed under the pilot project was 103.72 metric tonnes (MT) of CFC-12, collected in Turkey. However, the refrigerant banks in the country proved to be in many cases mixtures of sized all types of refrigerants from the market, and as a consequence, not all quantities found under the inventory could be undertaken for being financed by the project, that was developed to address mainly CFC 11 and CFC12.

Implementing partners:

- National Ozone Unit and UNIDO local Team
- UNIDO HQ, Project Management Team
- Pan Gulf Industrial Systems
- Remtech

Strategy: Collection of 103.2 mt CFC-12 in the domestic refrigeration sector from the MLF "seed money" – incentive provided by Pan Gulf, then destruction in an accredited facility in the United States. Complementing technical assistance activities (health, safety & environment training, institutional strengthening, adaptation of legislation, awareness raising).

In total, 9.162 metric tonnes (MT) of CFC 12 containing waste in relevant percentage were destroyed.

Private contribution of the quoted stakeholders has been achieved from technical point of view, since relevant knowledge was shared with the countries stakeholders, however the destruction of thelimitted CFC 12 quantities in the US facility was not found financially acceptable.
The waste was treated in European facility selected upon international bidding, in Poland
The project also served to demonstrate synergy with national stakeholders for the management of ODS stocks and wastes, and thus contributing to the knowledge base on current issues under discussion by TEAP. As result, it is expected that the lessons learnt under this project may be beneficial to other A5 countries.

Through an established regional information and knowledge sharing platform related to ODS destruction activities in the Europe and Central Asia (ECA) region, the Government of Turkey exchanged lesson learnt and good practices on how to implement the approved pilot ODS destruction project.

Background information

In the context of the Montreal Protocol on Substances that Deplete the Ozone Layer, chlorofluorocarbons (CFCs) were mostly phased out in developing countries (Article 5 countries of the protocol) by 2010. The main intermediary replacements of CFCs are hydrochorofluorocarbons (HCFCs), which are also ozone depleting substances (ODS) subject to a phase-out schedule.

Parties to the Montreal Protocol (MP) have agreed on the fact that most ODS management plans implemented under the protocol are focused on recovery to reclaim and recycle and that active consideration needs to be given to the destruction of ODS arising in this cycle. In this context, the Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol (ExCom) decided at its 58th Meeting (July 2009) to fund a limited number of demonstration projects for the disposal of ODS.

Further, the Meeting of Parties requested the Executive Committee in its Decision XXI/2 to set a window for funding for Disposal and Destruction of ODSs. This window is reserved to Low-Volume Consuming countries (LVCs). The rationale for this Decision provides the opportunity to look at common solutions to address the question of disposal/destruction of stockpiles of unwanted ODSs in a region. Regional approaches may bring useful solutions for LVCs - countries in which disposal/destruction facilities may not be available - to address existing ODS banks.

In this context, the Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol at the 66th Meeting in April 2012 approved the pilot project "Demonstration Project for Disposal of Unwanted Ozone Depleting Substances" to be implemented by UNIDO in cooperation with the Government of Turkey, with a funding of USD 1,076.250. This project is submitted in line with decision 58/19 and addressed the destruction of 103.72 metric tonnes (MT) of waste ODS in the country. The project aims to cover the disposal of a chlorofluorocarbons (CFCs 11 and CFC-12) from the domestic refrigerator sector of Turkey.

The cost of the project was agreed at the level of US $1,076,250 plus support costs of US $80,719 calculated at US $10.37/kg which is lower than the threshold of US $13.2/kg provided for in decision 58/19.

Turkey's pilot demonstration project seeks to demonstrate a sustainable business model for ODS waste management from collection to disposal using Multilateral Fund assistance as seed money to destroy unwanted ODS and generate carbon credits. This pilot project for Turkey covers already collected ODS waste as well as additional amounts collected through a number of recovery and collection systems in place at the local level. Turkey is a country with the potential to collect significant amounts of refrigerant waste, taking into account the consumption patterns in the country.

The aim of the ODS disposal pilot project is the collection, verification in the authorized recovery centers and then incineration for destruction of the Chlorofluorocarbons (CFC) phased out by 2005, especially in the Refrigeration and Air conditioning (RAC) sector. With the mentioned project, as well as realization of this target, the establishment and operating of a nationwide ODS collection, registry, recovery, monitoring and destruction system will be ensured. The special consideration of benefiting from carbon market opportunities included to the implementation method of the project, developed in close cooperation with the relevant public and sector institutions, reflects its originality not only being the first of its context, in the country. In the project document, Turkey proposed to use carbon credits to fund changes in legislation and to ensure long-term sustainability of the project.

Objective and activities

The objective of the project was to put in place institutional measures that will organize the existing recovery and collection systems in the country into an integrated and efficient collection validation and valuation system, which will support sustainability of the project in the future. Private and public sector cooperation had already been sought for this initiative through consultation workshops held during the project preparation process. The expected amount of ODS waste to be destroyed under the project was 103.72 metric tons of CFC-12 in the refrigerator sector in Turkey.
The export of ODS waste for destruction has been the selected method of disposal in Turkey.

Regulatory framework related to ODS and waste management

The legislation on ODS and waste management gives the authority of the regulating certification and monitoring of waste recycling and recovery activities to the Ministry of Environment and Urbanization (MoEnU), Directorate General of Environmental Management. Work is ongoing to adapt the system to the requirements of the EU legislation, under the coordination of Ministry of Environment and Urbanization and in close cooperation with the relevant institutions.

Project Activities

The major project activities included several categories of activities for the disposal of ODS namely collection of ODS waste at national level, transportation of ODS waste, storage and destruction, however it only received funding from the MLF for the later three activities in relation to the existing stock of 103.72 metric tonnes of CFC-12 in line with the interim guidelines for the funding of demonstration projects for the disposal of ODS.

The project also aimed to raise the awareness and commitment of relevant stakeholders toward the project topic including development and delivery of a training programme.

In Turkey, there are government-authorized recovery and reclamation centers established in three cities, Ankara (TUHAB), Istanbul (ISISO) and Izmir (ESSIAD). There are also numerous smaller recovery and collection industries, which feed into these larger centers.

The expected amount of CFC-12 for incineration is estimated to be 103.72 MT, based on the data on the already collected and recorded quantities provided in the below table (Table 1).

Source of collection	Expected amount of CFC-12/ MT
ASO Recovery Center (TUHAB)	0,62
Metal Goods Craftsmen Federation (MESF)	5,1
Service Shops (members of MESF)	3
ESSIAD	20
Other sources (reported by servicing companies for refrigeration and air-conditioning equipment, responsibility programmes, etc)	75
Total	**103.72**

Table 1: Estimated amount of ODS-waste to be disposed/destroyed under the project

Aggregation of already collected ODS at central facility/storage

Collection and aggregation of already collected ODS waste was performed on the national level. The RRR canter TUHAB was equipped with equipment and tools necessary for proper aggregation at the national level.

Photos 1-3. ASO Recovery Center (TUHAB). Collection and aggregation of already collected ODS waste.

Supply of 10 standardized cylinders and tools were delivered to the recycling center that organize the collection and the preparation for shipment for destruction.

Chemical analysis

Chemical composition and analysis of collected ODS waste mixtures was important step due to following reasons:

a) to determine the quantity of ODS waste that will be destroyed under the pilot project;
b) to reduce the destruction costs. Cost estimates provided by eligible destruction facilities indicated 25-30% higher costs for destruction of waste mixtures without chemical analysis of their composition.

The certified laboratory for composition analysis of the refrigerant mixtures stored in the recycling center was selected.

CFC – based refrigerant waste stored in Turkey

Refrigerant	Composition	Amount (kg.)
R-11	Trichlorofluoromethane	1,755
R-12	Dichlorodifluoromethane	7,407
	Sub-Total	**9,162**

Selection of ODS destruction technology and destruction facility

The project aimed to develop a sustainable business model for ODS waste management from collection to disposal. To do this, it was necessary to export the ODS to a United States of America-accredited facility. The absence of expected revenue from carbon markets, and difficulties in collecting the foreseen amount of ODS waste has led to a redesign of the disposal strategy.

Turkey have chosen to export their ODS waste for destruction to a destruction facility outside the country. The Government made this decision based on costs, ease of operations, and time for destruction.

The countries in European Union (EU) were considered because of its geographical proximity and the sustainability of the scheme in the future, when the Turkey might become a member of the European Union (EU). Technology and Economic Assessment Panel (TEAP) standards and criteria related to the approved destruction technologies in the European Union were the base for selecting eligible destruction facilities. Within the European Union (EU), ozone-depleting substances (ODS) are covered by Regulation (EC) No 1005/2009 (known as the ODS Regulation).

Twenty-eight licensed facilities in thirteen European Countries were identified that met the defined criteria. The list of destruction facilities in EU countries that allow import of ODS waste for destruction is contained in Annex 1. Through international bidding procedures the Polish destruction facility “SARPI Dąbrowa Gornicza” was selected.

Transport from Collection Centers to ODS Disposal Centre in the Poland

The ODS waste from Turkey was shipped in 2017 and the destruction combined with that of ODS waste from Montenegro, where UNIDO was implementing a similar project funded by the Multilateral Fund [Demonstration of a Regional Strategy for ODS Waste Management and Disposal in the ECA Region (EUR/DES/69/DEM/14)].

Ten (10) cylinders were sent for destruction to Poland by the Turkey Halon Bank (TUHAB). The waste from Turkey safety arrived to SARPI Dąbrowa Górnicza at 10 May 2017. The quantity of waste sent to the destruction facility in Poland was 9,162 metric tonnes (MT).

The shipment was subject to rules and permitting requirements stipulated in the Basel Convention. The permits were obtained by the local beneficiary Recovery & Recycling (RRR) facility. There were costs related to obtaining of all necessary permits – export permits from the country, transit permit from each transit country, import permits from the destination country in which the destruction facility is located.

Regional cooperation on ODS waste disposal and knowledge sharing platform

The programme of pilot projects in the regions, which started in 2013, also included a platform for exchanging experience through regular meetings. In addition, a core group of representatives of the pilot projects has been created which meets annually and enables a direct exchange of experience between the projects.

In 2013, UNIDO in cooperation with UNEP organized the kick-off meeting related to ODS destruction activities in the Europe and Central Asia (ECA) region in Vienna, Austria, with participation of ozone officers from Albania, Bosnia and Herzegovina, Croatia, Macedonia FY, Montenegro and Turkey. In the workshop, preliminary information concerning the ODS disposal needs in Article 5 countries in the region are collected for discussion of further actions to be taken.

Photo 4: Kick-off meeting related to ODS destruction activities in the Europe and Central Asia (ECA), October 2013, Vienna, Austria

Regional cooperation framework

The platform for sharing experience among the countries consists of regular workshops on how to develop a waste management and disposal strategy. A range of annual workshops on ODS waste management and disposal (Croatia 2014, Romania 2015) bring together experts from around the world to share experience and lessons learned.

UN Environment for example, in the 2015 Regional Ozone Network thematic meeting on implementation of HCFC phase-out management plans (HPMPs) for Europe & Central Asia (Bucharest / Romania, 29 September – 1 October 2015), representatives of the participating countries namely Albania, Bosnia and Herzegovina, Georgia, Macedonia FYR, Serbia, Turkey and implementing agencies (UNDP, UNEP,UNIDO), presented their experience related to disposal of ozone depleting substances, participated in discussion on a need of Article 5 countries to address the problem of disposal of contaminated CFCs that cannot be re-used, pointed out the need to take into consideration associated costs of transportation and destruction and need for more information on reclamation and destruction technologies to address these issues in the future.

Photo 5. Regional cooperation forum at Regional Ozone Network thematic meeting ECA. October 2015, Bucharest, Romania.

Key findings and lessons learned derived from experiences with the regional approach were summarized and shared among the participating countries from the region, namely Albania, Macedonia FYR, Serbia and Turkey.

Through an established regional information and knowledge sharing platform related to ODS destruction activities in the Europe and Central Asia (ECA) region, the Government of Turkey exchanged lesson learnt and good practices on how to implement the approved pilot ODS destruction project.

Awareness raising and training activities

The Ministry of Environment and Urbanization (General Directorate of Environmental Management Department of Climate Change) in cooperation with UNIDO, organized the national training workshops on ODS waste disposal for the main stakeholders involved in ODS waste management in Turkey.

Three national training workshops on aggregation of ODS stocks for destruction and improvements in the RRR system were organized in Ankara (14 March, 2013), Istanbul (18-19 March, 2013) and Izmir (21-22 March 2013). The main goal of the workshops was:

- to build the capacity of major stakeholders involved in ODS waste management (representatives of RRR centres, companies and association representatives, vocational school teachers, technicians, national experts on ODS management, etc.);
- to address the challenges and opportunities for the collection, recycling and destruction of ODS;
- to review and discuss key steps for implementation of disposal activities, such as data survey, laboratory analysis, training, aggregation, transportation, verification, destruction and monitoring.

Representatives from the Ministry on Environment presented their best practice approaches for the management and destruction of existing ODS banks. The training workshops were attended by approximately 135 participants (not including the project team and the experts acting as resource participants from the private sector, projects counterpart)

Counterpart organizations

The counterpart organizations involved in this project were the Ministry of Environment and Urbanization of Turkey, more specifically the National Ozone Unit (NOU), which works, together with the implementing agencies of the Montreal Protocol, on the development of strategies, policies and regulations governing the production, import and consumption of ozone-depleting substances and equipment containing such substances. Besides the NOU, the following relevant institutions were involved in the project implementation: Waste Management Department of the Ministry of Environment and Urbanization, Turkish Municipalities Union, Recycling & Electronic Equipment Demanufacturing Facilities (ULUSOY SDK, EXITCOM Co.), Recovery and Reclamation Centers (TUHAB, ISISO, ESSIAD), Professional sector associations (Metal Craftsmen Federation) and Refrigeration and air-conditioning sector and servicing enterprises.

Cost considerations of the disposal activities

The pilot demonstration project on ODS-waste management and disposal for Turkey was approved at a funding level of US $1,076,250 plus agency support costs of US $80,719 for UNIDO. The cost of the project was calculated at US $10.37/kg which is lower than the threshold of US $13.2/kg provided for in decision 58/19. The residual balance upon financial completion of the project will be returned to the Multilateral Fund.

This MLF-funded project implemented by UNIDO aimed to demonstrate the safe, environmentally sound and efficient disposal of 103.72 metric tonnes of ODSs waste in Turkey. The actual amount of ODS waste destroyed is 9,162 metric tonnes (MT) CFC 11 and 12.

The actual total cost of the project is US$ 598,354.

Lessons learned, Key Findings and Conclusions

The accumulated lessons learned and key findings from this destruction pilot project provided valuable knowledge base and were shared with other countries in the region.

a) To allow proper collection and aggregation of ODS waste at the national level, RRR centres need to be well equipped with ISO standard cylinders and other necessary tools and equipment.

b) Assumptions related to the functioning of the ODS waste collection system in the country were not accurate, resulting in much lower availability of ODS waste, and leading to a re-design of the disposal strategy.

c) The technical knowledge gained in Turkey is thought to be replicable in neighboring countries to the European Union (EU).

d) Projects proved to be a good source of information to allow policy-makers to modify legislation to address ODS waste destruction appropriately.

e) Long-term sustainability of ODS waste management requires involvement and cooperation from collection centres.

f) Related to management and financial set-up: As the project in Turkey demonstrates, the status of voluntary carbon markets prevents carbon revenue generation, regardless of the amount of ODS waste to be disposed of. The revised implementation plan is looking into the most cost-efficient way of managing the ODS waste collected while paying attention to the interests of Turkey when it comes to aligning their ODS waste management practices and procedures with those in the EU, given Turkey’s candidate-member status.

g) Related to training and capacity building: training on how to manage ODS waste contained in equipment upon arrival at collection centres seems to be needed.

h) The project provides for transfer of knowhow, capacity development in the field of management of ODS containing waste and treatment options.

i) Changes needed to legislation/regulation: Revision of the legislative waste framework has to be done to ensure that ODS waste management and disposal is regulated. This is ongoing work that will be finalized upon completion of the project. The development of the national legislation reflects Turkey's intention to join the EU and its effort to transpose European Union regulations into national laws.

j) Co-financing can only be made available from revenue obtained at collection centres from valuable components and materials contained in the equipment reaching the centres.

k) In Turkey the ODS waste available was calculated on assumptions mostly related to the functioning of the ODS waste collection system, which proved to be misleading. This led to a redesign of the ODS disposal strategy.

l) The ODS waste collection system, which proved to be misleading. This led to a redesign of the ODS disposal strategy.

m) Destruction costs:
    - May range from 1.64 to 2.15 Euros/kg and the price differences are not caused by different types of technology since all interested bidders used rotary kiln incineration
    - Transportation costs ranged from 0.36 to 0.66 Euros/kg and the price differences were not related to the transport distance
    - The **mode of storage** of the ODS waste i.e. in several pressure cylinders at the point of origin has an impact on the transport costs. They can be up to 30% higher compared with the ideal scenario of transporting a single container in a single trip.

n) **Obtaining necessary permits**
- Shipment is subject to rules and permitting requirements of the Basel Convention.
- The permits were obtained by the beneficiary RRR center.
- There are also **costs related to obtaining of all necessary permits – export permits** from the country of origin, transit permit from each transit country, import permits from the destination country in which the destruction facility is located. There are also costs associated with translation of some of the required paperwork.

Through an established regional information and knowledge sharing platform related to ODS destruction activities in the Europe and Central Asia (ECA) region, the Government of Turkey exchanged lesson learnt and good practices on how to implement the approved pilot ODS destruction project.

The regional cooperation forum helped countries and implementing agencies to hold discussions on practical aspects of project implementation, to organize common disposal operations, such as coordination for national aggregation, launching of bidding tenders, evaluation of offers, etc. Important outputs of the activities of the forum include :

- List of equipment and tools that are necessary for proper aggregation of waste
- Check list for laboratory analysis of ODS waste

- List of eligible destruction facilities in the EU

List of Annexes

Annex 1: The list of facilities registered for ODS destruction in the European Union

No.	Company Name	Address	Contact details
1	Indaver Poldervlietweg	Indaver nv – registered office Poldervlietweg 5, Haven 550 BE-2030 ANTWERPEN 3 Belgium	t + 32 3 568 49 11 f + 32 3 568 49 99 info@indaver.be www.indaver.be
2	Kommunekemi A/S	Lindholmvej 3 DK-5800 Nyborg Denmark	Tel.: +45 80 31 71 00 Kenneth Simonsen Combustion Manager kenneth.simonsen@nordgroup.eu www.nordgroup.eu
3	Odense Kraftvarmevaerk	Havnegade 120, 5000 Odense Denmark	Helle L. Poulsen Tlf: (+45) 27 87 54 22 Helle.lisbet.poulsen@vattenfall.com www.vattenfall.dk/da/odense-kraftvarmevaerk.htm
4	Ekokem Oy Ab	Kuulojankatu 1 11120 Riihimäki Finland	export@ekokem.fi Taina Noopila, export manager taina.noopila@ekokem.fi Hanna Leena Luostarinen, export assistant hanna-leena.luostarinen@ekokem.fi www.ekokem.fi
5	CLIMALIFE	26 avenue du petit parc 94300 Vincennes France	Christophe MOROTE Activity Director Tel: +33 143 987 507 Mobile: +33 614 257 056 cmorote@climalife.dehon.com
6	VEOLIA Proprete Centre SIAP	Boulevard de l'Industrie , BP 8, 33565 Carbon Blanc France	Pascal Lefevre Tél. :05 57 77 65 50 Fax :05 57 77 65 55 plefevre@sarpindustries.fr www.sarpindustries.fr/
7	SARP Industries	427 Route du Hazay, 78520 Limay France	

<table>
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<tr><td>10</td><td>GSB – Sonderabfall-Entsorgung Bayern GmbH</td><td>Äußerer Ring 50, 85107 Baar-Ebenhausen
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entsorgung@pfahler.de
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<tr><td>16</td><td>Thermische Rückstandsverwertung GmbH & Co. KG</td><td>Rodenkirchener Straße
50389 Wesseling
Germany</td><td>Tel: +49 (0) 2236 / 94 32 4 - 0
Fax: +49 (0) 2236 / 94 32 4 - 53
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</table>

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17	SARPI Dąbrowa Górnicza Sp. z o.o.	42-523 Dąbrowa Górnicza ul. Koksownicza 16 Poland	Karina Szafranek - Bras Marketing and Sales Director Mobile: +48 693 466 568 Email: kbras@sarpi.pl www.sarpi.pl
18	ScanArc Plasma Technologies AB	Värnavägen 7, 813 35 Hofors Sweden	Phone: +46 290 767 800 Sven Santén sven.santen@scanarc.se Patrik Hilding patrik.hilding@scanarc.se Matej Imris matej.imris@scanarc.se Maria Swartling maria.swartling@scanarc.se www.scanarc.se/
19	TERIS	Rue Lavoisier - BP 17 - Plate-forme Chimique Le Pont de Claix France	Téléphone : +33 04 76 69 50 00 Fax: +33 04 76 69 53 87
20	TREDI	Parc Industriel de la Plaine de l'Ain BP 55 Saint-Vulbas 01152 Lagnieu. France	Téléphone : 04 74 46 22 00 Fax : 04 74 61 52 44 www.tredi.com

Annex 2. Movement document for the shipment from Montenegro

REPUBLIC OF MONTENEGRO Environmental Protection Agency
TRANSBOUNDARY MOVEMENT OF WASTE – Movement document

Movement document from DOP
Regulation on supervision of transboundary movement of waste

1. Corresponding to notification No: MNE 480

2. Serial/total number of shipments: 01 / 10

3. Exporter - notifier Registration No:
Name: HEMOSAN D.O.O.
Address: STARA RASKRSNICA BB, MNE - 85000 BAR
Contact person: ZORAN NIKOLOVIĆ
Tel: +382 30 346232 Fax: +382 30 346234
E-mail: hemosan@t-com.me

4. Importer - consignee
Name: SARPI Dabrowa Górnicza Sp. z o.o.
Address: Koksownicza 16, 42-523 Dabrowa Górnicza, Poland
Contact person: Mrs. Martyna Koshuchow
Tel: +48 695 927 897 Fax: +48 32 639 5020
E-mail: mkoshuchow@sarpi.pl

5. Actual quantity: Tonnes (Mg): 980 kg m³:

6. Actual date of shipment: 12.04.2017.

7. Packaging Type(s) (¹): 7 Number of packages:
Special handling requirements: (²) Yes: ☐ No: ☒

8.(a) 1st carrier (³): ANNAN METAL TRANS PL Sp. z o.o.
Registration No:
Name: TRASA PÓŁNOCNA 4
Address: 65-119 ZIELONA GÓRA
Tel:
Fax: 68 4700 6/68 92 536
E-mail:

8.(b) 2nd carrier (³):
Registration No:
Name:
Address:
Tel:
Fax:
E-mail:

8.(c) Last carrier (³):
Registration No:
Name:
Address:
Tel:
Fax:
E-mail:

------- To be completed by carrier's representative ------- More than 3 carriers (²) ☐

Means of transport (¹): R (road) Means of transport (¹): Means of transport (¹):
Date of transfer: Date of transfer: Date of transfer:
Signature: Signature: Signature:

9. Waste generator(s) - producer(s) (¹)(⁵)(⁶):
Registration No:
Name: HEMOSAN D.O.O.
Address: STARA RASKRSNICA BB, MNE - 85000 BAR
Contact person: Zoran Niković
Tel: +382 30 346232 Fax: +382 30 346234
E-mail: hemosan@t-com.me
Site of generation (¹): Waste collecting / MNE – 85000 Bar

10. Disposal facility ☒ or recovery facility ☐
Registration No:
Name: SARPI Dabrowa Górnicza Sp. z o.o.
Address: Koksownicza 16, 42-523 Dabrowa Górnicza, Poland
Contact person: Mrs. Martyna Koshuchow
Tel: +48 695 927 897 Fax: +48 32 639 5020
E-mail: mkoshuchow@sarpi.pl
Actual site of disposal/recovery: Dabrowa Górnicza

11. Disposal/recovery operation(s)
D-code / R-code (¹): D10

12. Designation and composition of the waste (²):
Refrigerant gas (chlorofluorocarbons HCFC, HFC)

13. Physical characteristics (¹): 5

14. Waste identification (fill in relevant codes)
(i) Basel Annex VIII (or IX if applicable): Not listed
(ii) OECD code (if different from (i)): AC150
(iii) EC list of wastes: 140601*
(iv) National code in country of export: 140601*
(v) National code in country of import: 140601*
(vi) Other (specify): xx
(vii) Y-code: Y15, Y45
(viii) H-code (¹): H12
(ix) UN class (¹): 9
(x) UN Number: 1028,1078,2159
(xi) UN Shipping name: Dichlorodifluoromethane; Refrigerant gas (Refrigerant gas R12, refrigerant gas n.o.s. such as mixture F1, mixture F2 or mixture F3; 1,1,1,2-tetrafluoroethane
(xii) Customs code(s) (HS): 38256900

15. Exporter's - notifier's / generator's - producer's (¹) declaration:
I certify that the above information is complete and correct to my best knowledge. I also certify that legally enforceable written contractual obligations have been entered into, that any applicable insurance or other financial guarantee is in force covering the transboundary movement and that all necessary consents have been received from the competent authorities of the countries concerned.
Name: Zoran Niković Date: 12.04.2017. Signature: [signature]

16. For use by any person involved in the transboundary movement in case additional information is required

17. Shipment received by importer - consignee (if not facility): Date: Name: Signature:

TO BE COMPLETED BY DISPOSAL / RECOVERY FACILITY

18. Shipment received at disposal facility ☒ or recovery facility ☐
Date of reception: 2017-04-18 Accepted: ☒ Rejected (*): ☐
Quantity received: Tonnes (Mg): 980,908 m³:
*immediately contact competent authorities
Approximate date of disposal/recovery: 2017-04-25
Disposal/recovery operation (¹): D10
Name: Agata Gruszek
Date: 2017-04-18
Signature:
SARPI DĄBROWA GÓRNICZA Spółka z ograniczoną odpowiedzialnością, 42-523 Dąbrowa Górnicza, ul. Koksownicza 16, tel. 32 639 50 00, fax 32 639 50 20

19. I certify that the disposal/recovery of the waste described above has been completed.
Name: JOANNA LECH
Date: 2017-04-25
Signature and stamp:
SARPI DĄBROWA GÓRNICZA Spółka z ograniczoną odpowiedzialnością, 42-523 Dąbrowa Górnicza, ul. Koksownicza 16, tel. 32 639 50 00, fax 32 639 50 20

(¹) See list of abbreviations and codes on the next page
(²) Attach details if necessary
(³) If more than 3 carriers, attach information as required in block 8 (a,b,c).
(⁴) Required by the Basel Convention
(⁵) Attach list if more than one
(⁶) If required by national legislation

REPUBLIC OF MONTENEGRO Environmental Protection Agency
TRANSBOUNDARY MOVEMENT OF WASTE – Movement document

Movement document from DOP
Regulation on supervision of transboundary movement of waste

1. Corresponding to notification No: MNE 480

2. Serial/total number of shipments: 01 / 10

3. Exporter - notifier Registration No:
Name: HEMOSAN D.O.O.
Address: STARA RASKRSNICA BB, MNE - 85000 BAR
Contact person: ZORAN NIKITOVIĆ
Tel: +382 30 346232 Fax: +382 30 346234
E-mail: hemosan@t-com.me

4. Importer - consignee
Name: SARPI Dabrowa Górnicza Sp. z.o.o.
Address: Koksownicza 16, 42-523 Dabrowa Górnicza, Poland
Contact person: Mrs. Martyna Kostuchow
Tel: +48 605 827 897 Fax: +48 32 639 5020
E-mail: mkostuchow@sarp.pl

5. Actual quantity: Tonnes (Mg): 20 kg ... m³

6. Actual date of shipment: 12.04.2017.

7. Packaging Type(s) (1): 7 Number of packages:
Special handling requirements: (2) Yes: ☐ No: ☒

8.(a) 1st carrier (3):
Registration No: ARVEN Artur Transport
Name: TRASA ...
Address: 65-117 ZIELONA GORA
Tel:
Fax: 724900 F/ 72 92157
E-mail:

8.(b) 2nd carrier (3):
Registration No:
Name:
Address:
Tel:
Fax:
E-mail:

8.(c) Last carrier (3):
Registration No:
Name:
Address:
Tel:
Fax:
E-mail:

- - - - - - - *To be completed by carrier's representative* - - - - - - - *More than 3 carriers (2)* ☐

Means of transport (1): R (road) | Means of transport (1): | Means of transport (1):
Date of transfer: | Date of transfer: | Date of transfer:
Signature: | Signature: | Signature:

9. Waste generator(s) - producer(s) (4)(5)(6)
Registration No:
Name: HEMOSAN D.O.O.
Address: STARA RASKRSNICA BB, MNE – 85000 BAR
Contact person: Zoran Nikitović
Tel: +382 30 346232 Fax: +382 30 346234
E-mail: hemosan@t-com.me
Site of generation (2): Waste collecting / MNE – 85000 Bar

10. Disposal facility ☒ or recovery facility ☐
Registration No:
Name: SARPI Dabrowa Górnicza Sp. z.o.o.
Address: Koksownicza 16, 42-523 Dabrowa Górnicza, Poland
Contact person: Mrs. Martyna Kostuchow
Tel: +48 605 827 897 Fax: +48 32 639 5020
E-mail: mkostuchow@sarp.pl
Actual site of disposal/recovery: Dąbrowa Górnicza

11. Disposal/recovery operation(s)
D-code / R-code (1): D10

12. Designation and composition of the waste (2):
Refrigerant gas (chlorofluorocarbons – CFC, HFC)

13. Physical characteristics (1): 6

14. Waste identification (fill in relevant codes)
(i) Basel Annex VIII (or IX if applicable): Not listed
(ii) OECD code (if different from (i)): AC150
(iii) EC list of wastes: 140601*
(iv) National code in country of export: 140601*
(v) National code in country of import: 140601*
(vi) Other (specify): -
(vii) Y-code: Y18, Y45
(viii) H-code (1): H12
(ix) UN class (1): 9
(x) UN Number: 1028,1078,3159
(xi) UN Shipping name: Dichlorodifluoromethane
Refrigerant gas (Refrigerant gas R12, refrigerant gas n.o.s. such as mixture F1, mixture F2 or mixture F3; 1,1,1,2-tetrafluoroethane
(xii) Customs code(s) (HS): 38256900

15. Exporter's - notifier's / generator's - producer's (4) declaration:
I certify that the above information is complete and correct to my best knowledge. I also certify that legally enforceable written contractual obligations have been entered into, that any applicable insurance or other financial guarantee is in force covering the transboundary movement and that all necessary consents have been received from the competent authorities of the countries concerned.
Name: Zoran Nikitović Date: 12.04.2017. Signature: [signature]

16. For use by any person involved in the transboundary movement in case additional information is required

17. Shipment received by importer - consignee (if not facility): Date: Name: Signature:

TO BE COMPLETED BY DISPOSAL / RECOVERY FACILITY

18. Shipment received at disposal facility ☒ or recovery facility ☐
Date of reception: 2017 -04- 18 Accepted: ☒ Rejected(*): ☐
Quantity received: Tonnes (Mg): 0,0028 0,03 m³
*immediately contact competent authorities
Approximate date of disposal/recovery: 2017 -04- 25
Disposal/recovery operation (1): D10
Name: Agata Glusacki
Date: 2017 -04- 18
Signature:

SARPI DĄBROWA GÓRNICZA
Spółka z ograniczoną odpowiedzialnością
42-523 Dąbrowa Górnicza, ul. Koksownicza 16
tel. 32 639 50 00, fax 32 639 50 20
...

19. I certify that the disposal/recovery of the waste described above has been completed.
Name:
Date:
Signature and stamp:

(1) See list of abbreviations and codes on the next page
(2) Attach details if necessary
(3) If more than 3 carriers, attach information as required in block 8 (a,b,c).
(4) Required by the Basel Convention
(5) Attach list if more than one
(6) If required by national legislation

Annex 3. Refrigerant ODS Waste Collected in Turkey (TUHAB)

TUHAB_Forms_TUBIT
AK_REcords.pdf