Keeping Cool Under Threat of Fire – Managing the Risks of Flammable Refrigerants

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Until now, air-conditioning refrigerants have mostly been fluorinated compounds, whose leakage into the atmosphere contributes substantially to global heating. The Kigali Amendment to the Montreal Protocol, which came into force in January 2019, commits the signatories to rapidly phasing out the more damaging substances and to achieving over 80% reduction by 2047 in the consumption of the markedly less damaging hydrofluorocarbons (HFCs). Unfortunately, both HFCs and their hydrocarbon replacements (mainly propane and isobutane) are flammable. Therefore, it is necessary to manage the risks associated with the potential ignition of leaked refrigerant, especially in occupied spaces. The authors summarise experimental and modelling studies highlighting the role of factors modifying the risks.

KEYWORDS: flammable refrigerants, air conditioners, heat pumps, refrigeration, propane, hydrofluorocarbons

1. Introduction

Approximately 100 million room air conditioners and about 20 million commercial/retail appliances (including drinks coolers, dispensers, food retail cabinets, etc.) are sold each year (UNEP, 2018). According to the International Institute of Refrigeration (IIR, 2017), the total number of refrigeration, air conditioning and heat pump (RACHP) systems in operation worldwide amounts to roughly 3 billion, with annual sales of about 300 billion USD. The sector employs close to 12 million people and consumes about 17% of worldwide electricity generation.

Leakage of refrigerant from RACHP systems represents about 10% of anthropogenic global warming contributions (on a 20-year time scale). Thus, any substantial reduction in the emissions of fluorinated refrigerants would represent a substantial climate benefit.

Historically, RACHP appliances have relied almost exclusively on non-flammable refrigerants, primarily chlorofluorocarbons (CFCs). Since the Montreal Protocol on Substances that Deplete the Ozone Layer (1987), increasing attention has been given to so-called “natural” refrigerants, i.e. those that generally do not require chemical synthesis. However, in large measure due to pressure from the industry, the transition from CFCs has been stepwise, via hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and hydrofluoroolefins (HFOs, aka unsaturated HFCs or uHFCs).

While these latter substances have far lower ozone depletion potential (ODP) than CFCs, many of them are potent greenhouse gases (have high global warming potential – GWP). In 2016, after nine years of intense discussions, the parties to the Montreal Protocol reached consensus on the Kigali Amendment, which added 18 high-GWP HFCs to the list of controlled substances.

The four main options of low-GWP refrigerants appear in Table 1 (UNEP, 2011): HFC single components and mixtures, hydrocarbons (HCs), ammonia and carbon dioxide. Not all options are suitable for use in commercial refrigeration appliances or air conditioners, especially in hot climates. Ammonia is an excellent refrigerant but its use within occupied spaces is limited due to its high toxicity. Carbon dioxide is widely used in commercial refrigeration, but with current technology is inefficient in air conditioners, particularly in hot climates, due to its low critical temperature. Unsaturated HFCs (termed “HFOs”) are relatively expensive.

Hydrocarbons, such as propane, propene and isobutane, have similar characteristics to conventional refrigerants, are low cost, have excellent thermo-physical properties, negligible direct environmental impact (no ODP and low GWP), and insignificant emissions and energy use during production (< 1 kg CO_2-eq/kg) compared to many other refrigerants. For these reasons there is growing interest in their use.

Table 1. Overview of Implications of Low-GWP Refrigerant Options

Refrigerant type	Safety	GWP*	Efficiency	Cost	Other
Unsaturated HFC e.g., $C_3H_3F_3$ and $C_3H_2F_4$ isomers	Lower toxicity, lower flammability – changes to system construction necessary if shifting from HCFCs, e.g. CHF_2Cl; few changes from HFCs, e.g. CH_2FCF_3	4 – 10	Expected to be acceptable	>> CHF_2Cl	Very new products, not widely commercially available, many unknown factors
HC e.g., propane, propene	Lower toxicity, higher flammability – changes to system construction MUST be addressed, and charge sizes reduced to mitigate flammability risk	2 – 6	Good/ Excellent	½ × to 2 × CHF_2Cl	Miscible with mineral oils; avoid drop-in*, for safety reasons
Ammonia	Higher toxicity, lower flammability – use mainly limited to indirect systems or direct systems in unoccupied spaces	~0	Excellent	<< CHF_2Cl	Incompatible with copper materials, cannot drop-in
Carbon dioxide	Lower toxicity, non-flammable – restriction in some applications due to low critical temperature, and has high operating pressures so entire construction must be suitable for such pressures	1	Good in cool, poor in hot climates, good for heat pumps	< CHF_2Cl	High operating pressures so cannot be used in existing systems; trans-critical cycle demands specialised design

** A refrigerant drop-in is a suitable replacement refrigerant, i.e. one that does not require system modifications.*

Since most of the medium- to low-GWP alternative refrigerants are flammable, this is a major new hurdle that the industry has to overcome. Table 2 provides a summary of the GWP values and flammability characteristics of the common flammable refrigerants.

Table 2 Common refrigerant flammability characteristics[1]

Refrigerant	$CH_2=CFCF_3$	$CHF=CHCH_3$	CH_2F_2	CH_2FCF_3	NH_3	CHF_2CH_3	$(CH3)_3CH$	CH_2CHCH_3	C_3H_8
ISO 817 R-number	R1234yf	R1234ze	R32	R143a	R717	R152a	R600a	R1270	R290
ISO 817 class*	A2L	A2L	A2L	A2L	B2L	A2	A3	A3	A3
Type	uHFC	uHFC	HFC	HFC	Inorg.	HFC	HC	HC	HC
GWP(100 yr)	1	1	704	4470	0	148	4.1	1.9	3.5
GWP(20 yr)	1	4	2530	7050	0	545	4.3	2.0	4.0
BPt (°C)	-29.4	-18.9	-51.7	-47.0	-33.3	-25.0	-11.7	-47.6	-42.1
AIT (°C)	405	368	648	750	630	455	460	455	470
MIE (mJ)	780	Un-known	29	27	45	0.9	0.7	0.28	0.35
S_u (cm/s)	1.5	1.2	6.7	7.1	7.2	23	38	45	46
LFL (% v)	6.2	6.5	14.4	8.2	16.7	4.8	1.8	1.8	2.1
UFL (%v)	12.0	12.7	29.3	17.9	30.4	17.3	8.4	11	9.8
ΔH_c (MJ/kg)	10.7	10.1	9.5	10.3	18.6	16.3	50	45.8	46.3
ρ (kg/m^3, STP)	4.66	4.66	2.13	3.44	0.70	2.70	2.51	2.35	1.80

Note:

***A2L – lower toxicity** (no identified toxicity at concentrations ≤ 400ppm); **lower flammability** ($S_u \leq 10$cm/s)*

B2L – higher toxicity** (evidence of toxicity at concentrations ≤ 400ppm); **lower flammability

***A2 – lower toxicity; flammable** ($S_u > 10$cm/s, $\Delta H_c \leq 19$MJ/kg)*

***A3 – lower toxicity; highly flammable** ($S_u > 10$cm/s, $\Delta H_c > 19$MJ/kg)*

NB the above flammability designations have no significance outside RACHP industry. In particular, they do not affect transport classification, according to which all the above are compressed flammable gases.

There is a now a broad consensus across the industry (although not with the fluorinated refrigerant manufacturers) that only natural (non-fluorinated) refrigerants will be used for the majority of applications in the future. At least for commercial refrigeration and small air conditioning, HCs will probably be the dominant choice.

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[1] From ISO 5149-1, ISO 817, Refprop 9.1; GWPs from RTOC (2018)

European health and safety directives that govern the RACHP sector, along with several group and product standards under ISO, CEN, IEC and CENELEC, are discussed in UNEP (2017).

EU countries have implemented the ATEX (equipment) (2014) and ATEX (workplace) (1999) directives, and in fact almost all other countries subscribe to an equivalent or similar regulatory framework. The general approach taken is to ensure that there are no sources of ignition within potentially flammable zones. To achieve this, the standard EN and IEC 60079-10-1 specifies a methodology to determine the size of a zone, based on for example, the fluid flammability characteristics, fluid pressure, anticipated largest non-catastrophic leak hole size, ventilation in the area, etc. There exist standards that define requirements for ensuring that electrical or other components permitted within the assumed flammable zone do not act as ignition sources.

However, it is not practical to mandate Ex-type components throughout spaces where small RACHP systems and equipment are typically installed; this would substantially diminish the convenience and increase the cost of cooling (and heating) systems. Instead, control of explosive atmospheres is approached via the converse of ATEX: the refrigerant charge and other parameters are limited such that, in case of a leak, the flammable zone would not extend significantly beyond that of the RACHP equipment itself, where sources of ignition can be fairly easily eliminated.

Thus, most of the group and product standards utilise a charge limit as the principal means of minimising flammability risk. In the earlier editions of these standards, the charge per refrigerant circuit would be limited to LFL times a fraction of the potentially affected room volume – the use of a fraction being intended to account for stratification. Recent editions adopt some rather aggressively conservative assumptions, in terms of the possible leak mass flow rates and effects of RACHP equipment enclosures on pre-dilution. The result has been that the permissible quantities of HC refrigerant are so restricted as to often make their use impracticable in the majority of systems, leaving fluorinated refrigerants as the only viable options for medium to large capacity systems.

The EU-funded LIFE FRONT project seeks to remove the above barriers by improving system design to address flammability risk (http://lifefront.eu/). The project has been developing risk parameters based on field studies of leak frequency and hole sizes, and laboratory measurements of mass flow rates, leak time profiles and room concentrations arising from refrigerant releases from different parts of RACHP systems. Current results of both the field survey and the laboratory tests are summarised in two public databases: one on leak hole sizes and one on leak simulation/concentration measurements

Approaches adopted by the RACHP sector to minimise flammability risk include carrying out risk assessments, minimising refrigerant charge sizes, introducing measures to enhance leak dispersion/dilution, and improving technician training to minimise risk during maintenance.

2. Charge Size Reduction

Current HC charge size limits are challenging, both for commercial refrigeration systems and for air conditioners, especially in larger rooms with higher heat loads; although it is of some help that HCs are only about 40-50% as dense as conventional refrigerants, thus requiring smaller charges for a given cooling capacity.

In a room air conditioner, the majority of refrigerant is held within the condenser (typically about 63%) and the compressor (22%), with significant fractions in the evaporator (8%) and liquid line (5%). The biggest reductions can thus be achieved by improving the condenser design. Hydrocarbons have relatively high latent heat, high thermal conductivity and low viscosity, a combination which enables condenser coil diameters to be approximately halved, improving heat transfer without compromising pressure losses, and reducing the condenser charge by 50 – 70% without any reduction in system capacity/efficiency. The use of mini-channel (also referred to as micro-channel) heat exchangers, with port diameters of the order of 0.5mm, can further reduce the condenser charge by up to a factor of five (Jain and Bullard, 2004). The same approach can be applied to the evaporator, although the achievable reductions are, of course, smaller. In the compressor, about half of the charge is held within the vapour cavity and half within the oil. Design improvements have achieved reductions in both of these: by reducing cavity volumes and by using oils in which the HC charge is less soluble (Chen, 2012).

As a result of such developments, highly efficient cooling-only room air conditioners using propane need around 70-90 g per kW of cooling capacity (Colbourne, 2012), compared to around 300 g per kW for conventional (fluorinated) refrigerants. Similarly, Krieger et al (2011) reduced the refrigerant charge of commercial refrigeration cabinets from around 500 g of HFC blend to less than 150 g of propane, whilst improving energy efficiency by around 10%. There are continuing efforts to reduce refrigerant charge, but we are approaching limits achievable with current technology.

Attention is now switching to means of reducing the releasable (as distinct from the total) charge in the event of a leak, for instance, by using solenoid valves to retain as much refrigerant as possible within the system in the event of a leak (Colbourne, 2013). Proposals for revising the product standards include test methods to develop such systems (IEC, 2018).

3. Dispersion of Leak Within a Room

In the event of a leak, it is essential to ensure the refrigerant disperses to below LFL. The principal methods to achieve this rely on buoyancy-driven mixing and room circulation airflow. Regarding the former, the LIFE FRONT project has also identified benefits from optimising unit enclosure design.

Buoyancy

Under quiescent conditions, entrainment of surrounding air into a jet of refrigerant is strongly dependent on its momentum. However, since almost all refrigerant containing parts of RACHP equipment are encased to some extent, it is reasonable to assume that any leak will impinge upon an immediately adjacent surface, thus reducing the high-momentum jet to a buoyancy driven, weakly entraining plume sinking towards the floor.

Early attempts to mimic this process, employing a packed funnel diffuser, exaggerated the lack of entrainment and resulting floor-level concentrations (Kataoka et al, 1999). A series of more realistic tests have used capillary orifices to simulate leak points. For example, floor concentrations were compared following the release of 310 g released at a constant 60 g/min via a 3 mm^2 capillary orifice at various positions and orientations within the enclosure (Figure 1), which was fixed 1.5 m above the floor. Results for maximum mean concentration and peak concentration, among various sampling points spread across the floor, are given in Figure . The highest concentrations (but still much lower than obtained with a diffuser) were observed in releases originating from the right and left return bends, implying that the available internal volume within which the release can pre-mix before sinking out of the indoor unit (IDU) has a strong influence on floor concentrations.

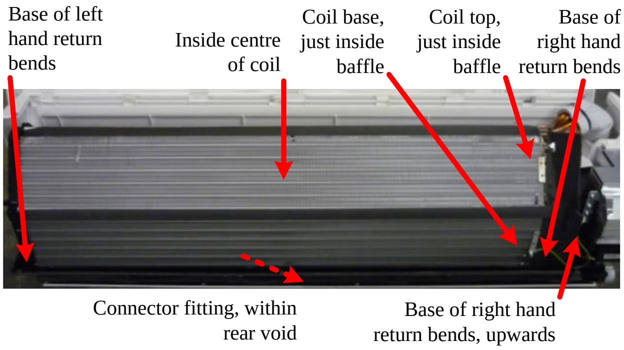

Figure 1: Indication of release positions from within an air conditioner enclosure (with cover removed)

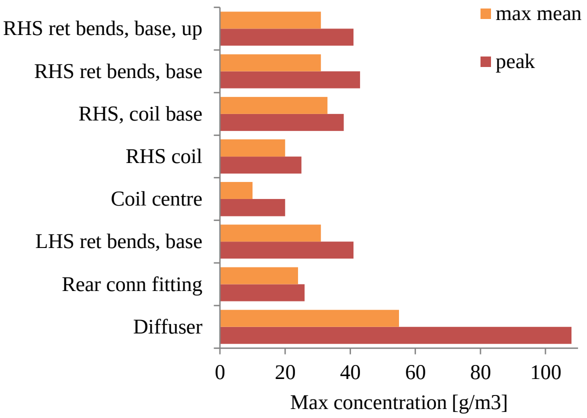

Figure 2: Comparing peak concentrations due to releases from positions within IDU and diffuser

Further series of experiments have confirmed that, generally, the more open the path is between the void containing the release and the remaining part of the enclosure, the better the pre-mixing and the lower the floor concentration. Overall, these results demonstrate that optimising the design of RACHP enclosures can substantially lower exiting concentrations and the resulting floor concentrations of leaked refrigerant.

Circulation airflow

Much RACHP equipment employs fans to transfer air across heat exchangers and within occupied spaces. This function can be exploited to help disperse and dilute any leaked refrigerant by entrainment of surrounding air into the contaminated discharged air stream. Whether the combined jet will terminate at the opposite wall or on the floor will depend on the relevant distances and the relative influence of buoyancy and momentum, as indicated in Figure 1. Ideally, it should be possible to determine the minimum airflow rate and jet outlet characteristics by setting the maximum concentration at the point of termination to the refrigerant LFL.

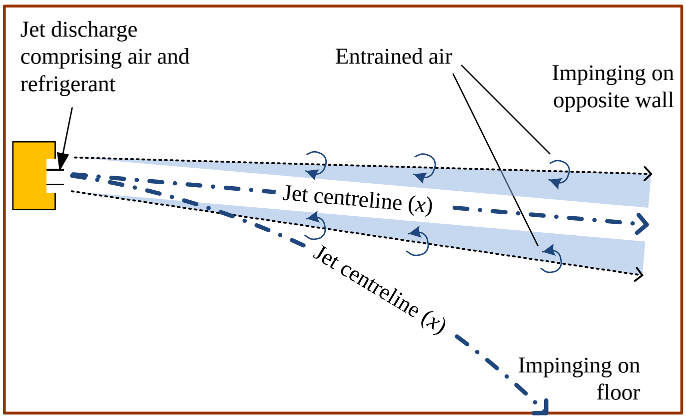

Figure 1: Schematic of entrainment process and jet termination

The analysis relies on a number of assumptions, including: negligible air exchange between the room and its surroundings, isothermal conditions, constant leak rate, negligible transit time for an element of refrigerant to flow from the IDU to the floor or wall, and – for the present work – horizontal air discharge. The work so far has been published at the IIR Gustav Lorentzen conference (Colbourne and Suen, 2018a) and at a subsequent conference focussing on application of HFCs (Colbourne and Suen, 2018b), where the background and derivation of the mathematical model are provided.

The picture is complicated by the heterogeneity of the mixture at the IDU discharge. Modelling has had to account for experimental results according to which, under many conditions, all of the leaked refrigerant is mixed into only about one-third, and the majority into just one-fifth, of the air stream, as shown in Figures 4 and 5. Homogeneous mixing into the whole width of the air stream was not achieved under any conditions.

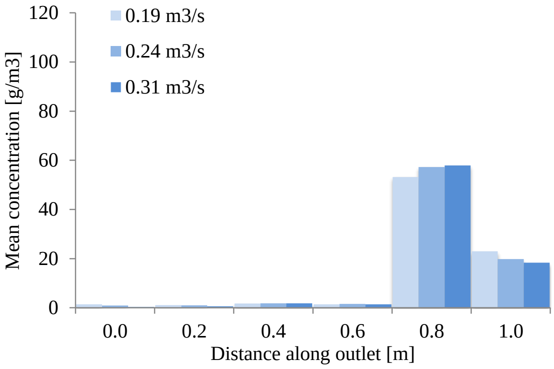

Figure 4: Measurements of propane concentration within air discharged from an IDU at varying airflow rates

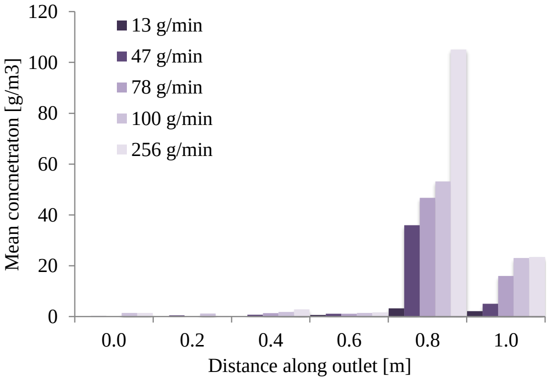

Figure 5: Measurements of propane concentration within air discharged from an IDU at varying release mass flow rates

As shown in Figure 2, model predictions show generally good agreement with a database of approximately 250 measurements involving different RACHP equipment under a wide range of conditions – varying airflow rates, outlet areas, unit height/positioning, released masses and mass flow rates, room sizes and sampling point locations. However, it was necessary to adjust the model, as shown in Figure , since its primary purpose is to determine a minimum airflow rate guaranteed to prevent a flammable mixture forming.

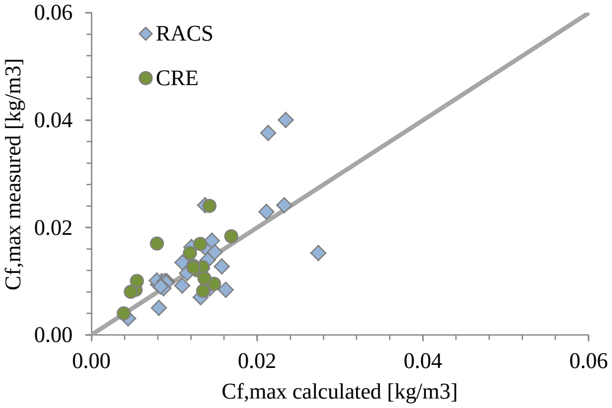

Figure 2: Comparison of measured maximum concentrations and unadjusted proposed formulae

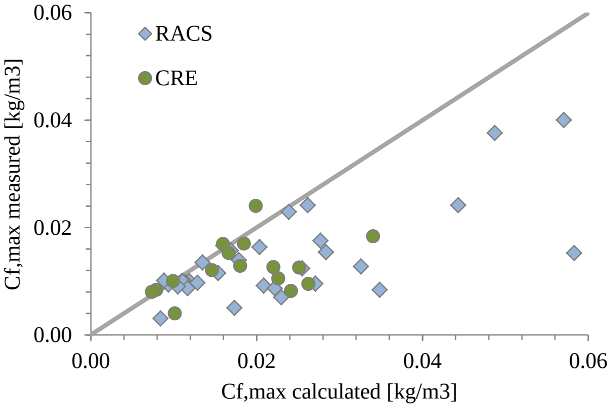

Figure 7: Comparison of measured maximum concentrations and proposed formulae adjusted to "catch all"

4. Risk Assessments

QRA studies have been conducted on various RACHP equipment that uses flammable refrigerants. ADL (1998) reported ignition frequencies in the order of 1×10^{-7} per year for freezer cabinets and 1×10^{-8} per year for drinks coolers. A more recent study on commercial refrigeration appliances using propane determined ignition frequency to be less than 1×10^{-8} per year. Changing the design and operating function of the unit enabled further reductions in predicted ignition frequency.

Tests were carried out (see Figure) with ignition in the compressor compartment (left) and on the floor (right). Maximum overpressure in the room was about 2.5 – 3 kPa. A manikin dressed in overalls was positioned next to the cabinet to mimic a service technician; examination after several ignition tests found clothing unaffected (and even the “eye lashes” remained in place).

Figure 8: Ignition tests involving commercial refrigerated cabinet

A further study (Colbourne, 2011) examined the flammability risk of servicing RACHP equipment. A summary of the results in Figure clearly indicates the importance of providing suitable service equipment and appropriate training for technicians unfamiliar with flammable refrigerants. Close attention to training and human factors was found to reduce the overall risk by over an order of magnitude. An analysis of 1,464 supermarket refrigeration incidents in the UK found the most common faults to be pipe or joint failure and leaking seal/gland/core. These faults were predominantly found within the compressor pack and high-pressure liquid lines. Flared joints accounted for 22% of the leaks and 50% of the refrigerant losses. It is particularly noteworthy that 96% of the refrigerant loss was through joints assembled in the field, rather than in the factory. Mechanical impact during handling, though relatively rare, was found to cause the largest leaks (Colbourne et al, 2013).

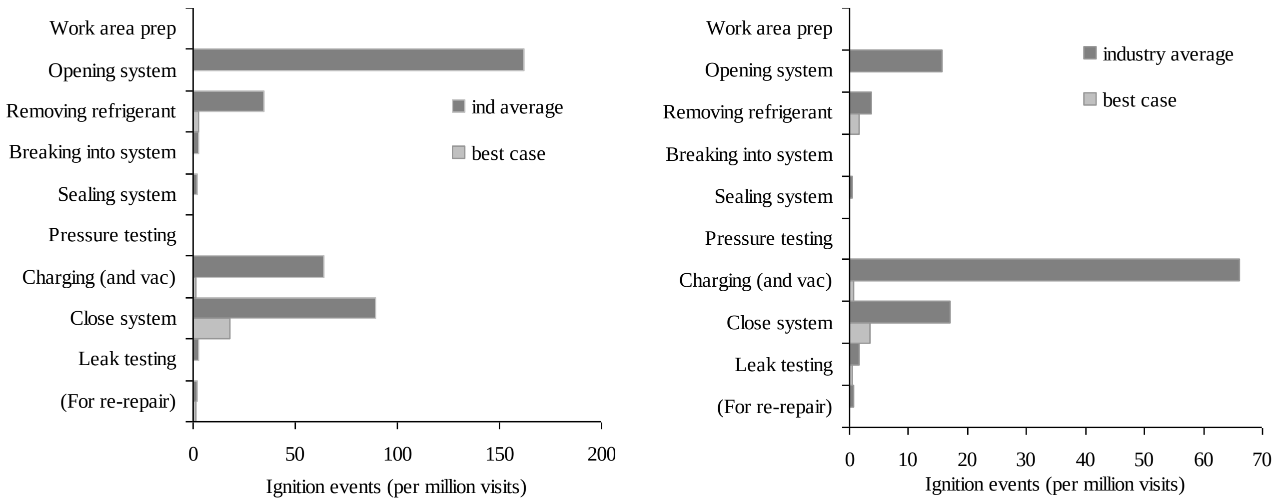

Figure 9: Ignition frequency for tasks for commercial refrigeration (left) and room air conditioner (right) during a visit when a refrigerant circuit is accessed; "industry average" refers to typical technician behaviour and equipment appropriate when servicing non-flammable refrigerant systems, whereas "best case" refers to technicians who have received flammable refrigerant training and are using the correct servicing tools and equipment.

The QRA findings are supported by the very low incidence of fire/explosion in the use of domestic and commercial refrigeration appliances. In the UK, where introduction of HCs in such appliances began about 20 years ago, there have been only about ten accidents demonstrably related to a release of flammable refrigerant. Flammability risks are even lower for air conditioners than for refrigeration appliances (Colbourne and Suen, 2015). Of course, this should not be used to justify or excuse complacency over the safety of flammable refrigerants.

On the other hand, there is a substantial history of fires arising from electrical faults within domestic refrigerators; for instance, DCLG (2014) reports about 250 – 300 dwelling fires per year. Thus, ignited leaks of refrigerant constitute a very small fraction of the fires originating in refrigerators. Since 2017, there have been concerted efforts within the international standards committee responsible for domestic refrigerator safety to revise IEC 60335-2-24 to address this electrical fire hazard.

5. Leak Hole Sizes and Leak Rates

Various elements of current safety standards such as ISO 5149, IEC 60335-2-24/89/40, EN 378, IEC-40 etc. are built upon assumptions regarding (flammable) refrigerant leak times or leak mass flow rates. Room concentrations (as a fraction of LFL) and therefore maximum charge sizes (or releasable charge sizes) are based on these assumptions, so it is important that they are robust.

Unfortunately, the various RACHP system standards are inconsistent and, in some cases, illogical on the subject of mass flow rate or a leak time. For instance, within EN 60335-2-89: 2010, assumed leak rate is based on 80% of the charged mass being released over either 10 min or 1 hour, depending only upon the type of appliance, irrespective of the refrigerant type and/or saturation pressure.[2] Again, within EN 60335-2-40: 2019, the 100% leak time is fixed for standard systems (at four minutes, again irrespective of the charged mass), but it is the leak rate that is fixed (at 10 kg/h, 167 g/minute) for A2L refrigerants in

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[2] Determination of leak mass flow under IEC 60335-2-89: 2019 now does include a method to determine mass flow according to refrigerant type and operating conditions, specifically for the so-called "surrounding concentration test" in order to evaluate whether flammable concentrations develop around the appliance in the event of a leak.

enhanced tightness refrigeration systems. Similar (or worse) problems are evident in EN 378: 2016 and ISO 5149: 2014.[3] Different standards can produce flow rates differing by a factor of 10 for a given system – without any supporting evidence.

Measurements on real systems make a mockery of the assumptions in any the above standards. For example, to "empty" an air conditioning system containing 400 g of propane in four minutes (to a gauge pressure of around 1/10th bar), the hole area would need to be 5 mm^2, or more than 13 times that of the largest hole (of 251) in the LIFE FRONT database referred to below. The quote marks around "empty" allude to the 100 g or so retained inside the system under atmospheric pressure, partly in the vapour phase and partly dissolved in compressor oil. Again, mass flow is far from constant: the average flow rate is generally about one-third of the choked flow rate observed at the start, due to rapid depressurisation.

The EU LIFE FRONT project

The project has assembled and analysed a representative database of leaks, covering a wide range of equipment types and applications from different manufacturers and system locations, including air conditioners, heat pumps and commercial refrigeration appliances. Almost all samples gathered show very small leaks. The finding that larger leaks occur only in exceptional cases is consistent with the long experience of industry partners involved, all of them being equipment manufacturers. This study currently represents the largest global database of refrigeration system leak hole sizes.

For each leakage sample the following parameters – as far as possible – are documented: Type of equipment, installation, date/age of leak, nominal refrigerating capacity, function (cooling, heating, reversible etc.), refrigerant type, refrigerant charge, location/component of leak, position of leak, assessed leak cause, compressor type, sealing, factory leak test; also, if available, total length of piping, type and number of joints in the system, number of line components, pipe diameter/component nominal diameter, information on condenser and evaporator, surface treatments etc. Analyses are informed also by visual inspection and photographic evidence.

Hole areas are calculated from the initial leak flow rates, assuming choked flow (realistic) and a discharge coefficient (C_D) of 0.6 (highly conservative for vapour, thus exaggerating the estimated hole area).

Two public databanks, one on leak hole sizes and one on concentration measurements show the results gathered from the field data and laboratory work. Both databanks are available on the EU FRONT project website at www.lifefront.eu. For confidentiality, all data are anonymised. Up to June 2019, the project collected 251 leakage data points from various RACHP systems. Most of the leak points of the AC models (cooling only) were located at the condenser coil of the system and at the return bends in the indoor units. The assessed causes are corrosion, condenser fin forming pits and mechanical impact from external objects.

Distributions of hole size and mass flow rate are shown in Figure and Figure , respectively. About 84% of the samples showed leak hole sizes varying from 0 to 0.02 mm^2. The largest hole size measured was 0.36 mm^2. The distribution is comparable for the leak samples from the three different RACHP equipment types.

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[3] Note also that the text in the standard ignores the fact that 2L refrigerants can be ignited!

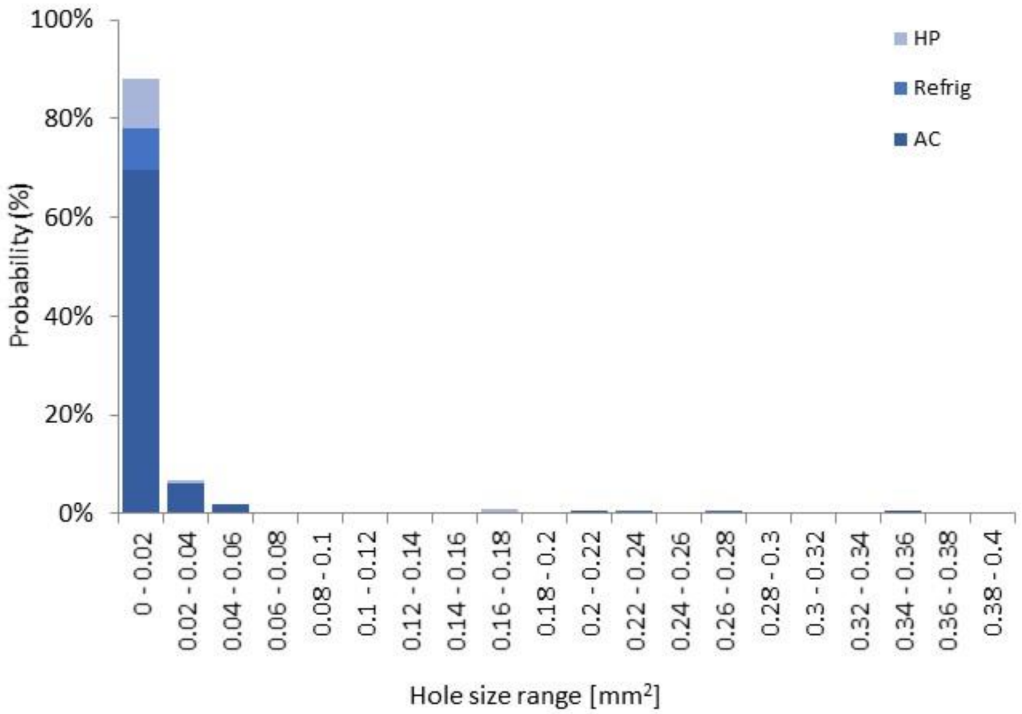

Figure 10: Leak hole size distribution (250 data points analysed), May 2019

The leak flow rate distribution shows a similar pattern, with the vast majority below 3 g/min. For holes that were not caused directly by technician intervention, the largest flow rate (normalised on propane under saturated vapour pressure at 35°C) was measured to be 48.3 g/min, corresponding to a leak hole area of 0.36 mm². Most of the holes were so small that the leak flow was below the limit of detection (0.4 litres per minute for the analogue flow meters and 0.2 g/min for the digital flow meters used). In these cases, the flow rate was recorded as half of the detection limit, the precise value being immaterial, since, in practice, such small flow rates are well below those necessary to form a flammable mixture.

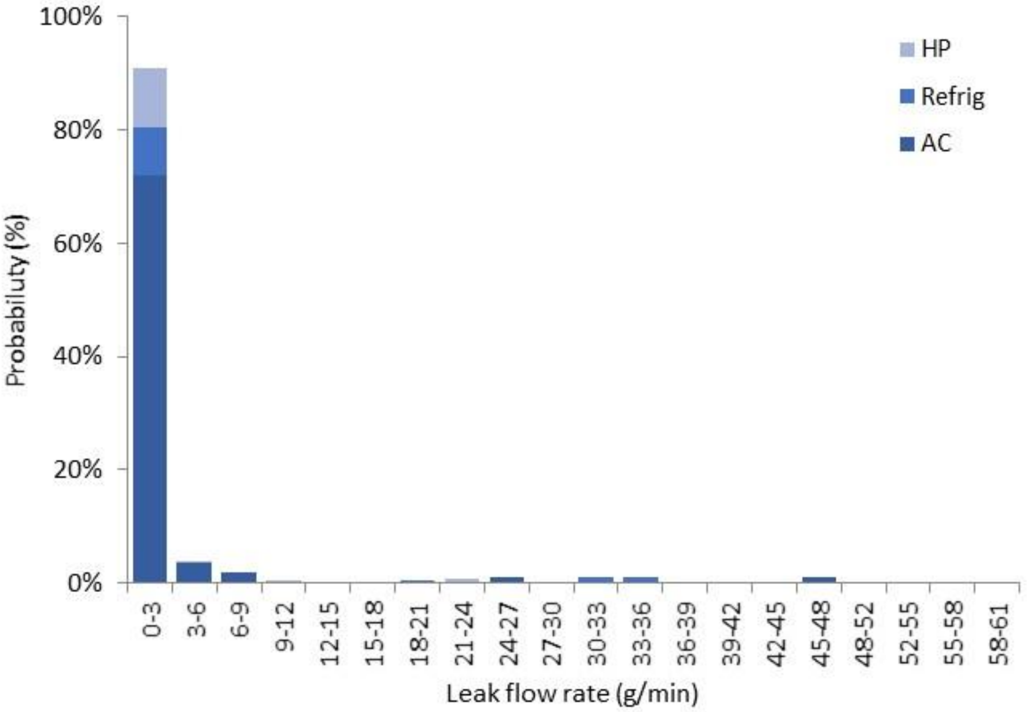

Figure 11: Leak mass flow rate distribution based on propane vapour under standard conditions (250 data points analysed), May 2019

Further tests are underway in order to extend the database, with the goal of improving rationales for charge size limits in RACHP safety standards. Updates can be found at the LIFE FRONT internet site[4]

Most of the leaks in the study were caused through typical mechanisms, but a small minority were clearly caused or augmented by direct human intervention, such as repeated re-brazing of a heat exchanger return bend, incorrect use of pipe-cutters, dropped objects etc. There are arguments to include or discount these latter from the analysis. It was decided to include all leaks in the analysis, but to present those caused through direct human intervention separately.

A statistical analysis has been carried out on the 251 elements in the leak data set, as it currently stands, using a non-parametric approach. Conservatively (by assuming $C_D = 0.6$ throughout), we can say with:

- 95% confidence that the 95th percentile of the population of holes will not exceed 0.17 mm^2.
- 99% confidence that the 95th percentile of the population of holes will not exceed 0.23 mm^2.
- 99.9% confidence that the 95th percentile of the population of holes will not exceed 0.36 mm^2.

Data collection on leak hole sizes turned out to be more challenging and time consuming than expected, due to limited availability of samples, servicing structures and confidentiality concerns. In case larger leaks were eventually identified in the field, the range of hole sizes/leak rates in the available data set was extended, in increments up to 150g/min, for the laboratory programme of room concentration measurements.

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[4] http://lifefront.eu/refrigerant-leakage-database/

The need to update formulae in standards

The set of 251 data points gathered by June 2019 is sufficient, in view of its highly skewed distribution towards very small leaks, to conclude that the assumptions underlying the RACHP safety standards do not correspond to reality and are, in general, far too restrictive. In any case, adopting a single leak time of four minutes cannot be justified, as refrigerants differ in properties and likely leak mechanisms. The determination of maximum charge sizes should be based on a variety of system and refrigerant parameters.

First results from the LIFE FRONT project have already been implemented in an output of the standardisation processes: based on the results so far, a formula to determine the assumed leak rate for commercial refrigeration appliances was introduced within the now published international standard IEC 60335-2-89 in Annex CC.2; this was finally approved on 10th May 2019. The outputs from this project are also being proposed as the basis of text for charge size calculations and leak simulation tests for the revision of EN 378 and IEC 60335-2-40.

The LIFE FRONT leakage databank not only provides information on leak hole sizes and resulting mass flow, but also gives valuable information on causes of leaks and other parameters. Specifically, the leak flowrate can be linked to the leak cause. This is especially important for manufacturers, to help them to address the underlying causes of leaks and to develop prevention and mitigation measures. This linkage should be considered in setting charge size limits for each type of product and refrigerant.

6. Concluding Remarks

Due to environmental concerns, conventional (fluorinated) refrigerants in refrigeration, air conditioning and heat pump systems are being replaced stepwise by increasingly flammable substances. Eventually, hydrocarbons will predominate, but progress is being hampered by unduly conservative, inconsistent and illogical refrigerant charge limits in the relevant safety standards. Experimental and modelling studies have confirmed that the risks from ignited refrigerant leaks are very low and a small fraction of the risks from electrical fires in the above systems.

Acknowledgement

The authors would like to acknowledge GIZ Proklima of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (https://www.giz.de/fachexpertise/html/61049.html) and the EU LIFE Front project (http://lifefront.eu/) for supporting this work.

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