Safe Use of HCFC Alternatives in Refrigeration and Air-conditioning

An overview for developing countries

UNEP

United Nations Environment Programme

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Executive Summary

As the phase-out of hydrochlorofluorocarbons (HCFCs) progresses under the *Montreal Protocol on Substances that Deplete the Ozone Layer*, it is expected that there will be a considerably higher uptake around the world, and in particular in developing countries of ‘alternative refrigerants’, such as hydrocarbons, ammonia, carbon dioxide, unsaturated hydrofluorocarbons (HFCs) –or HFO- and HFO mixtures. Many of these alternative refrigerants have particular characteristics in terms of toxicity, flammability and high pressure which are different from those used previously such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). When refrigeration and air-conditioning equipment is installed, serviced, repaired and dismantled, safety issues need to be carefully evaluated and considered particularly when servicing technicians have to deal with refrigerants with properties that they were previously not familiar with. It is therefore important that the refrigeration and air-conditioning industry adapts to both the technical and safety issues concerning these refrigerants.

This publication provides an overview of the alternatives to HCFCs, their general characteristics and the situations in which they may considered appropriate to be used in the context of the safety implications posed by these refrigerants.

Specific information is provided on flammable, higher toxicity and higher pressure alternatives to better understand how such alternatives may be used and the measures which should be considered to assist the industry to implement them in a safe and appropriate manner.

The publication, which is intended for National Ozone Units (NOUs) and other interested parties in developing countries, provides general suggestions and guidance on how NOUs can advise and assist their national stakeholders. The focus of the publication is on new systems, since the use of flammable, higher toxicity and/or higher pressure alternatives is strongly discouraged from being used in existing HCFC systems. Consideration is also given to the relevant requirements and recommendations of the *Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol.*

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Foreword

On the 1st January 2015 developing countries reached the second significant milestone in the phase-out of hydrochlorofluorocarbons (HCFCs) under the Montreal Protocol on Substances that Deplete the Ozone Layer – the 10% reduction in their production and consumption. Since many of the low GWP alternatives to HCFCs have properties such as flammability, toxicity, and high operating pressure the adoption of such alternative refrigerants needs to be carefully considered to ensure the safety of those who install, service and use the relevant equipment. This is particularly important when servicing technicians have to deal with refrigerants with properties that they were previously not familiar with.

UNEP OzonAction is assisting developing countries to comply with their commitments under the Montreal Protocol, particularly those related to the HCFC phase-out, which involves a range of sectors and approaches. A very important sector in developing countries is of course the refrigeration and air-conditioning sector and it is consequently important that the refrigeration and air-conditioning industry adapts to both the technical and safety issues concerning these refrigerants.

We are therefore pleased to bring you this short publication on the safe use of HCFC alternatives. While this guide is principally designed as an information tool for NOUs, it should also be of interest to refrigeration servicing technicians, refrigeration associations, and other stakeholders in the refrigeration and air-conditioning sector.

I hope you will find this guide interesting and informative and that it provides a useful overview and some practical guidance when considering the adoption of HCFC alternatives. OzonAction looks forward to continue supporting your efforts to phase out HCFCs and adopting non-ozone depleting, non-global warming and energy-efficient alternatives in a safe and reliable manner.

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1 Introduction

Hydrochlorofluorcarbons (HCFCs), such as HCFC-123 and HCFC-22, are in the process of being phased-out in Article 5 countries by 2030, with a small allowance for servicing thereafter. Many of the alternatives – especially those with lower GWP – have characteristics that demand a greater attention to safety than is required for ordinary HCFC and hydrofluorocarbon (HFC) refrigerants. Whilst the replacements for HCFC-123 (which include HFC-245fa, HFC-134a and more recently HCFC-1233zd) do not pose additional safety risks, the numerous alternatives that may be used to replace HCFC-22 in various applications are flammable, have higher toxicity or operate at substantially higher pressures.

Although many of these refrigerants have been in use to a greater or lesser extent, often in non-Article 5 countries, it is important for those involved in the substitution of HCFC-22 to alternative refrigerants to become aware of these characteristics and how to address them. In particular, safe and successful application of these refrigerants requires adequate policies and legislation, minimum skills of service technicians, relevant safety standards, proper maintenance procedures to be followed and necessary safety devices installed according to manufacturer instructions.

This publication is therefore intended to provide National Ozone Units (NOUs) with the background to understand when and where such alternatives may be used and the measures that need to be considered in order to assist the industry and other stakeholders to implement them in a safe and responsible manner, if and when they are chosen. The safety considerations apply broadly, including the production, installation, operation, servicing and decommissioning of systems.

Hence, this publication aims to provide:

- An overview of key ozone- and climate-friendly alternatives refrigerants for HCFC-22 and their basic characteristics
- The types of situations that these alternatives may be considered for use
- An appreciation of the different stages and associated stakeholders that the choice of refrigerant can affect
- A general introduction to the safety implications posed by refrigerants in general
- Classifications of different refrigerants and an understanding of the different types of refrigeration systems [1]
- A summary of the various safety standards that relates to the application of refrigerants
- Quantitative examples of limitations that can apply to different alternative refrigerants
- Specific implications important for flammable, higher toxicity and higher pressure alternatives
- Some examples of how the Montreal Protocol and developing countries have approached the issue of safety in projects
- General suggestions for how NOUs can advise and assist their national stakeholders accordingly

The focus of this publication is primarily upon new systems, since the use of flammable, higher toxicity and/or higher pressure alternatives should be strongly discouraged from being used in existing HCFC systems.

Lastly, the common HFC refrigerants – such as HFC-134a, R-404A and R-407C – are not addressed here since their safety characteristics are not substantially different from HCFC-22. Information relating to the application of these substances can be found widely in the literature.

[1] The term "refrigeration system" is used to refer to the refrigerant circuit that is found in systems for medium and low temperature cooling, air-conditioning equipment and heat pumps.

2 Overview of Refrigerants

Types and selection of refrigerants

There are a number of different substances used as refrigerants, with the main ones (that are single substances) summarised in Figure 1.

All of these substances except for chlorofluorocarbons (CFCs) and HCFCs are permitted under the Montreal Protocol; thus the remaining ones may be considered as alternative refrigerants. Amongst these there are the “synthetic” refrigerants and the so-called “natural” refrigerants.

Whilst some of these substances may be used as pure refrigerants, it is common practice to mix two or more substances (sometimes up to seven components) in order to achieve a certain set of desired characteristics (i.e., related to saturation pressure, flammability, oil solubility and so on).

Mixture refrigerants can be further subdivided into “zeotropic” and “azeotropic” types. Zeotropes exhibit a temperature glide and composition change during phase change, whilst azeotropes behave as pure substances during phase change. However, some zeotropes are sometimes classed as “near-azeotropic refrigerant mixtures” (NARMs) as their temperature glide and composition is sufficiently small that from a practical perspective, their behaviour mimics a pure refrigerant.

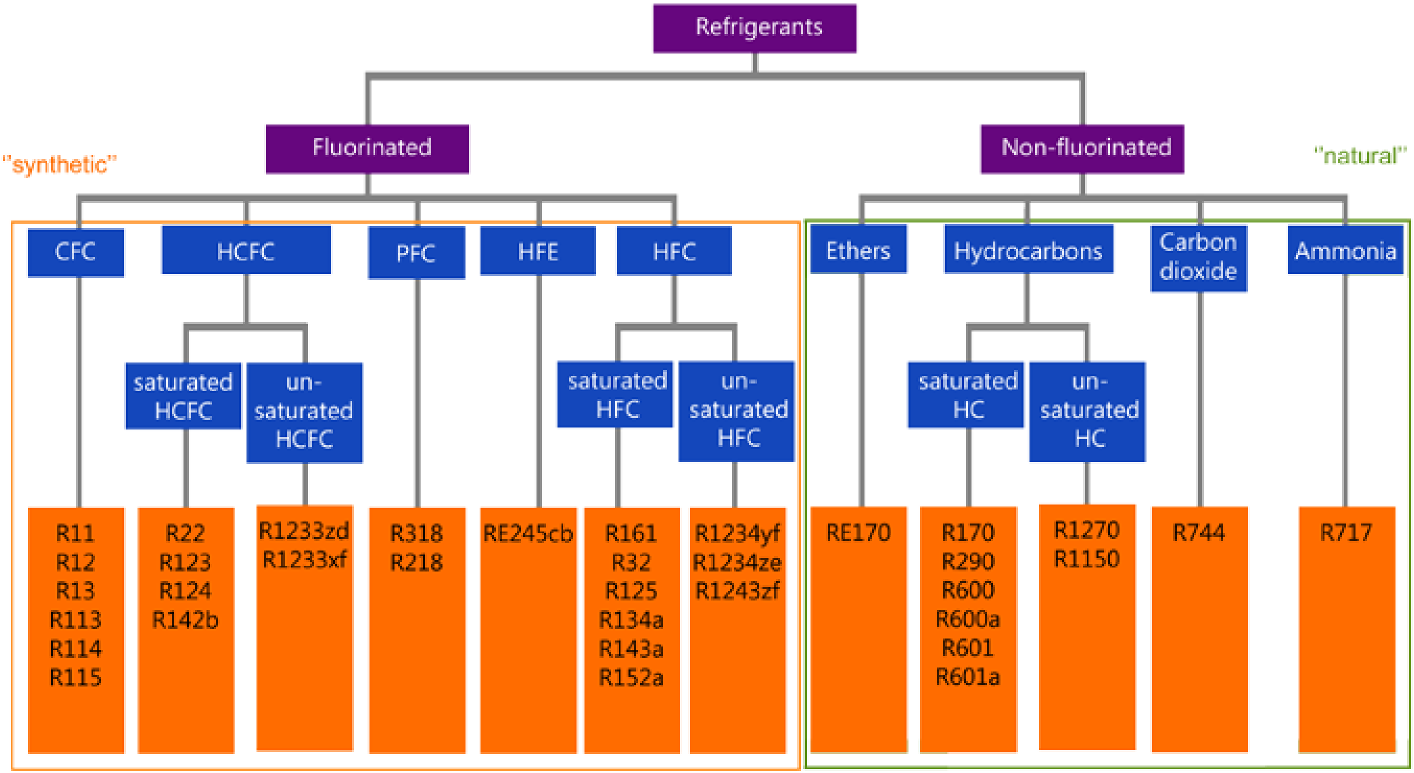


Figure 1. Categories and single substances as refrigerants

PFC: Perfluorocarbon
HFE: Fluorinated ethers

Other means of categorising refrigerants include:

- Ozone depletion potential (ODP)
- Global warming potential (GWP)
- Safety characteristics (flammability, toxicity)
- Pressure level

Such characteristics affect the selection of the refrigerant and often dictate the manner in which they are applied.

Some basic environmental information is provided in Table 1 for the ordinary refrigerants (HCFC-22, HFC-134a, R-404A and R-407C) and some selected alternative refrigerants that exhibit notably different safety characteristics. The Appendix (page 64) contains a list of all current refrigerants (with an R-number) and some relevant data.

Table 1. Basic information for selected refrigerants

Refrigerant	Chemical name or mixture composition (in % by mass)	ODP†	GWP‡		Comparable refrigerant *
			(100)	(20)	
HCFC-22	Chlorodifluoromethane	0.05	1780	5310	–
HFC-32	Difluoromethane	0	704	2530	R-410A
HCFC-123	2,2-dichloro-1,1,1-trifluoroethane	0.03	79	292	–
HFC-134a	1,1,1,2-tetrafluoroethane	0	1360	3810	CFC-12
HFC-152a	1,1-difluoroethane	0	148	545	CFC-12, HFC-134a
HC-290	Propane	0	5	18	HCFC-22
R-404A	125/143a/134a (44,0/52,0/4,0)	0	4200	6600	HCFC-22
R-407C	32/125/134a (23,0/25,0/52,0)	0	1700	4100	HCFC-22
R-410A	32/125 (50,0/50,0)	0	2100	4400	–
R-444A	32/152a/1234ze(E) (12,0/5,0/83,0)	0	90	330	CFC-12, HFC-134a
R-444B	32/152a/1234ze(E) (41,5/10/48,5)	0	310	1100	HCFC-22
R-445A	744/134a/1234ze(E) (6,0/9,0/85,0)	0	120	350	CFC-12, HFC-134a
R-446A	32/1234ze(E)/600 (68,0/29,0/3,0)	0	480	1700	R410A
R-447A	32/125/1234ze(E) (68,0/3,5/28,5)	0	600	1900	R410A
R-451A	1234yf/134a (89,8/10,2)	0	140	390	CFC-12, HFC-134a
R-451B	1234yf/134a (88,8/11,2)	0	150	430	CFC-12, HFC-134a
R-454A	32/R1234yf (35,0/65,0)	0	250	890	HCFC-22
R-454B	32/R1234yf (68,9/31,1)	0	490	1740	R410A
HC-600a	Iso-butane	0	4	15	CFC-12, HFC-134a
R-717	Ammonia	0	0	0	HCFC-22
R-744	Carbon dioxide	0	1	1	–
HFC-1234yf	2,3,3,3-tetrafluoro-1-propene	0	< 1	1	CFC-12, HFC-134a
HFC-1234ze(E)	Trans-1,3,3,3-tetrafluoro-1-propene	0	< 1	4	CFC-12, HFC-134a
HC-1270	Propene	0	2	7	HCFC-22

† ODP are regulatory values and ‡ GWP are scientific values (UNEP, 2014)[2]
* "Comparable refrigerant" means in terms of operating pressures and volumetric refrigerating capacity

[2] Chapter 2, UNEP, 2014 Report of the Refrigeration, Air-conditioning and Heat pumps Technical Options Committee, 2014 Assessment, United National Environment Programme, Nairobi

A simple graphic mapping of the hazards associated with some alternative refrigerants is shown in Figure 2; it should be recognised that this is a basic indication and that within a particular hazard class, the severity is subject to a wide range. The safety characteristics indicated here are addressed in more detail in later sections.

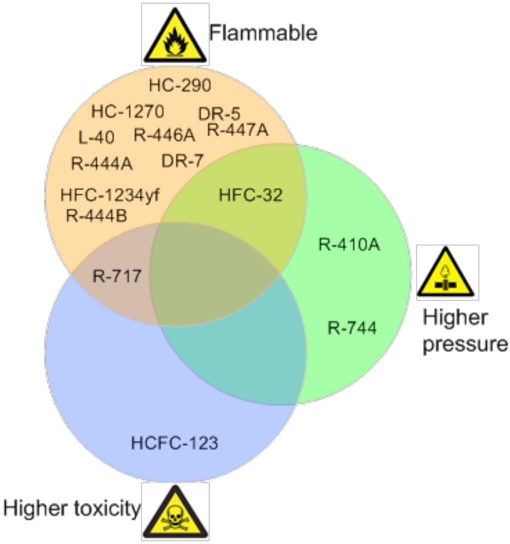


Figure 2. Map of safety hazards of alternative refrigerants

In general, there are several important factors that should be considered when selecting an alternative refrigerant. These include:

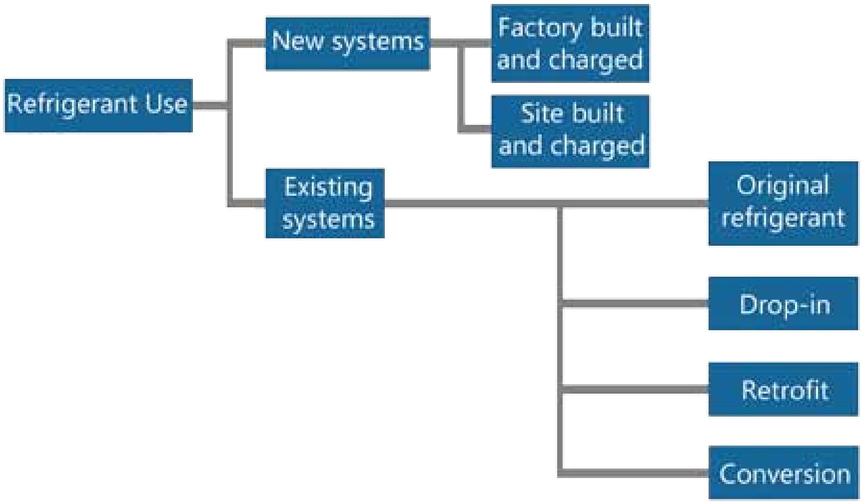
- Zero ODP
- Climate change impact (direct and energy-related emissions)
- Performance (capacity and efficiency)
- Safety, including flammability, toxicity and pressure
- Impact on product cost
- Availability and cost of the refrigerant
- Availability and cost of system components
- Skills and technology required to use
- Recyclability
- Good stability under system operating conditions and with system materials

The selection of a refrigerant for a given application will be a compromise of the above criteria. Other than zero ODP, the remaining parameters have to be traded-off against one another to arrive at the optimum for each type of system and application. In particular the carbon emissions will need to include both the “direct” and “indirect” contribution of the product over its life time. A number of approaches have been documented in the literature including: Total Equivalent Warming Impact (TEWI), Life Cycle Climate Performance (LCCP), Multilateral Fund Climate Impact Indicator (MCII) and other methods.

Type of refrigerant application

Alternative refrigerants are used in several different ways, as indicated in Figure 3. Refrigerants may be used in new systems – whether they are charged in a factory such as on a production line, or charged on-site in a locally assembled system – or used to replace old refrigerant within an existing system. For existing systems, the refrigerant which is charged may be the same type as the original one or it may be a different one which typically necessitates some intervention to the equipment or results in some change in the system performance.

Figure 3. Main situations under which refrigerants are used



Application in new systems

For new systems, the two general situations are for factory built and charged systems and for systems built and charged on site. Factory built and charged systems include domestic refrigerators, plug-in commercial refrigerators, window ACs, split ACs, packaged chillers, rooftop units, etc. Systems built and charged on-site normally include commercial cabinets or cold stores using condensing units, centralised supermarket systems, some industrial systems, etc. For factory built and charged systems, the manufacturer of the products normally chooses the refrigerant and designs the system and selects components specifically for their preferred refrigerant. With systems built and charged on-site, the contractor or end users normally selects the refrigerant on a case-by-case basis and then designs the system and selects components accordingly.

Figure 4: Charging equipment on a production line

Application in existing systems

As the HCFC phase-out proceeds there is still a need to service the installed population of systems until the end of their useful lives. Changing the refrigerant in existing systems can be more complex and requires deeper consideration of the consequences.

When servicing these products the choice of refrigerant can fall into the following categories:

- Original refrigerant
- Drop-in[3]
- Retrofit
- Conversion (to flammable refrigerant)

Since about 60 – 80% of refrigerant sales are for the servicing sector, the majority of refrigerant consumption is used for existing systems. HCFC consumption can be reduced by the use of alternative refrigerants in existing equipment. In the case of refrigerant replacement and retrofit in HCFC systems, the GWP of the new refrigerant should also be given consideration as many blends have a higher GWP.

With new refrigerants for existing systems, there are a number of criteria to target for a desirable choice of refrigerant; in summary these are:

- As close a volumetric refrigerating capacity over the range of normal operating evaporator and condenser temperatures;
- Does not lead to lower energy efficiency;
- Does not exceed the system design pressure at maximum condenser temperature;
- As close a match to the temperature glide, or negligible temperature glide if the original was a single component;
- Similar oil solubility and miscibility gap;
- Non-flammable;
- Lower toxicity;
- Commercial availability of refrigerant (with reasonable cost)
- Zero ODP, lower GWP and generally no greater environmental impact

There are a number of other parameters that should be considered. However, in practical terms it is unlikely that any of the commercially available refrigerants can meet all of the above criteria and therefore some compromise should be anticipated.

Note that the quantity of the replacement refrigerant will nearly always be different from the original one.

In all cases, before changing from the original refrigerant it is recommended that the system manufacturer be consulted.

[3] Usually the term "drop-in" is used for this type of replacement. However, since there are no alternatives with identical thermophysical, safety and chemical properties as the existing refrigerant (e.g., HCFC-22) the term "drop in" is not entirely correct.

Original refrigerant

Using the existing refrigerant following a repair, one can follow normal practices using virgin, recycled or reclaimed refrigerant (i.e., typically HCFC-22). Therefore, implementing recovery and reclaim programmes coupled with the availability of replacement and retrofit refrigerants could help reduce the demand for HCFC-22.

Figure 5: Charging HCFC-22 into an air-conditioning system

Drop-in

Drop-in represents refrigerant replacement only, where the HCFC is replaced with a blend, but without changing the lubricant used in the original equipment or any other system component. Refrigerants used for this activity are sometimes referred to as "service blends" or "drop-ins". Such a change in refrigerant in most cases results in a lower capacity and/or efficiency, different operating pressures, temperatures and compressor power compared to HCFC.

There are several refrigerants currently introduced to replace HCFC-22 for servicing, which attempt to mimic the performance of HCFC-22. However, they seldom perform as well as HCFC-22; having either lower capacity, efficiency or both.

Retrofit

Retrofit refers to not only changing the refrigerant, but also system components such as lubricant (although not always necessary), filter dryer (if required) and more extensive modifications which could include the replacement of the compressor, expansion device, and purging and flushing the system to remove all residual lubricant from the system. Retrofitting can be substantially more costly than using existing refrigerant, replacing the refrigerant without additional changes or even unit replacement.

Figure 6: Changing refrigerant in air-conditioning unit

Conversion with flammable refrigerants[4]

Conversion is where the existing refrigerant is replaced with another without necessarily having to address the refrigeration circuit components and lubricant in the same way as retrofit, but because the replacement refrigerant is flammable, the external aspects of the equipment, such as potential sources of ignition, have to be addressed. However, since this is a complex process and can lead to unforeseen safety risks, it is not normally recommended. Again, such a change in refrigerant can affect capacity and/or efficiency, operating pressures,

[4] At a recent meeting of the Executive Committee, Decision 72/17 was agreed, which stated: "anyone engaging in retrofitting HCFC-based refrigeration and air-conditioning equipment to flammable or toxic refrigerants and associated servicing, does so on the understanding that they assume all associated responsibilities and risks" (www.multilateralfund.org/72/English/1/7247.pdf). Essentially this implies that the bodies under the Montreal Protocol do not necessarily condone or will take responsibility for any adverse consequences arising from the choice to use flammable refrigerants in equipment not intended for their use.

temperatures, lubricity, etc., compared with HCFC.

This is occurring in some countries, whilst in others the practice is not legal. Although these refrigerants may provide capacity and efficiency close to that of HCFC-22, this practice can pose significant flammability safety hazards. In general, HCs are not recommended for use in systems that have not been specifically designed appropriately. If HCs are being considered then the applicable safety standards and codes of practice should be strictly followed; the handbook for hydrocarbon safety (GIZ, 2010) and another specifically addressing such conversions (GIZ, 2011) are sources of information on the utilisation of these refrigerants (see Further Reading page 63).

Figure 7: Servicing a rooftop system

Use in new refrigeration, air-conditioning and heat pump systems

According to the different selection criteria and appropriate trade-off, the practical use of the HCFCs and various alternative refrigerants can be summarised. The table 2 indicates where a particular refrigerant is or potentially can be used.

It can be seen that in every common sector and sub-sector, alternative refrigerants with additional safety characteristics are already being applied (to some extent) or at least have the potential to be applied.

Table 2: Application of refrigerants by sector

Sector/ sub-sector	HCFC-22	HFC-32	HCFC-123	HFC-152a	HC-290	R-410A	R-444A	R-444B	R-445A	R-446A	R-447A	R-451A	R-451B	R454A	R454B	HC-600a	R-717	R-744	HFC-1234yf	HFC-1234ze(E)	HC-1270
Domestic refrigeration																					
Refrigerators and freezer							P		P			P	P			C			P	P	
Commercial refrigeration																					
Stand alone equipment				C	C		P		P			P	P			C		C	P	P	C
Condensing units	C	P		C	C	C	P	P		P	P	P	P	P	P			C	P		C
Centralised systems	C			[C]	[C]			P									[C]	C			
Transport refrigeration	C	P		P	P	C	P	P		P	P	P	P	P	P			C	P		P
Large size refrigeration	C	P		C	C			P		P	P			P	P		C	C			C
Air-conditioning and heat pumps																					
Small self contained	C			C	C	C	P	P				P	P						P		C
Mini-split (non-ducted)	C	C		C	C	C		P		P	P			P	P						C
Multi-split	C	P				C		P		P	P			P	P						
Split (ducted)	C	P				C		P		P	P			P	P			C			
Ducted split comm. & non-split	C	P		[C]	[C]	C		P		P	P			P	P			C			[C]
Hot water heating HPs	C			C	C	C	P	P	P			P	P			P	C	C	P	P	C
Space heating HPs	C	P		C	C	C	P	P	P	P	P	P	P	P	P		C	C	P	P	C
Chillers																					
Positive displacement	C	P		C	C	C	P	P	P	P	P	P	P	P			C	C	P	C	C
Centrifugal			C				P												P	P	
Mobile air-conditioning																					
Cars				P	P		P		P			P	P					C	C		P
Public transport	C	P				C	P	P	P	P	P	P	P	P	P			C	C		

Key:

C indicates current use on a commercial-scale

P indicates potential use in the future

[ ] indicates that the substance is used in an alternative system

Consideration of system lifetime

In order to ensure that products and installations are safe throughout the lifetime of equipment – both with regards to members of the public and workers, it is essential to address each stage in the equipment lifetime. The main stages in the equipment lifetime are shown in Figure 8.

To the left of Figure 8 are the key stages in the equipment lifetime, from conception of the product to the disposal of the equipment. In the centre column are examples of the personnel that are primarily concerned with working on those stages. To the right are examples of the types of activities those personnel are required to be competent at, in order to maintain a high level of safety. All the personnel involved need to be aware of their responsibilities, and those in charge must make sure that the workers are informed and aware of those responsibilities. Furthermore, it is clear that the actions taken by personnel at any stage in the equipment life usually have consequences at the latter equipment stages.

In general, since the equipment spends most of its lifetime in 'in-use – operation' stage, this represents the period within which the safety implications are most prominent.

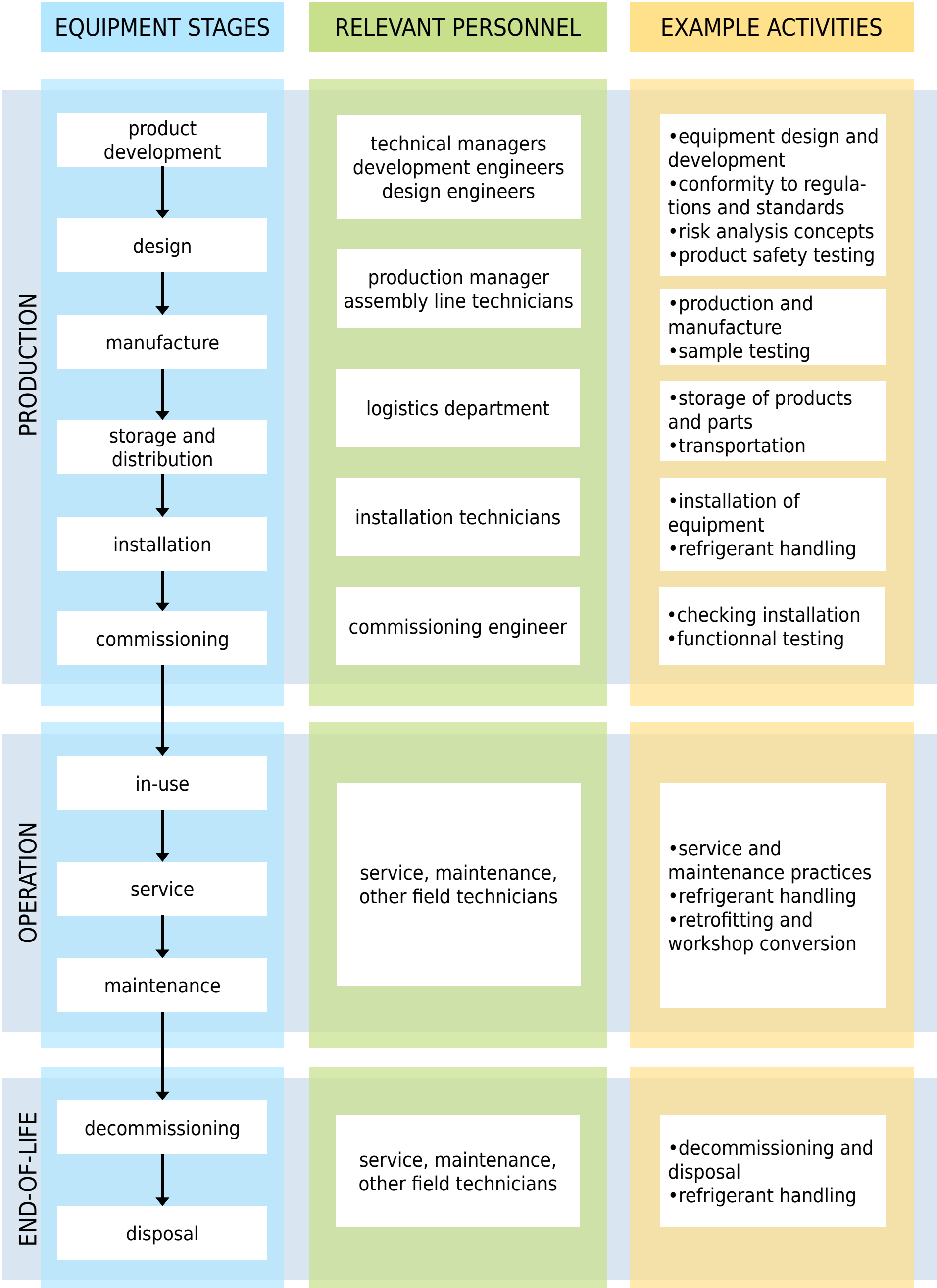


Figure 8. Overview of the stages within the equipment lifetime, the key personnel and the subject groups that may be needed to execute the work

There are common activities within many of the stages, meaning that many of the people involved in such stages need to be familiar with the technical details from various sections. For example, people working in production, installation, servicing, maintenance and decommissioning all need to be aware of good refrigerant handling practices. Also, people involved with the design, installation, commissioning, servicing and maintenance all need to be familiar with the requirements of the safety standards, to some extent depending upon their duties. Thus, many of the issues are interrelated throughout all the stages of the equipment life.

In general, whilst an organisation is preparing material for and working on each of the stages within the equipment lifetime, the following issues should be kept in mind for the purposes of ensuring the necessary levels of safety:

- In order to assist those working at the various stages, it would be useful to provide staff with concise, easy to use manuals, guidance notes, etc, focussed on each part or for each key activity they are expected to carry out. Ensure that it is comprehensible and peer reviewed.
- Provide proper and thorough training to those involved, both theoretical and practical.
- Check other literature; manuals, handbooks, industry guidelines, manufacturers documentation, refrigerant suppliers information, etc, and the original regulations and safety standards to ensure that the correct information is used.[5]
- Develop a system for obtaining feedback from other stages and set up a scheme for information sharing. Using such feedback, for example, from field data, technicians, etc, on aspects such as leakage, equipment and component failures, problems with repairs, actual minor or major accidents, and so on. Utilising this information will greatly enhance the level of safety for the future.

Lastly, producing guidelines can never anticipate all the situations that may be encountered, or all the peculiarities of different types of equipment. Therefore it is important that individuals understand the logic behind the rules and in this way they can be adapted to new or unforeseen equipment and situations.

[5] Refer to Further Reading, page 63

3 Safe Use of Refrigerants

Introduction to hazards

All refrigerants pose a number of safety implications:

- Asphyxiation, where displacement of oxygen causes suffocation
- Freeze burn, where cold refrigerant on the skin causes frostbite
- Toxicity effects – acute (e.g., anaesthesia, cardiac sensitisation) and chronic (e.g., liver damage)
- Flammability and explosion, where the refrigerant rapidly combusts when ignited
- Pressure (release), where a shock wave occurs from a rapid release of gas

The risk posed by refrigerants can be considered with regards to primary and secondary consequences, as shown in Figure 9. Essentially following a release of refrigerant, a sequence of events can follow that ultimately can lead to some form of damage to persons and property. Depending upon the type of substance, the conditions and environment within which it is released can result in a variety of different consequences.

With the introduction and potentially wide use of refrigerants that are flammable, have higher toxicity and/or operate at notably higher pressures than the ordinary refrigerants, consideration of safety matters becomes more important. Accordingly, more attention must be paid to the requirements of safety standards, regulations and good working practices that directly relate to refrigerants that exhibit these characteristics.

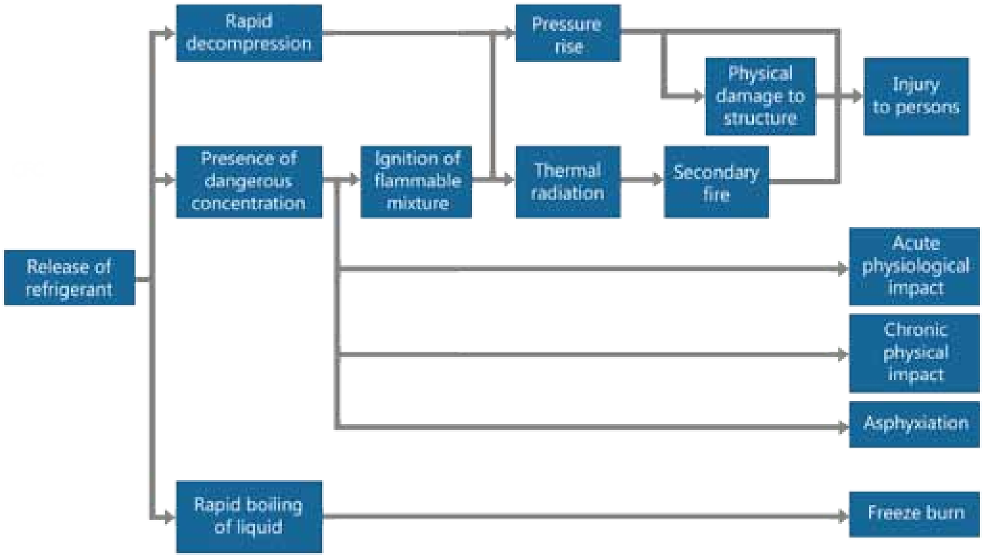


Figure 9. Overview of the various hazards associated with a release of refrigerant

Safety classification of refrigerants

The most widely used classification of substances is under the UN system for dangerous goods. Substances receive an alphanumeric designation, related to its state and other safety hazards. Depending upon a substance's classification, there are sets of generic rules which regard handling, labelling and other matters. An illustration of the system for selected refrigerants is shown in Table 3.

Number for state	State	Letter(s) for hazard	Hazard	Examples
2	Liquefied gas (under pressure)	A	Non-flammable	HCFC-22, R-744
		A	Flammable	HC-290, HFC-32
		TC	Toxic and corrosive	R-717

Table 3. Classification examples for UN system for dangerous substances

Within the refrigeration industry, a different classification scheme is applied, where most refrigerants are assigned a safety classification, which is a function of toxicity and flammability. The classification scheme is adopted by standards such as ISO 817.[6]

The toxicity classification is based on whether toxicity has or has not been identified at a certain concentration; there are two toxicity classes:

- **Class A**: no chronic toxicity effects have been observed below 400 ppm
- **Class B**: chronic toxicity effects have been observed below 400 ppm

The flammability classification depends upon whether or not the substances can be ignited in standardised tests, and if so, what the lower flammability limit (LFL) is and what the heat of combustion is. There are now four flammability classes (according to ISO 817):

- **Class 1**: do not show flame propagation when tested in air at 60°C and standard atmospheric pressure
- **Class 2L**: as Class 2 but with a laminar flame speed of less than 0.10 m/s
- **Class 2**: exhibit flame propagation when tested at 60°C and atmospheric pressure, but have a LFL higher than 3.5% by volume, and have a heat of combustion of less than 19,000 kJ/kg
- **Class 3**: exhibit flame propagation when tested at 60°C and atmospheric pressure, but have an LFL at or less than 3.5% by volume, or have a heat of combustion that is equal to or greater than 19,000 kJ/kg

Typically, a “higher” classification – that is toxicity Class B instead of Class A, and flammability Class 3 instead of Class 1 – means that the refrigerating system has more onerous design requirements associated with it, in order to handle the higher risk presented by the refrigerant (Figure 10).

6 International Organization for Standardization (ISO) 817, Refrigerants – designation and safety classification

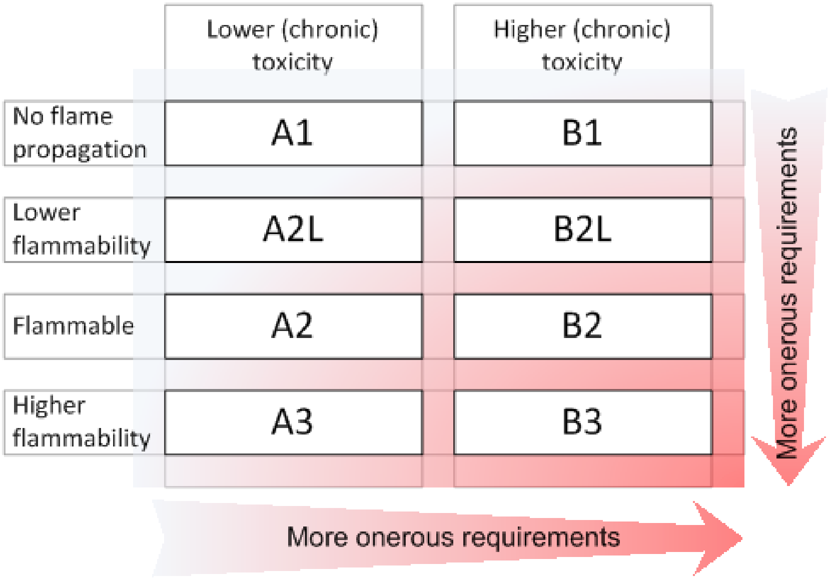


Figure 10. Refrigerant safety classification according to ISO 817 and influence on safety requirements

In addition to the alphanumeric classification, there are three other parameters that are determined for each refrigerant that helps to enable acceptable quantities of the refrigerant for a given set of circumstances (related to the type and installation of the refrigeration system).

- **Lower flammability limit**: The lower flammability limit (LFL) of refrigerants is typically applied as a constraint to the amount of refrigerant that can be released into a room or enclosure, as it represents the smallest quantity that, when in the presence of an active source of ignition, could sustain a flame.
- **Acute toxicity exposure limit**: The acute toxicity exposure limit (ATEL) of any refrigerant may also applied as a constraint to the amount of refrigerant that can be released into a room or enclosure, as it represents the smallest quantity that could impose adverse toxicological effects onto occupants.
- **Practical limit** (PL) and **room concentration limit** (RCL): This is a further safety measure for the application of refrigerants and represents the highest concentrations level in an occupied space which will not result in any escape impairing (i.e., acute) effects. Thus, it is principally, the lowest “dangerous” concentration of a refrigerant, with a safety factor applied. For class A1, class B and sometimes class A2L refrigerants, the PL and RCL is normally based on the ATEL, whereas for A2 and A3 refrigerants it is normally dictated by the LFL.

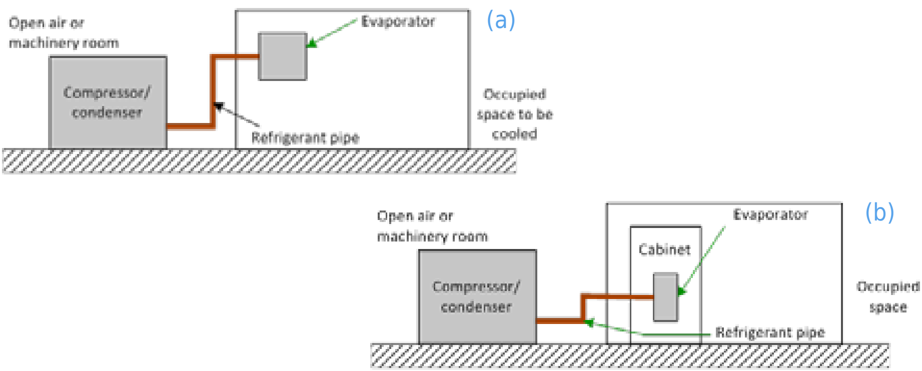
Classification of refrigeration systems, locations and occupancies

When applying a particular refrigerant, the characteristics of the system within which it is used and the characteristics of the local environment dictate the manner in which it is applied and also the quantities of refrigerant that are allowed, according to the common safety standards (e.g., EN 378[7], ISO 5149[8]). There are different arrangements for refrigeration systems, locations within which parts of the system are present and types of occupancy.

The main system arrangements can be broadly divided into two types: "direct" and "indirect" (with respect to the "target" of the cooling or heating). A direct system is where the refrigerant-containing parts are located in the space to be cooled or heated (whether it is a cold room, a display cabinet or an air conditioned room) and the refrigerant from a leak could flow unobstructed into the space to be cooled or heated. An indirect system is one that uses some heat transfer fluid (HTF) such as water, brine or glycol, to transfer heat between the space to be cooled and the primary refrigerant circuit; in this regard, if there is a leak of refrigerant then it is unlikely to enter the cooled or heated space and the risk is typically lower.

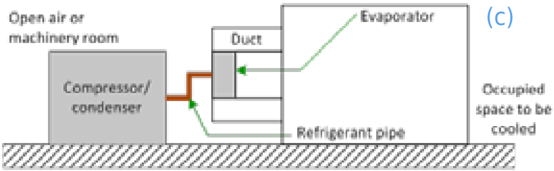
Figure 11 shows some examples of direct systems. Case (a) could be a split air-conditioner or a cold store, case (b) could be a refrigerated display case connected to an external condensing unit, case (c) could be a ducted air-conditioning system and case (d) could be a plug-in storage cabinet or a portable air-conditioner. In all cases, there is refrigerant piping and/or refrigerant-containing parts that could directly leak refrigerant into the occupied space.

Figure 11. Examples of direct systems



[7] EN 378, Refrigeration systems and heat pumps – Safety and environmental requirements
[8] ISO 5149, Refrigerating systems and heat pumps — Safety and environmental requirements

Figure 11. (continued) Examples of direct systems



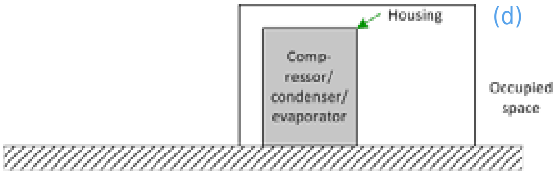
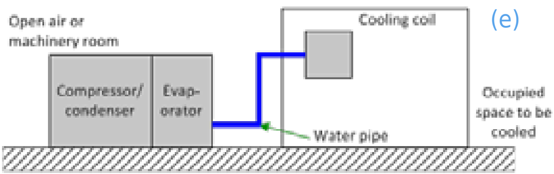
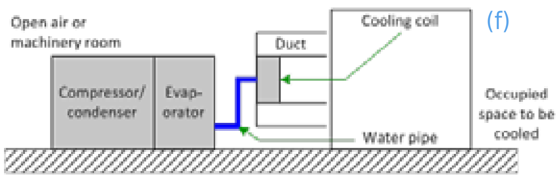


Figure 12 gives examples of indirect systems. Case (e) could be a refrigerated warehouse using a brine or a chilled water air-conditioning system and case (f) could be an air-conditioning system using a chilled water coil in a central air handling unit. With both cases, no refrigerant piping or other parts of the circuit are directly within the occupied space and so a leak of refrigerant would be highly unlikely to be present in those occupied spaces.

Figure 12. Examples of indirect systems





The "occupancy" refers to the intended use of the space and degree of knowledge of safety procedures by those that are present. As such, occupancies are normally categorised into four types:

- Public spaces (with "general" occupancy): 'category a' – such as retail areas in shops and public parts of auditoria
- Private spaces (with "supervised" occupancy): 'category b' – such as offices
- Restricted access (with "authorised" occupancy): 'category c' – such as workshops, cold stores, etc
- Unoccupied spaces – such as machinery rooms and authorised access-only spaces

Since the risk to persons is greater in *occupancy a* spaces, where there are broadly uncontrolled numbers, most of whom have no idea about safety procedures in the event of an emergency, requirements tend to be more stringent. Whereas for restricted access spaces with (typically) only a small number of authorised persons that have a high level of knowledge of safety procedures, the requirements are less severe.

Figure 13 provides an illustration of these concepts. Here, "more severe" requirements refer to the obligations on the design and construction of the refrigeration equipment, which may include:

- A limit on the amount of refrigerant that is permitted in the system
- The number of safety devices (such as pressure relief valves, pressure switches and temperature limiters) to be added to the system
- The use of additional features such as gas detection and mechanical ventilation

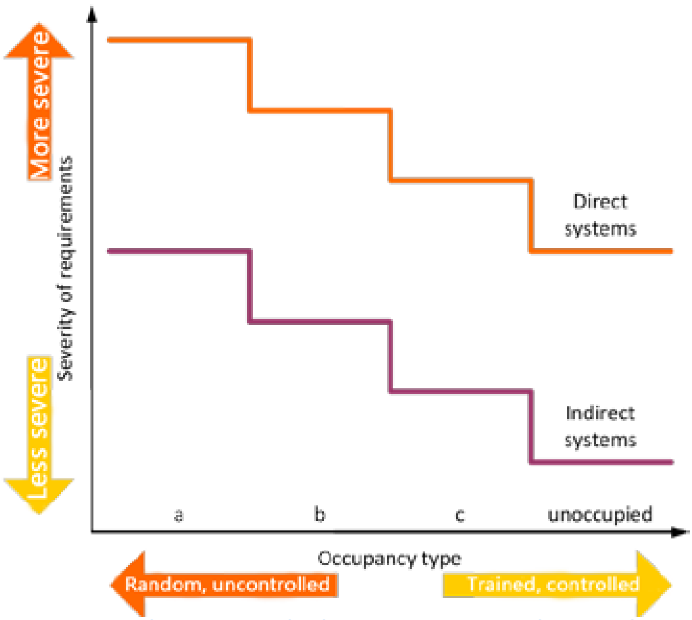


Figure 13. Representation of the severity of safety requirements as a function of occupancy and system type

Regulations, safety standards and guidelines[9]

Depending upon the country and the circumstances, there are a large number of regulations, safety standards, codes of practice and industry guidelines to help with the safe application of flammable, higher toxicity and higher pressure refrigerants. The Further Reading section (page 63) provides a more comprehensive list of various publications that are available.

National and regional regulations represent the overarching authority in terms of special considerations for the use, design and installation of equipment. Given the diversity amongst Article 5 countries, it is not possible to generalise particular regulations. However, it is common to have regulations covering these topics in most regions:

- Safe use and application of flammable substances
- Safe handling of flammable substances
- Safe design and use of equipment under elevated pressures
- Characterisation and controls of substances that pose toxicity risks

Typically such regulations provide a framework for evaluating hazards and mitigating risk and only with basic provision of practical requirements with a demand that things must be "safe"; such a formulation therefore allows for implementation of new substances and

[9] For more information, refer to http://www.unep.fr/ozonaction/information/mmcfiles/7679-e-International_Standards_in_RAC.pdf

applications and allows for technological development where needed. Since almost all refrigerants operate under pressure and have some extent of toxic effects and many of them are also flammable, it is to be expected that most of the previously mentioned types of regulations need to be considered.

At the next level, safety standards (and industry codes of practice) are developed in order to provide more practical interpretation of the guidance from regulations. Sometimes these are developed for specific types of equipment or applications (so-called "vertical standards") whilst others are more generic ("horizontal standards"). Safety standards are generated internationally (e.g., ISO, IEC), regionally (e.g., EN in Europe) and nationally. Often there are parallels or alignment between standards of similar scope across these different levels, although individual countries can elect to adopt alternative requirements than those at international level. The main international and regional standards that affect design and construction of systems according to refrigerant selection are listed in Table 4 along with the relevant application sectors.

Sector	IEC 60335-2-24[10]	IEC 60335-2-40[11]	IEC 60335-2-89[12]	ISO 5149	ISO 13043[13]	EN 378
Domestic refrigeration	x					
Commercial refrigeration			x	x		x
Industrial systems				x		x
Transport refrigeration				x		x
Air-to-air air-conditioners		x		x		x
Water heating heat pumps		x		x		x
Chillers		x		x		x
Vehicle air-conditioning					x	

Table 4. Scope of different international and regional safety standards for refrigeration systems

Throughout these standards, there are some basic implications that relate to the application of flammable, higher toxicity and higher pressure refrigerants; these are summarised in Table 5. In principle, these measures are intended to offset the potentially more severe risk arising from the greater hazards posed by the alternative refrigerants.

Safety standards are chiefly a set of guidelines that have been developed and agreed upon by some sort of consensual process amongst a group of representatives typically from a small number of stakeholder enterprises often over several years. Consequently, the published requirements may not and often do not reflect the state-of-the-

[10] IEC 60335-2-24, Specification for safety of household and similar electrical appliances. Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers
[11] IEC 60335-2-40, Specification for safety of household and similar electrical appliances. Particular requirements for electrical heat pumps air-conditioners, and dehumidifiers
[12] IEC 60335-2-89, Specification for safety of household and similar electrical appliances. Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor
[13] ISO 13043, Road vehicles – Refrigerant systems used in mobile air-conditioning systems (MAC) – Safety requirements

Greater flammability	Greater toxicity	Greater pressure
• Stricter limits on the quantity of refrigerant in occupied spaces • Use of gas detection, alarms and emergency ventilation • Prohibition of items that could act as sources of ignition • Warnings/signage	• Stricter limits on the quantity of refrigerant in occupied spaces • Limited use in more densely populated areas • Use of gas detection, alarms and emergency ventilation • Provision of personal protective equipment	• Thicker materials/higher pressure rating for pipes and components • Additional use of pressure relief devices and/or pressure limiting devices • Higher competencies for workers involved in construction of components and assemblies

Table 5. Main measures to be considered for substances with greater pressure, toxicity and/or flammability

art in technology and can also favour certain technologies over others, as according to the enterprises that participate in the process. Similarly, standards are continually evolving and requirements also tend to change over time; despite this, standards are seldom without oversights. For these reasons, stakeholders that utilise such standards must give close consideration to the text and meaning of these standards and where necessary use diligence in adopting suitable measures.

Often industry bodies, such as technical institutes and associations develop publications such as codes of practice and technical guidelines on safety matters. These typically provide further practical interpretation of the requirements of regulations and to some extent safety standards. These are particularly useful when the formal sources contain errors (which may take many years to correct due to bureaucratic procedures) or ambiguities that need explicit interpretation for industry practitioners. Furthermore, the information can also be tailored for local conditions and practices and also provide alternative routes to achieving the level of safety required by regulations but not otherwise offered by safety standards.

4 Detailed Considerations for Refrigerants

Important considerations for various activities

Since the various alternative refrigerants pose additional safety hazards compared to the ordinary refrigerants, it is essential that they are handled differently in some respects, or the same with additional precautions. Table 6 lists a selection of some of these refrigerants and observation of some of their respective safety parameters – such as safety class, saturation pressure, LFL, ATEL and PL provide an introduction to the basic difference compared to HCFC-22.

It is essential that these "new" characteristics are taken into consideration throughout the entire lifetime of the use of the refrigerant.

Depending upon the stage at which refrigeration equipment is, there are various activities that may be considered to be of particular importance when working with certain alternative refrigerants. Table 7 provides a summary of some of the more important activities that should be planned and carried out carefully in order to minimise the additional risk associated with switching to a flammable, higher toxicity or higher pressure refrigerant.

Of particular importance are aspects related to risk assessment, design requirements for systems, leak tightness of systems[14], topics for training and tools and equipment normally used by technicians; these are addressed in more detail henceforth. Standards such as EN 13313[15] are helpful for identifying the competence criteria for the training of persons carrying out different types of tasks.

Table 6: Safety data for selected refrigerants[16]

Refrigerant	Safety class (ISO 817)	Saturation pressure at 25°C (bar, abs)	Lower flammability limit (LFL) in % by volume in air (and g/m³)	Acute toxicity exposure limit (ATEL) in % by volume in air (and g/m³)	Practical limit (PL) in % by volume in air (and g/m³)
HCFC-22	A1	10.4	None	5.9% (209)	5.9% (209)
HFC-32	A2L	16.9	14.4% (306)	22% (468)	2.9% (61)
HCFC-123	B1	0.9	None	0.9% (57)	0.9% (57)
HFC-134a	A1	6.7	None	5.0% (210)	(250)
HFC-152a	A2	6.0	4.8% (130)	5.0% (140)	1.0% (27)
HC-290	A3	9.5	2.1% (38)	5% (90)	0.4% (8)
R-404A	A1	12.5	None	13.0% (520)	13.0% (520)
R-407C	A1	11.9	None	8.8% (310)	8.2% (290)
R-410A	A1	16.6	None	14.8% (440)	14.2% (420)
R-444A*	A2L	7.1	7% (290)	6% (270)	1.4% (60)
R-444B*	A2L	10.6	7% (180)	8% (200)	1.4% (40)
R-445A*	A2L	7.4	8% (340)	6% (250)	1.5% (70)
R-446A*	A2L	13.7	8% (180)	3% (60)	1.6% (40)
R-447A*	A2L	13.8	9% (220)	11% (260)	1.9% (50)
R-451A*	A2L	6.8	7% (320)	9% (420)	1.4% (60)
R-451B*	A2L	6.8	7% (320)	9% (410)	1.4% (60)
R454A*	A2L	6.8	8% (290)	12% (470)	1.5% (60)
R454B*	A2L	12.8	10% (300)	16% (470)	2.0% (60)
HC-600a	A3	3.5	1.8% (43)	2.9% (69)	0.4% (9)
R-717	B2L	10.0	16.7% (116)	0.03% (0.2)	0.03% (0.2)
R-744	A1	64.3	None	4.0% (72)	4.0% (72)
HFC-1234yf	A2L	6.8	6.2% (289)	10% (466)	1.2% (58)
HFC-1234ze(E)	A2L	5.0	6.5% (303)	5.9% (275)	1.3% (61)
HC-1270	A3	11.5	2.7% (46)	0.1% (2)	0.5% (9)

* Data for these new mixtures is not publically available so LFL, ATEL and PL are approximated and rounded

[14] Useful standards include EN 15834, Refrigerating systems and heat pumps — Qualification of tightness of components and joints
[15] EN 13313: 2008 – Refrigeration Systems and Heat Pumps. Competence of Personnel
[16] Refer to the Appendix (page 64) which provides safety characteristics for most commercially available refrigerants.

''It is essential that alternative refrigerants are handled with additional precautions.''

Table 7. Considerations for main activities for all flammable, higher toxicity and higher pressure refrigerants

Activity	Important considerations
Product development	• Awareness of the need for features to mitigate flammability/toxicity/pressure risk • Flammability/toxicity/high pressure risk assessment • Suitable safety testing
Design	• Adherence to regulations, standards (avoiding flammable releases, leakage, ignition sources) • Third party approvals
Manufacturing	• Suitable storage of refrigerant, charging equipment, leak detection, factory safety systems • Availability of proper parts and components (e.g., safe electrical equipment) • Workers are suitably trained
Storage and distribution	• Suitability of transport is properly assessed • Warehousing is properly assessed • Proper markings/warnings for packaging
Installation	• Technicians in possession of proper refrigerant handling tools and equipment • Technicians are suitably trained • Safe work procedures are provided and followed
Commissioning	• Engineers are suitably trained • Leak tightness and strength pressure checking • Checking safety systems (gas detectors, gas detection, emergency ventilation and alarms)
In-use	• For large systems, gas detection, emergency ventilation and alarms are functional • For all systems, product development, design and installation should be adequate for inherent safety
Service	• Technicians are suitably trained • Technicians in possession of proper refrigerant handling tools and equipment • Safe work procedures are provided and followed
Maintenance	• Technicians are suitably trained • Technicians in possession of proper refrigerant handling tools and equipment • Safe work procedures are provided and followed
Decommissioning	• Technicians are suitably trained • Technicians in possession of proper refrigerant handling tools and equipment • Safe work procedures are provided and followed • Proper and safe venting procedures, where appropriate
Disposal	• Disposal facility is aware of residual potentially flammable gas • Proper markings/warnings for packaging

Safety issues related to flammable refrigerants

There are a number of flammable refrigerants – some old and some recently developed. Table 6 (page 35) lists some of the basic safety characteristics of the flammable refrigerants that are currently used and some that are being studied in anticipation of their commercialisation. Although there are many flammable refrigerants the extent of their flammability varies quite widely; it can be seen that some substances have relatively low LFLs (Lower flammability limit) (e.g., HC-290 with 38 g per m^3) whilst others have significantly greater LFL (e.g., HFC-1234yf with 289 g per m^3). There are other flammability characteristics such as minimum ignition energy, heat of combustion and burning speed that have an impact of the ease to which a substance can be ignited and the severity of the consequence following ignition; these are all broadly proportionate to the LFL.

General risk assessment

With all flammable refrigerants, the risk arises with the possible ignition of a flammable concentration.
Ignition is caused by an unprotected source of ignition – this could be an electric spark, a naked flame, a very hot surface or some other event that creates sufficient energy. Ignition may occur wherever the refrigerant has leaked and mixed with air in the correction proportions, i.e., between the lower and upper flammability limits. Depending upon the architecture of the equipment, this could occur within the refrigerated space, within equipment housing, within other spaces that piping or parts are present or in the open air. The initial consequences can include pressure rise ("overpressure"), thermal radiation and formation of toxic decomposition products (e.g., from the flammable HFCs). Depending upon the local conditions, subsequent consequences may be physical damage to property and persons, creation of a secondary fire and toxic effects of the decomposition products on persons. Figure 14 provides the basic steps for a flammability risk assessment. Note that it is not only sufficient to assess the risk but also to identify and introduce risk mitigation measures in order to avoid or minimise the likelihood and consequences of unintended outcomes.

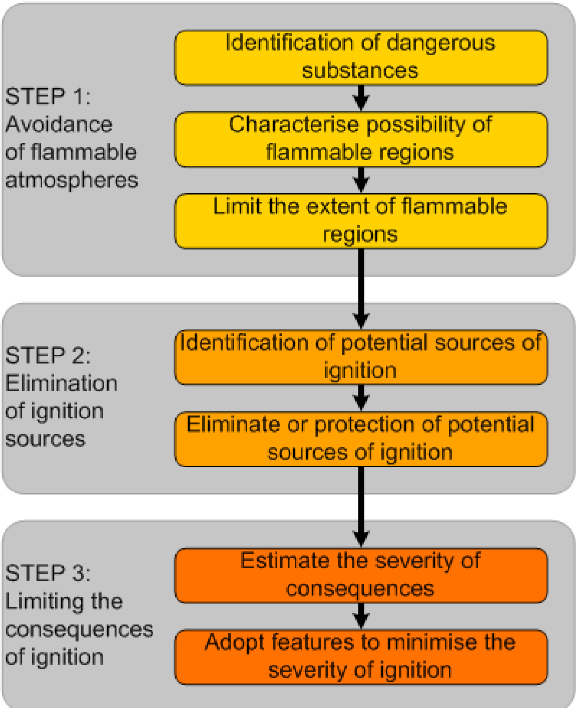


Figure 14. Basic steps for flammability risk assessment

Refrigeration system design requirements

For flammable refrigerants, appropriate design requirements – that are over and above what would normally be required for ordinary refrigerants – can be found in regulations, standards, codes of practice and industry guidelines. The main issues described in these sources to be addressed, include:

- Limiting the quantity of refrigerant to an amount that is unlikely to be ignited (i.e., refrigerant charge limits)
- Designing the system and components for smaller refrigerant charge amounts
- Not installing equipment in vulnerable locations (i.e., where there are an excess of potential sources of ignition)
- Ensuring systems have a high level of leak tightness.
- Constructing the system so that there are no potential sources of ignition that could ignite a refrigerant leak (e.g., no sparking components where a leak of refrigerant could accumulate)
- More frequent use of gas detection and ventilation systems to assist with dispersing any leak of refrigerant

- Applying the necessary warnings to accessible parts of the system to ensure that technicians are aware of the hazard (e.g., flammable gas stickers near charging points)
- Including the necessary information relating to flammability in installation and operating documentation

Table 8 provides some example charge size limits based on selected conditions for various flammable refrigerants (noting that different standards and guidelines tend to have different limits). It can be seen that refrigerants with a higher LFL are permitted larger quantities (per refrigerant circuit) than those with lower LFL. In such cases where a greater refrigerant charge is desired, additional features can be applied to the design of the system so that the amount of refrigerant that would be released or the developed concentration in the event of a leak can be limited. For example, the use of shut-off valves within the circuit, which are initiated by gas detectors or operating parameters, thereby preventing all the refrigerant leaking out. Similarly gas detectors or other parameters can be used to initiate airflow to dilute the refrigerant in the event of a leak such that the concentration cannot reach the LFL. Also, larger systems can be divided into smaller systems with smaller refrigerant charges. By adopting such measures, these flammable refrigerants can be applied more widely. For systems installed outside in the open air or in machinery rooms, there are normally no such limitations. Standards such as EN 1127-1[17] are useful for assisting with the design considerations of systems use flammable refrigerants.

Key topics for training

As discussed previously, training is necessary for all those involved at all stages throughout the life of the equipment; amongst factory workers, system design engineers and field technicians, a number of topics are generally necessary (in addition to those for general safety of all refrigerants). Table 9 provides an indicative list of the general topics that are normally required for persons involved in applying and handling flammable refrigerants. Generally the basic principles are necessary for all involved, whereas the other topics may be more relevant to those involved in the development and design of equipment or refrigerant handling activities during installation, service, maintenance, etc.

[17] EN 1127-1, Explosive atmospheres – explosion prevention and protection. Basic concepts and methodology

Table 8. Example test pressures and charge limits for selected refrigerants and occupancies for ISO 5149

Refrigerant Class	Refrigerant	Example design test pressure [a] (bar, abs)	Allowable charge in 15 m^2 occupied space (comfort) [b] (kg)	Allowable charge in 15 m^2 occupied space (general) [c] (kg)	Max. charge in occupied space (occupancy A / B) (kg)	Max charge in open air or machinery room	Max charge for a ventilated enclosure (kg)
A1	HCFC-22	32	11.3	11.3	PL×RV [d]	no limit	PL×RV [d]
	HFC-134a	22	9.4	9.4			
	R-404A	38	19.5	19.5			
	R-407C	36	11.6	11.6			
	R-410A	50	16.5	16.5			
	R-744	129 [f]	3.8	3.8			
A2L	HFC-32	51	1.3 – 4.9	2.3	12 (60 [e])	no limit	60
	R-444A	22	1.2 – 4.6	2.2	11 (57 [e])		57
	R-444B	32	0.7 – 2.5	1.4	7 (36 [e])		36
	R-445A	22	1.5 – 5.5	2.5	13 (66 [e])		66
	R-446A	41	0.7 – 2.2	1.4	7 (35 [e])		35
	R-447A	42	0.9 – 3.3	1.7	9 (43 [e])		43
	R-451A	21	1.4 – 5.1	2.4	12 (62 [e])		62
	R-451B	21	1.4 – 5.1	2.4	12 (62 [e])		62
	R-454A	29	1.2 – 4.6	2.2	11 (57 [e])		57
	R-454B	39	1.3 – 4.7	2.2	12 (58 [e])		58
	HFC-1234yf	21	1.2 – 4.5	2.2	11 (56 [e])		56
	HFC-1234ze(E)	17	1.3-4.8	2.3	12 (59 [e])		59
A2	HFC-152a	20	0.5 – 1.7	1.0	3.4	no limit	17
A3 [g]	HC-290	28	0.1 – 0.4	0.3	1.5 / 2.5	no limit	4.9
	HC-600a	11	0.1 – 0.4	0.3	1.5 / 2.5		5.6
	HC-1270	33	0.1 – 0.4	0.3	1.5 / 2.5		6.0
B1	HCFC-123	4	2.1	2.1	PL×RV	no limit	PL×RV
B2L	R-717	34	0.01	0.01	4.5	no limit	23

PL=Practical limit; RV=Room volume
a Assuming 46°C ambient, 10 K condenser temperature difference, individual test (1.43 times the maximum condenser pressure)
b Depending upon installation conditions
c 2.5 m high room
d For systems with multiple indoor heat exchangers a higher charge may be allowed depending on circumstances.
e For systems with multiple indoor heat exchangers
f Since condition is supercritical (i.e., in a transcritical process), pressure based on 90 bar design pressure for gas cooler
g HC refrigerants have much lower densities so 2 – 3 times greater refrigerating capacity can be achieved with the same charge of refrigerant
Note: Allowable and maximum charges are per individual refrigerant circuit and there is no limit on the number of separate circuits in a room
Note: The values provided within this table are indicative and determination of refrigerant charge size limits for particular types of systems and installation locations requires the use of the standard and the values within this table should not be taken as a substitute

Table 9. Key topics for training (not exhaustive)

Topics	Flammable	Higher toxicity	Higher pressure
Basic principles			
• How to carry out flammability risk assessment for systems and installations	X		
• How to carry out toxicity risk assessment for systems and installations		X	
• How to carry out elevated pressure risk assessment for systems and installations			X
• Awareness of material safety data sheets (MSDS)	X	X	X
• Flammability characteristics ("fire triangle", LFL, ignition energy, heat of combustion, etc)	X		
• Toxicity characteristics (short term, long term, physiological effects, etc)		X	
• Relevant safety standards and regulations that relate to equipment using flammable, higher toxicity and higher pressure gases	X	X	X
• Differences in refrigerant density compared to ordinary refrigerants and the implications on charge size and cylinder filling	X		
• Differences in refrigerant pressure compared to ordinary refrigerants and the implications on system design pressure and size and cylinder pressure ratings			X
• Behaviour of a leak of refrigerant under different circumstances, i.e., the flow of denser-(or lighter-) than-air gas in closed rooms, enclosures, the outside in still or windy conditions and the effect of ventilation	X	X	
System design and construction			
• Classifications within refrigeration safety standard – flammability, toxicity, occupancies, locations, system types	X	X	X
• Requirements of safety standards – determination of charge size limits (or minimum room sizes), need for safety devices (such as pressure limiters, pressure relief, etc), gas detection, ventilation, etc	X	X	X
• Sources of ignition; types of ignition sources, spark energies, temperature effects, etc	X		
• Need for and types of protection appropriate for potential sources of ignition	X		
• Importance of leak minimisation and methods for avoiding leakage	X	X	X
• Information requirements such as equipment marking, labelling and signage	X	X	X

(continued...)

Table 9. (continued) Key topics for training (not exhaustive)

Topics	Flammable	Higher toxicity	Higher pressure
Working practices			
• How to carry out a risk assessment for creating and maintaining a safe working area and for carrying out work on a system containing flammable refrigerants	X		
• How to carry out a risk assessment for creating and maintaining a safe working area and for carrying out work on a system containing higher toxicity refrigerants		X	
• How to carry out a risk assessment for creating and maintaining a safe working area and for carrying out work on a system containing higher pres-sure refrigerants			X
• Selection and use of appropriate tools, equipment and personal protective equipment (PPE) when handling flammable, higher toxicity or higher pressure refrigerants	X	X	X
• Appropriate use of fire extinguishers	X		
• Standard procedures for safe charging, recovery, evacuation, venting, etc	X	X	X
• Emergency response procedures, such as in the event of a major release or a fire or carrying out first aid	X	X	X
• Provision of relevant information for data-plates, equipment documentation and owners/operators	X	X	
• Selection of appropriate 'like for like' replacement components for electrical devices, electrical enclosures, compressors, etc., and maintaining the integrity of sealed electrical enclosures	X		
• Presence and absence of odorant	X		
• Restriction on relocation of existing systems/equipment	X	X	X

Service tools and equipment

For technicians and engineers that are working directly with flammable refrigerants, it is essential that workers have available and use the appropriate tools and equipment. Whilst it is often the case that certain tools and equipment are equally applicable to most refrigerants, there are some that may ordinarily present an ignition risk. The most relevant tools and equipment are discussed in Table 10.

Figure 15. Refrigerant recovery machines for HCs (left) and all flammable refrigerants except R-717 (right)

Figure 16. Ex-type mechanical fan using used for ventilating area when handling flammable refrigerants

Figure 17. Electronic manifold gauge set that can be used with flammable refrigerants, R-717 and high pressure refrigerants (up to 50 bar)

Figure 18. Flammable gas warning sign that must be on flammable refrigerant recovery cylinders

Figure 19. Refrigerant gas detectors for hydrocarbon (HC) refrigerants

Table 10. Considerations for tools and equipment for use with flammable refrigerants

Item	Remarks
Gas detectors	Should be electronic and intended for use with flammable gases and the refrigerant intended (Figure 19).
Balance/scales	If electronic, should be suitable for use in an area where flammable refrigerant may be present, as confirmed by the manufacturer.
Manifold/gauge/hose set	Materials should be compatible, be able to withstand the maximum pressure and, if electronic, be suitable for use in the presence of flammable refrigerant (Figure 17).
Vacuum gauge	If electronic, be suitable for use in the presence of flammable refrigerant, as confirmed by the manufacturer.
Vacuum pump	Should be suitable for use with flammable gases (e.g., not with a brushed motor) or arranged so that it can be switched on/off in a location where a release of flammable refrigerant cannot reach.
Refrigerant cylinder adapters	Ensure that the correct type of cylinder adapter is present to enable safe removal of refrigerant from the cylinder
Recovery cylinder	Must be rated for the maximum pressure of the refrigerant being used and have the appropriate flammable gas warnings, also proper refrigerant cylinder handling rules must be adhered to (Figure 18, Figure 28)
Refrigerant recovery machine	Must be suitable for use with the type of refrigerant under consideration and also be designed appropriately for flammable refrigerants (Figure 15)
Venting hose	Due to the negligible environmental impact of direct releases for certain flammable refrigerants, specifically hydrocarbons, venting is sometimes practiced instead of recovering (generally for small refrigerant charges); in this case, a venting hose with sufficient length to allow venting directly to a safe place in the open air is necessary.
Mechanical ventilation	When working with larger charges of refrigerant, it can be beneficial to use a safe mechanical ventilation unit to help dilute refrigerant that has been accidentally released
Personal protective equipment (PPE)	Normally standard items such as goggles, gloves, fire extinguisher (Figure 29, Figure 30)

Safety issues related to higher toxicity refrigerants

As seen in Table 6, there is primarily one alternative refrigerant that is of higher toxicity, ammonia (R-717); as such this is the only refrigerant discussed in this section. The table lists some of the basic safety characteristics, which shows that it is flammable as well as being higher toxicity. Another important consideration for R-717 is its corrosivity and its affinity for moisture.

General risk assessment

With higher toxicity refrigerants and specifically R-717, the primary hazard is the inhalation of leaked refrigerant by persons. Other hazards, albeit less common include direct contact with liquid refrigerant and possible ignition of a flammable concentration. Excessive exposure to a toxic concentration may arise due to an accidental release of refrigerant within an enclosed space – or even an open space if the release is of sufficient magnitude – and the occupants are not in immediate possession of the appropriate Personal Protective Equipment (PPE). Particularly with R-717, adverse reactions can occur even at extremely low concentrations (in the order of tens or hundreds of parts per million in air). The consequences of inhalation can include irritation of eyes and nose with a sore throat, cough, chest tightness, inflammation, lacrimation, photophobia, headache and confusion and eventual fatality. The consequence of direct contact to the skin exposure may result in deep burns whereas inhalation may result in burns to the mouth and throat. Figure 18 provides the basic steps for a risk assessment for higher toxicity substances. Note that it is not only sufficient to assess the risk but also to identify and introduce risk mitigation measures in order to avoid or minimise the likelihood and consequences of unintended outcomes.

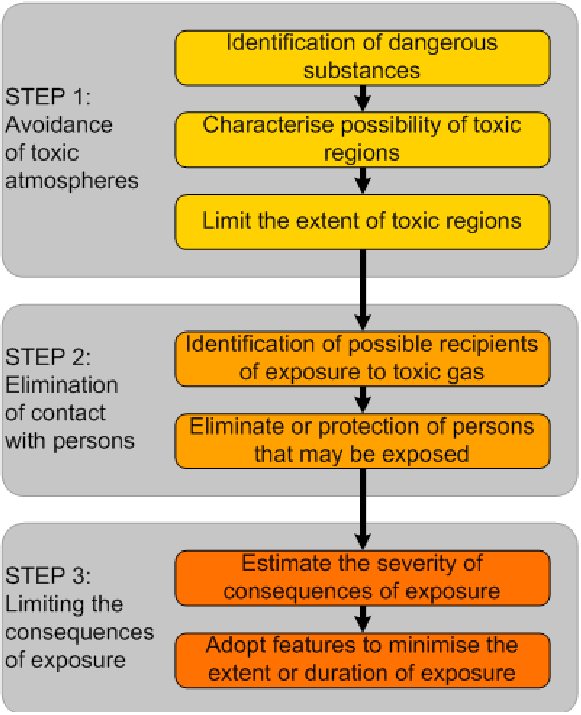


Figure 20. Basic steps for toxicity risk assessment

Refrigeration system design requirements

For higher toxicity refrigerants, appropriate design requirements – that are over and above what would normally be required for ordinary refrigerants– can be found in regulations, standards, codes of practice and industry guidelines. The main issues described in these sources to be addressed, include:

- Limiting the quantity of refrigerant to an amount that is unlikely to pose a toxicity risk (i.e., refrigerant charge limits)
- Designing the system and components for smaller refrigerant charge amounts
- Not installing equipment in vulnerable locations (i.e., where there are large groups of uncontrolled occupants)
- Ensuring systems have a high level of leak tightness.
- More frequent use of gas detection and ventilation systems to assist with dispersing any leak of refrigerant
- Provision of specialist personal protective equipment (PPE), such as respirators, suitable clothing and washing facilities.
- Applying the necessary warnings to accessible parts of the system to

ensure that technicians are aware of the hazard (e.g., warning signs near charging points)
- Including the necessary information relating to toxicity effects in installation and operating documentation

Table 8 (page 41) provides some example charge size limits based on selected conditions for R-717 (noting that different standards and guidelines tend to have different limits) and HCFC-123. It can be seen that particularly with R-717, because of its very low acute toxicity exposure limit (ATEL), the permitted quantities of refrigerant (per refrigerant circuit) are extremely small. Depending upon the occupancy, location and type of system, larger quantities are allowed and furthermore, additional features can be applied to the design of the system so that the amount of refrigerant that would be released is limited. For systems installed outside or in machinery rooms, there are normally no such limitations.

Key topics for training

As discussed previously, training is necessary for all those involved at all stages throughout the life of the equipment; amongst factory workers, system design engineers and field technicians, a number of topics are generally necessary (in addition to those for general safety of all refrigerants). Table 9 (page 42) provides an indicative list of the general topics that are normally required for persons involved in applying and handling higher toxicity refrigerants. Generally the basic principles are necessary for all learners, whereas the other topics may be more relevant to those involved in the development and design of equipment or refrigerant handling activities during installation, service, maintenance, etc.

Service tools and equipment

For technicians and engineers that are working directly with higher toxicity refrigerants, it is essential that workers have available and use the appropriate tools and equipment. Whilst it is often the case that certain tools and equipment are equally applicable to most refrigerants, there are some that may ordinarily compromise safety. The most relevant tools and equipment are discussed in Table 11.

Figure 21. Refrigerant gas detector for ammonia (R-717)

Figure 22. R-717 recovery pump set

Figure 23. Example of respiratory equipment

Figure 24. Example of protective suit for R-717

Table 11. Considerations for tools and equipment for use with ammonia (R-717)

Item	Remarks
Gas detectors	Should be electronic and intended for use with R-717 (Figure 21).
Manifold/gauge/hose set	Materials must be compatible with R-717, be able to withstand the maximum pressure and, if electronic, be suitable for the characteristics of R-717 (Figure 17).
Vacuum gauge	Materials must be compatible with R-717.
Vacuum pump	Should be suitable for the characteristics of R-717.
Refrigerant cylinder adapters	Ensure that the correct type of cylinder adapter is present to enable safe removal of refrigerant from the cylinder
Recovery cylinder	Must be rated for the maximum pressure of R-717, have the appropriate warnings and be of a material that is compatible with R-717. Also proper refrigerant cylinder handling rules must be adhered to (Figure 28, Figure 31)
Refrigerant recovery machine	Must be suitable for use with R-717 (Figure 22)
Personal protective equipment (PPE)	Further to normal PPE, depending upon the quantity of refrigerant involved, special respiratory protection (canister type self-contained respirators or breathing equipment) shall be provided. In addition, protective clothing including face-shield with transparent visor, gas-tight goggles, gauntlet thermal insulating gloves, protective suit and hood impervious to R-717 and rubber boots shall be available (Figure 23, Figure 24). Also a safety shower or bath and an eye fountain must be present.

Safety issues related to higher pressure refrigerants

As seen in Table 6 (page 35), although there are several refrigerants with a higher pressure than HCFC-22, most of these are within a pressure range which is not more than 50% greater. There is on alternative refrigerant, though, carbon dioxide (R-744), which has a substantially higher pressure – typically by a factor of six; as such the implications of this is the focus of the present discussion. For some others such as R-410A and HFC-32, the pressure is notably higher than what people are used to with HCFC-22, so paying attention to the pressure aspects still remains important.

General risk assessment

With all refrigerants that operate under pressure (i.e., above atmospheric pressure, 1.01 bar, abs), there is always a risk of rapid release of pressure due to accidental opening or breakage of pressure containing parts. Such a release can result in physical damage to persons directly from the resulting pressure wave or, more often, indirectly through impact from projectiles. Refrigerants that operate under higher pressure have the potential to cause proportionally more severe consequences (assuming all other conditions are equal). Figure 25 provides the basic steps for a risk assessment for substances that are operating under pressure. In principle, the general procedure for all refrigerants is to ascertain the maximum expected pressure levels under which the equipment – or different parts of the equipment – will be operating and then to design the piping and components to withstand that pressure (with safety factors). Any unanticipated operating conditions that may lead to a further rise in pressure have to be handled through the use of safety devices, which may terminate operation or relieve the pressure in a safe manner. Thus, subsequent to assessing the risk, mitigation measures are identified and applied in order to avoid or minimise the likelihood and consequences of unintended outcomes. Generally, for refrigerants with higher pressures, more comprehensive mitigation measures are demanded.

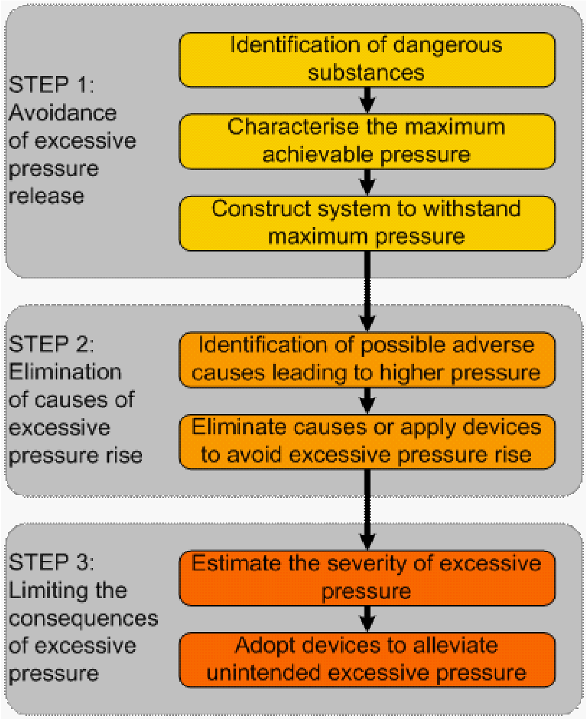


Figure 25. Basic steps for high pressure risk assessment

Refrigeration system design requirements

For higher pressure refrigerants, appropriate design requirements – that are over and above what would normally be required for ordinary – can be found in regulations, standards, codes of practice and industry guidelines. The main issues described in these sources to be addressed, include:

- Ensuring systems have a high level of leak tightness.
- Designing components and piping to withstand considerably higher pressures than normal
- Careful selection and application of additional pressure safety devices (such as pressure limiting switches and pressure relief valves)
- Applying the necessary warnings to accessible parts of the system to ensure that technicians are aware of the hazard (e.g., high pressure signage on the equipment)
- Including the necessary information relating to operating pressures in installation and operating documentation

Key topics for training

As discussed previously, training is necessary for all those involved at all stages throughout the life of the equipment; amongst factory workers, system design engineers and field technicians, a number of topics are generally necessary (in addition to those for general safety of all refrigerants). Table 9 (page 42) provides an indicative list of the general topics that are normally required for persons involved in applying and handling higher pressure refrigerants. Generally the basic principles are necessary for all learners, whereas the other topics may be more relevant to those involved in the development and design of equipment or refrigerant handling activities during installation, service, maintenance, etc.

Service tools and equipment

For technicians and engineers that are working directly with higher pressure refrigerants, it is essential that workers have available and use the appropriate tools and equipment. Whilst it is often the case that certain tools and equipment are equally applicable to most refrigerants, there are some that may ordinarily compromise safety. The most relevant tools and equipment are discussed in Table 12.


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Figure 26. Refrigerant gas detector for carbon dioxide (R-744)

Figure 27. Manifold gauge set for use with R-744 (up to 160 bar)

Figure 28. Refrigerant recovery cylinder

Figure 29. Basic protective equipment - goggles and gloves

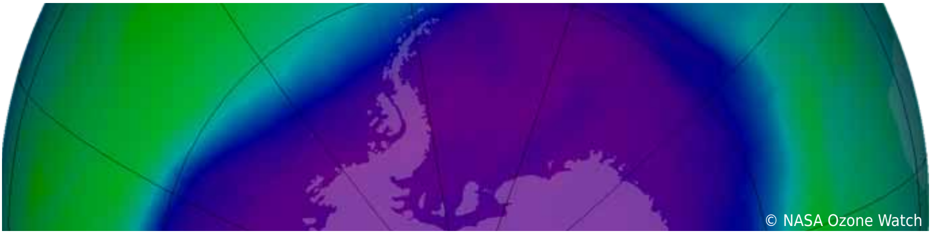
Item	Remarks
Gas detectors	Should be electronic and intended for use with the refrigerant intended (Figure 26).
Manifold/gauge/hose set	Materials must be able to withstand the maximum pressure; currently no digital models are available for very high pressures (Figure 27).
Refrigerant cylinder adapters	Ensure that the correct type of cylinder adapter is present to enable safe removal of refrigerant from the cylinder.
Recovery cylinder	Must be rated for the maximum pressure of the refrigerant being used and have the appropriate high pressure warnings where relevant (see also Table 10), also proper refrigerant cylinder handling rules must be adhered to (Figure 28, Figure 31).
Venting hose	Due to the negligible environmental impact of direct releases for R-744, it is common practice to vent it instead of recovering; in this case, a venting hose with sufficient length to allow venting directly to a safe place in the open air is necessary.
Refrigerant recovery machine	Must be suitable for use with the type of refrigerant under consideration and also be designed appropriately to handle the high pressure of the refrigerant.
Personal protective equipment (PPE)	Normally standard items such as goggles and gloves are necessary (Figure 29).

Table 12. Considerations for tools and equipment for use with higher pressure refrigerants

Figure 30. Fire extinguisher

Figure 31. Warning signs/labels

5 Montreal Protocol Approaches to HCFC Alternatives and Safety Issues



Encouraging climate-friendly alternatives

In 2007 when the Parties to the Montreal Protocol agreed to phase out HCFCs, the decision was not taken in isolation and only considering the issue of ozone depletion. The relevant decision (Montreal Protocol MOP decision XIX/6) as well as setting out the timelines and milestones for the phase out in Article 5 and non-Article 5 countries also had some wider considerations and recommendations. It encouraged Parties to "*promote the selection of alternatives to HCFCs that minimize environmental impacts, in particular impacts on climate, as well as meeting other health, safety and economic considerations*". Practically, when pursuing low GWP refrigerants, consideration should be given to associated safety implications and how to address them.

In 2013 the Multilateral Fund Secretariat developed an important discussion paper on minimising adverse climate impact of HCFC phase-out in the refrigeration servicing sector (http://www.multilateralfund.org/72/English/1/7242.pdf). This paper provides some useful guidance to countries and Implementing Agencies when considering HCFC alternatives and provides some specific guidance on safety issues. The document strongly recommends the development of relevant regulations and codes of practice and adoption of standards for the safe introduction of flammable, higher toxicity and higher pressure refrigerants, recognising that this may be a challenge without additional technical support. Latterly, the issue of safety related to retrofitting was specifically considered by the Executive Committee in 2014 (Decision

72/17), which stated: "*anyone engaging in retrofitting HCFC-based refrigeration and air-conditioning equipment to flammable or toxic refrigerants and associated servicing, does so on the understanding that they assume all associated responsibilities and risks*". As there is increasing consideration of alternatives to HCFCs and in light of recent discussions of a potential phase down of HFCs in the future, the issue of safety of alternatives is becoming more prominent. Many Article 5 counties have requested training, awareness raising and information on the safe use of these alternatives.[18] Other counties already have well establish training schemes, appropriate standards, regulations and codes of practice in place and can provide good examples and assistance to those who wish to develop similar initiatives and can take informed decisions about implementation of the range of low GWP alternatives to HCFCs.

Examples of activities from developing countries

The issue of addressing safety issues is not yet well implemented in a systematic and institutional way in the majority of Article 5 countries. However, there are some examples of actions taken to address the important issue of safety of alternatives.

Training

Most HPMPs include a component on providing capacity building and training for refrigeration and air-conditioning technicians. Integrated into these training initiatives in many countries is a component on safety issues. This can include specific syllabus or specific modules and information materials on safety of flammable, higher toxicity and higher pressure refrigerants as appropriate. In many of these training courses, practical sessions are incorporated and they can include competence assessments. In India, for example, as part of the HPMP, the training provided to SME servicing technicians includes a significant module on safety issues related to HCFC alternatives. This includes training on the importance of maintenance and safety while servicing equipment, guidance on preventive and breakdown maintenance and information on the various specific tools and equipment required for maintenance. It also covers practical approaches and procedures to accident prevention and emergency preparedness on how to deal with them if the occur. Such topics are also increasingly considered in regional network and thematic meetings organised by the UNEP OzonAction Compliance Assistance Programme (CAP).

[18] http://conf.montreal-protocol.org/meeting/mop/cop10-mop26/presession/English/MOP-26-9E.pdf

Standards

Another important approach is the adoption of safety standards. In many cases this requires the NOU to work cooperatively with the national certification/standards body (e.g. National Bureau of Standards). For example in China and St. Kitts and Nevis, a safety standard was drafted for the safe handling of natural refrigerants. In the Kingdom of Bahrain and State of Kuwait, for example, the HPMPs include the development and introduction of National Standards and Codes for equipment and installations operating with hydrocarbons and R-717 as well as codes for operating and servicing such equipment. This includes international consultancy services, consultation workshops, south-south field visits, drafting and reviewing of codes/standards, pilot testing of final codes/standards before finalisation and issuance as well as orientation sessions about the new codes/standards to different stakeholders. It can be useful for National Ozone Officers and the National Experts to be trained in the establishment of credible certification schemes, and for example in a number of training organised by OzonAction, countries were trained in European certification standards, as was the case in Mozambique.

Risk analysis

In China, a series of risk assessments and safety studies into the alternative refrigerants were undertaken. In particular these investigated the flammability risks of the use of hydrocarbons in room air-conditioners in a range of risk-related scenarios, such as leaks, flammable concentrations, over-pressurised systems, external fires, etc.[19] Such studies are very important in understanding and making informed decisions on the adoption of alternatives and the specific safety measures needed. Mexico in its HPMP also plans to conduct safety tests with respect to the application of hydrocarbons in air-conditioning systems. The safety level and potential hazards of selected equipment will be evaluated and reflected in the recommendation for the safety standards to be developed for the sector.

[19] Zhang et al., Research on the flammability hazards of an air-conditioner using refrigerant R-290. International Journal of Refrigeration, Volume 36, Issue 5, August 2013, Pages 1483–1494

6 Guidance for National Ozone Units (NOUs)

General approach

Where NOUs want to consider alternative refrigerants that present additional safety hazards, it is useful to understand the various implications and have an appropriate action plan in place to satisfy their own concerns and also those of the stakeholders. It is essential that authorities handle the matters strategically and carry out the necessary actions. For example:

- Identify which substances are likely to or are intended to be used
- Understand who all the stakeholder groups are that would be affected by the adoption of particular alternatives
- Find out the topics that need to be addressed and to what extent
- Set up relevant workshops, conferences, training sessions, etc., to disseminate the relevant information and skills
- Determine whether specific tools, equipment or machinery is needed and facilitate its selection and acquisition
- Establish an interest group and feedback loop to encourage continuous discussion and improvements in experience and knowledge

All the appropriate tools and techniques should be implemented in order to ensure as high a level of safety as possible, whether it is related to the conception of the product or equipment within a manufacturing enterprise or at the disposal stage at the end of life of some refrigeration equipment. Implementing various measures can be seen as providing different layers of protection and are applied to minimise the risk posed by the application of the alternative refrigerants. Therefore, general considerations for the introduction of alternative refrigerants may include those briefly discussed in the following sections.

Awareness raising

Provide awareness to all stakeholders (in addition to technicians). In particular, awareness-raising for both the RAC industry and for the wider sectors, such as for architects, construction personnel, building operators, facilities managers, end-users, etc.

Focus on training

Ensure a high level of safety by training of technicians and other engineers within the sector such as for appliance design, component selection, system design, installation planning, commissioning, etc. Not only does this target safety, but it also helps uplift the entire sector in terms of improvements in knowledge and know-how, quality of work, awareness, and so on. Supporting this should be a focus on certification, registration and licensing schemes for technicians and engineers. Within this, it may be appropriate to set levels of qualifications and allocation of corresponding levels of permission to work on particular types of systems.

Culture shift

In many regions, the importance of a "safety culture" is not as embedded within the industry as in others. Measures should be introduced to help shift the industry culture to taking the issue of safety (as well as related topics such as leakage avoidance, efficiency, etc) much more seriously. Again, this may be done through legislation, awareness raising and incentives.

Slowly but surely

Approach the introduction of these refrigerants in a controlled and steady manner, so that working practices and behaviour can be changed in a measured and controlled way. One approach may be to consider a phased introduction of new refrigerants according to sectors, for example, start with simple/easy systems and build-up to more complex installations over time. Another option is to integrate with existing or new technician registration schemes, where only the more highly trained or more qualified technicians are permitted to use for example HCs, and the use of accreditation systems.

National experts

Establish an expert base within the country or region, where relevant safety issues may be resolved. For this, authorities could encourage selected individuals from the field to become "national experts" who can be dedicated to information gathering and who can work with and coach enterprises that are applying these refrigerants.

A further option can be to give authority to organisations or expert individuals to carry out checks and inspections to ensure that the relevant rules are being followed and the necessary level of safety is being achieved.

Regulations and standards

Authorities may consider introducing legal and other instruments such as safety standards. Alternatively if such rules currently exist, authorities can identify means for modifying existing regulations and standards to enable more appropriate use of these refrigerants. However, it is important to ensure that regulations and standards are not overly prescriptive, as this can lead to misuse.

Identify cooperation partners

Assuming there is an absence of knowledge or experience, support should be sought from cooperation partners. Some refrigeration institutions, associations, universities, laboratories, national ministries and governmental departments offer companies support and consulting on how to deal with refrigeration systems. Other entities that can be consulted include industry associations, technical institutes, development agencies and international funds, national authorities, standardisation bodies, accreditation bodies.

Development of safety policies

It is preferential to avoid safety-related problems in whatever stage and whichever stakeholder since they can result in cessation of production process, endemic fault within a specific design, injury to staff, injury to members of the public and departure from a particular technological direction. Devising institutional controls to avoid accidental loss is therefore desirable. Such a scheme comprises implementation of certain stages:

i) identification of hazards
ii) assessment of risks
iii) decisions on precautions needed
iv) implementation of guidelines
v) verifying that they are used
vi) feedback to the management
vii) modification of rules or procedures where necessary

This defines the basis for a safety policy, and such policies should cover all activities that the organisation is involved in. This may include the selection of personnel for particular jobs, equipment and materials, design of equipment and products, the way work is carried out, how services are provided, and so on. Key elements of a policy should guarantee: lessons are learned from mistakes and successes, safety audits are carried out, action is taken according to the findings of audits and it is documented, audits involve personnel at all levels as well as external contractors and reviews of safety policy and guidelines are carried out frequently.

7 Further Reading

Australian Institute of Refrigeration, Airconditioning and Heating (AIRAH) – Flammable Refrigerant Safety Guide,
http://www.airah.org.au/imis15_prod/Content_Files/TechnicalPublications/Flammable-Refrigerant-Safety-Guide-2013.pdf

BRA (British Refrigeration Association) – Guide to Flammable Refrigerants,
http://www.feta.co.uk/uploaded_images/files/BRA%20Guide%20to%20Flammable%20Refrigerants%20-%20Issue%201%20-%20Oct%2012.pdf

Eurammon – information sheets,
http://www.eurammon.com/information-materials

GIZ Proklima – Guidelines for the safe use of flammable refrigerants in the production of room air-conditioners,
http://www.giz.de/expertise/downloads/giz-2012-Guidelines-Safety-AC.pdf

GIZ Proklima – Guidelines for the safe use of hydrocarbon refrigerants,
http://www.giz.de/expertise/downloads/Fachexpertise/giz2010-en-guidelines-safe-use-of-hydrocarbon.pdf

GIZ Proklima - Operation of split air-conditioning systems with hydrocarbon refrigerant,
http://www.giz.de/expertise/downloads/giz2011-en-split-air-conditioning.pdf

International Institute of Ammonia Refrigeration (IIAR) – CO_2 Handbook,
http://www.iiar.org/iiar/ItemDetail?iProductCode=01BOO-EN0402

Institute of Refrigeration – Safety Code of Practice for Refrigerating Systems Utilising A2/A3 Refrigerants,
http://www.ior.org.uk/R0EW5TVYAI

Institute of Refrigeration – Safety Code of Practice for Refrigerating Systems Utilising ammonia –
http://www.ior.org.uk/X6EXMVYYAD

Institute of Refrigeration – Safety Code of Practice for Refrigerating Systems Utilising carbon dioxide,
http://www.ior.org.uk/P8EXMV1JAD

KHLim - NARECO_2, Natural Refrigerant CO_2 handbook,
http://shecco.com/files/NaReCO2-handbook-2009.pdf

UNEP – International Standards in Refrigeration and Air-conditioning
http://www.unep.fr/ozonaction/information/mmcfiles/7679-e-International_Standards_in_RAC.pdf

Appendix: Data Summary for Refrigerants[18]

Table A1. Data summary for single component refrigerants

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ ppm)	GWP 100 Year	GWP 20 Year	ODP
Methane series												
CFC-11	CCl_3F	trichlorofluoromethane	137,4	24	0,006 2	NF	A1	52	0,26	5 160	7 090	1
CFC-12	CCl_2F_2	dichlorodifluoromethane	120,9	-30	0,088	NF	A1	102	0,32	10 300	10 800	0,73
CFC-13	$CClF_3$	chlorotrifluoromethane	104,5	-81	ND	NF	A1	640	0,25	13 900	10 900	1
BFC-13B1	BrF_3	bromotrifluoromethane	148,9	-58	ND	NF	A1	72	0,30	6 670	7 930	15,2
PFC-14	CF_4	tetrafluoromethane (carbon tetrafluoride)	88,0	-128	0,40	NF	A1	50000	0,09	6 630	4 880	
HCFC-22	$CHClF_2$	chlorodifluoromethane	86,5	-41	0,21	NF	A1	12	0,21	1 780	5 310	0,034
HFC-23	CHF_3	trifluoromethane	70,0	-82	0,15	NF	A1	228	0,18	12 500	10 800	
HCC-30	CH_2Cl_2	dichloromethane (methylene chloride)	84,9	40	ND	NF	B1	0,4	0,03	9	33	
HFC-32	CH_2F_2	difluoromethane (methylene fluoride)	52,0	-52	0,30	0,307	A2L	5,4	0,11	704	2 530	
HC-50	CH_4	methane	16,0	-161	ND	0,032	A3	12,4	3,63e-4	30	85	
Ethane series												
CFC-113	CCl_2FCClF_2	1,1,2-trichloro-1,2,2-trifluoroethane	187,4	48	0,02	NF	A1	93	0,30	6 080	6 560	0,81
CFC-114	$CClF_2CClF_2$	1,2-dichloro-1,1,2,2-tetrafluoroethane	170,9	4	0,14	NF	A1	189	0,31	8 580	7 710	0,5

(continued...)

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ ppm)	GWP 100 Year	GWP 20 Year	ODP
30,1	$CClF_2CF_3$	chloropentafluoroethane	154,5	-39	0,76	NF	A1	540	0,20	7 310	5 780	0,26
PFC-116	CF_3CF_3	hexafluoroethane	138,0	-78	0,68	NF	A1	10000	0,25	11 100	8 210	
HCFC-123	$CHCl_2CF_3$	2,2-dichloro-1,1,1-trifluo-roethane	152,9	27	0,057	NF	B1	1,3	0,15	79	292	0,01
HCFC-124	$CHClFCF_3$	2-chloro-1,1,1,2-tetrafluo-roethane	136,5	-12	0,056	NF	A1	5,9	0,20	527	1 870	0,02
HFC-125	CHF_2CF_3	pentafluoroethane	120,0	-49	0,37	NF	A1	31	0,23	3 450	6 280	
HFC-134a	CH_2FCF_3	1,1,1,2-tetrafluoroethane	102,0	-26	0,21	NF	A1	14	0,16	1 360	3 810	
HCFC-142b	CH_3CClF_2	1-chloro-1,1-difluoro-ethane	100,5	-10	0,10	0,329	A2	18	0,19	2 070	5 140	0,057
HFC-143a	CH_3CF_3	1,1,1-trifluoroethane	84,0	-47	0,48	0,282	A2L	51	0,16	5 080	7 050	
HFC-152a	CH_3CHF_2	1,1-difluoroethane	66,1	-25	0,14	0,130	A2	1,6	0,10	148	545	
HC-170	CH_3CH_3	ethane	30,1	-89	0,008 6	0,038	A3			5,5	20	
Ethers												
HE-E170	CH_3OCH_3	methoxymethane (di-methyl ether)	46,1	-25	0,079	0,064	A3	0,015	0,02	1	1	

(continued...)

[18] Taken from Chapter 2, UNEP, 2014 Report of the Refrigeration, Air-conditioning and Heat pumps Technical Options Committee, 2014 Assessment, United National Environment Programme, Nairobi

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ ppm)	GWP 100 Year	GWP 20 Year	ODP
Propane series												
PFC-218	CF_3CF2CF_3	octafluoropropane	188,0	-37	0,34	NF	A1	2600	0,28	8 900	6 640	
HFC-227ea	CF_3CHFCF_3	1,1,1,2,3,3,3-heptafluoro-propane	170,0	-16	0,19	NF	A1	36	0,32	3 140	5 250	
HFC-236fa	$CF_3CH_2CF_3$	1,1,1,3,3,3-hexafluroro-propane	152,0	-1	0,34	NF	A1	242	0,24	8 060	6 940	
HFC-245fa	$CHF_2CH_2CF_3$	1,1,1,3,3-pentafluoro-propane	134,0	15	0,19	NF	B1	7,9	0,24	882	2 980	
HC-290	$CH_3CH_2CH_3$	propane	44,1	-42	0,09	0,038	A3	12,5 days		5	18	
Cyclic organic compounds												
PFC-C318	$-(CF_2)_4-$	octafluorocyclobutane	200,0	-6	0,65	NF	A1	3200	0,32	9 540	7 110	
Hydrocarbons												
HC-600	$CH_3CH_2CH_2CH_3$	butane	58,1	0	0,002 4	0,038	A3			4	15	
HC-600a	$CH(CH_3)_2CH_3$	2-methylpropane (iso-butane)	58,1	-12	0,059	0,043	A3	6,0 days		~20	74	
HC-601	$CH_3CH_2CH_2$-CH_2CH3	Pentane	72,2	36	0,0029	0,035	A3	3,4 days		~20	74	
HC-601a	$CH(CH_3)_2CH_2$-CH_3	2-methylbutane (isopen-tane)	72,2	27	0,0029	0,038	A1	3,4 days		~20	74	

(continued...)

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ ppm)	GWP 100 Year	GWP 20 Year	ODP
Inorganic compounds												
R-702	H_2	Hydrogen	2,0	-253			A3					
R-704	He	Helium	4,0	-269		NF	A1					
R-718	H2O	Water	18,0	100		NF	A1					
R-720	Ne	Neon	20,2	-246		NF	A1					
R-728	N_2	Nitrogen	28,0	-196		NF	A1					
R-740	Ar	Argon	39,9	-186		NF	A1					
R-744	CO_2	carbon dioxide	44,0	-78c	0,072	NF	A1		1,37e-5	1	1	
Unsaturated organic compounds												
HC-1150	$CH_2=CH_2$	ethene (ethylene)	28,1	–104	ND	0,036	A3			3,7	14	
HCFC-1233zd(E)	$C_{F3}CH=CHC_l$	trans-1-chloro-3,3,3-trifluoro-1-propene	130,5	18,1	0	NF	A1	26,0 days	0,04	1	5	0,000 34
HFC-1234yf	$CF_3CF=CH_2$	2,3,3,3-tetrafluoro-1-propene	114,0	-29,4	0,47	0,289	A2L	10,5 days	0,02	<1	1	
HFC-1234ze(E)	$CF_3CH=CHF$	trans-1,3,3,3-tetrafluoro-1-propene	114,0	-19,0	0,28	0,303	A2L	40,4 days	0,04	<1	4	
HC-1270	$CH_3CH=CH_2$	propene (propylene)	42,1	-48	0,001 7	0,046	A3	0,35 days		1,8	6,6	

Table A.2. Data summary for zeotropic refrigerant blends

Refrigerant Designation	Refrigerant Composition (Mass %)	Molecular Weight	Bubble Point/ Dew Point (°C)	ATEL/ODL (kg/ m³)	LFL (kg/m³)	Safety Class	GWP 100 Year	GWP 20 Year	ODP
R-401A	R-22/152a/124 (53,0/13,0/34,0)	94,4	-34,4/-28,8	0,10	NF	A1	1 100	3 500	0,02
R-401B	R-22/152a/124 (61,0/11,0/28,0)	92,8	-35,7/-30,8	0,11	NF	A1	1 200	3 800	0,03
R-401C	R-22/152a/124 (33,0/15,0/52,0)	101	-30,5/-23,8	0,083	NF	A1	880	2 800	0,02
R-402A	R-125/290/22 (60,0/2,0/38,0)	101,5	-49,2/-47,0	0,27	NF	A1	2 700	5 800	0,01
R-402B	R-125/290/22 (38,0/2,0/60,0)	94,7	-47,2/-44,9	0,24	NF	A1	2 400	5 600	0,02
R-403A	R-290/22/218 (5,0/75,0/20,0)	92	-44,0/-42,3	0,24	0,480	A2	3 100	5 300	0,03
R-403B	R-290/22/218 (5,0/56,0/39,0)	103,3	-43,8/-42,3	0,29	NF	A1	4 500	5 600	0,02
R-404A	R-125/143a/134a (44,0/52,0/4,0)	97,6	-46,6/-45,8	0,52	NF	A1	4 200	6 600	
R-406A	R-22/600a/142b (55,0/4,0/41,0)	89,9	-32,7/-23,5	0,14	0,302	A2	1 800	5 000	0,04
R-407A	R-32/125/134a (20,0/40,0/40,0)	90,1	-45,2/-38,7	0,31	NF	A1	2 100	4 500	
R-407B	R-32/125/134a (10,0/70,0/20,0)	102,9	-46,8/-42,4	0,33	NF	A1	2 800	5 400	
R-407C	R-32/125/134a (23,0/25,0/52,0)	86,2	-43,8/-36,7	0,29	NF	A1	1 700	4 100	
R-407D	R-32/125/134a (15,0/15,0/70,0)	91	-39,4/-32,7	0,25	NF	A1	1 600	4 000	
R-407E	R-32/125/134a (25,0/15,0/60,0)	83,8	-42,8/-35,6	0,27	NF	A1	1 500	3 900	
R-407F	R-32/125/134a (30,0/30,0/40,0)	82,1	-46,1/-39,7	0,32	NF	A1	1 800	4 200	
R-408A	R-125/143a/22 (7,0/46,0/47,0)	87	-45,5/-45,0	0,33	NF	A1	3 400	6 200	0,02
R-409A	R-22/124/142b (60,0/25,0/15,0)	97,4	-35,4/-27,5	0,12	NF	A1	1 500	4 400	0,03
R-409B	R-22/124/142b (65,0/25,0/10,0)	96,7	-36,5/-29,7	0,12	NF	A1	1 500	4 400	0,03
R-410A	R-32/125 (50,0/50,0)	72,6	-51,6/-51,5	0,42	NF	A1	2 100	4 400	
R-410B	R-32/125 (45,0/55,0)	75,6	-51,5/-51,4	0,43	NF	A1	2 200	4 600	

(continued...)

Refrigerant Designation	Refrigerant Composition (Mass %)	Molecular Weight	Bubble Point/ Dew Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	GWP 100 Year	GWP 20 Year	ODP
R-411A	R-1270/22/152a) (1,5/87,5/11,0)	82,4	-39,7/-37,2	0,074	0,186	A2	1 600	4 700	0,03
R-411B	R-1270/22/152a (3,0/94,0/3,0)	83,1	-41,6/-41,3	0,044	0,239	A2	1 700	5 000	0,03
R-412A	R-22/218/143b (70,0/5,0/25,0)	88,2	-36,4/-28,8	0,17	0,329	A2	3 000	5 800	0,02
R-413A	R-218/134a/600a (9,0/88,0/3,0)	104	-29,3/-27,6	0,21	0,375	A2	2 000	4 000	
R-414A	R-22/124/600a/142b (51,0/28,5/4,0/16,5)	96,9	-34,0/-25,8	0,10	NF	A1	1 400	4 100	0,03
R-414B	R-22/124/600a/142b (50,0/39,0/1,5/9,5)	101,6	-34,4/-26,1	0,096	NF	A1	1 300	3 900	0,03
R-415A	R-22/152a (82,0/18,0)	81,9	-37,5/-34,7	0,19	0,188	A2	1 500	4 500	0,03
R-415B	R-22/152a (25,0/75,0)	70,2	-23,4/-21,8	0,15	0,13	A2	560	1 700	0,009
R-416A	R-134a/124/600 (59,0/39,5/1,5)	111,9	-23,4/-21,8	0,064	NF	A1	1 000	3 000	0,008
R-417A	R-125/134a/600 (46,6/50,0/3,4)	106,7	-38,0/-32,9	0,057	NF	A1	2 300	4 800	
R-417B	R-125/134a/600 (79,0/18,3/2,7)	113,1	-44,9/-41.5	0,069	NF	A1	3 000	5 700	
R-417C	R-125/134a/600 (19,5/78,8/1,7)	103,7	–32,7/–29,2		NF	A1	1 700	4 200	
R-418A	R-290/22/152a (1,5/96,0/2,5)	84,6	-41,2/-40,1	0,20	0,31	A2	1 700	5 100	0,03
R-419A	R-125/134a/E170 (77,0/19,0/4,0)	109,3	-42,6/-36,0	0,31	0,25	A2	2 900	5 600	
R-419B	R-125/134a/E170 (48,5/48,0/3,5)	105,2	–37,4/–31,5			A2	2 300	4 900	
R-420A	R-134a/142b (88,0/12,0)	101,8	-25,0/-24,2	0,18	NF	A1	1 400	4 000	0,007
R-421A	R-125/134a (58,0/42,0)	111,7	-40,8/-35,5	0,28	NF	A1	2 600	5 200	
R-421B	R-125/134a (85,0/15,0)	116,9	-45,7/-42,6	0,33	NF	A1	3 100	5 900	
R-422A	R-125/134a/600a (85,1/11,5/3,4)	113,6	-46,5/-44,1	0,29	NF	A1	3 100	5 800	
R-422B	R-125/134a/600a (55,0/42,0/3,0)	108,5	-40,5/-35,6	0,25	NF	A1	2 500	5 100	

(continued...)

Refrigerant Designation	Refrigerant Composition (Mass %)	Molecular Weight	Bubble Point/ Dew Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	GWP 100 Year	GWP 20 Year	ODP
R-422C	R-125/134a/600a (82,0/15,0/3,0)	113,4	-45,3/-42,3	0,29	NF	A1	3 000	5 700	
R-422D	R-125/134a/600a (65,1/31,5/3,4)	109,9	-43,2/-38,4	0,26	NF	A1	2 700	5 300	
R-422E	R-125/134a/600a (58,0/39,3/2,7)	109,3	–41,8/–36,4		NF	A1	2 500	5 100	
R-423A	134a/227ea (52,5/47,5)	126	-24,2/-23,5	0,30	NF	A1	2 200	4 500	
R-424A	R-125/134a/600a/600/601a (50,5/47,0/0,9/1,0/0,6)	108,4	-39,1/-33,3	0,10	NF	A1	2 400	5 000	
R-425A	R-32/134a/227ea (18,5/69,5/12)	90,3	-38,1/-31,3	0,27	NF	A1	1 500	3 700	
R-426A	R-125/134a/600/601a (5,1/93,0/1,3/0,6)	101,6	-28,5/-26,7	0,083	NF	A1	1 400	3 900	
R-427A	R-32/125/143a/134a (15,0/25,0/10,0/50,0)	90,4	-43,0/-36,3	0,29	NF	A1	2 200	4 600	
R-428A	R-125/143a/290/600a (77,5/20,0/0,6/1,9)	107,5	-48,3/-47,5	0,37	NF	A1	3 700	6 300	
R-429A	R-E170/152a/600a (60,0/10,0/30,0)	50,8	-26,0/-25.6	0,098	0,052	A3	21	77	
R-430A	R-152a/600a (76,0/24,0)	64	-27,6/-27,4	0,10	0,084	A3	120	430	
R-431A	R-290/152a (71,0/29,0)	48,8	-43,1/-43,1	0,10	0,044	A3	46	170	
R-432A	R-1270/E170 (80,0/20,0)	42,8	-46,6/-45,6	0,002 1	0,039	A3	1,6	5,5	
R-433A	R-1270/290 (30,0/70,0)	43,5	-44,6/-44,2	0,005 5	0,036	A3	4	15	
R-433B	R-1270/290 (5,0/95,0)	44	-42,7/-42,5	0,025	0,025	A3	4,8	17	
R-433C	R-1270/290 (25,0/75,0)	43,6	-44,3/-43,9	0,006 6	0,032	A3	4,2	15	
R-434A	R-125/143a/134a/600a (63,2/18,0/16,0/2,8)	105,7	-45,0/-42,3	0,32	NF	A1	3 300	5 800	
R-435A	R-E170/152a (80,0/20,0)	49	-26,1/-25,9	0,09	0,069	A3	30	110	
R-436A	R-290/600a (56,0/44,0)	49,3	-34,3/-26,2	0,073	0,032	A3	12	43	
R-436B	R-290/600a (52,0/48,0)	49,9	-33,4/-25,0	0,071	0,033	A3	12	45	

(continued...)

Refrigerant Designation	Refrigerant Composition (Mass %)	Molecular Weight	Bubble Point/ Dew Point (°C)	ATEL/ODL (kg/ m³)	LFL (kg/m³)	Safety Class	GWP 100 Year	GWP 20 Year	ODP
R-437A	R-125/134a/600/601 (19,5/78,5/1,4/0,6)	103,7	-32,9/-29,2	0,081	NF	A1	1 700	4 200	
R-438A	R-32/125/134a/600/601a (8,5/45,0/44,2/1,7/0,6)	99,1	-43,0/-36,4	0,079	NF	A1	2 200	4 700	
R-439A	R-32/125/600a (50,0/47,0/3,0)	71,2	-52,0/-51,8	0,34	0,304	A2	2 000	4 200	
R-440A	R-290/134a/152a (0,6/1,6/97,8)	66,2	-25,5/-24,3	0,14	0,124	A2	170	590	
R-441A	R-170/290/600a/600 (3,1/54,8/6,0/36,1)	48,3	-41,9/-20,4	0,006 3	0,032	A3	5,6	20	
R-442A	R-32/125/134a/152a/227ea (31,0/31,0/30,0/3,0/5,0)	81,8	–46,5/–39,9	0,33	NF	A1	1 900	4 200	
R-443A	R-1270/290/600a (55,0/40,0/5,0)	43,5	–44,8/–41,2			A3	4	15	
R-444A	R-32/152a/1234ze(E) (12,0/5,0/83,0)	96,7	–34,3/–24,3			A2L	93	330	
R-444B	R-32/1234ze(E)/152a (41,5/48,5/10)	72,8	–44,6/–34,9			A2L	310	1 100	
R-445A	R-744/134a/1234ze(E) (6,0/9,0/85,0)	103,1	–50,3/–23,5			A2L	120	350	
R-446A	R-32/1234ze(E)/600 (68,0/29,0/3,0)	62	–49,4/–44,0			A2L	480	1 700	
R-447A	R-32/125/1234ze(E) (68,0/3,5/28,5)	63	–49,3/–44,2			A2L	600	1 900	
R-448A	R-32/125/1234yf/134a /1234ze(E) (26/26/20/21/7)	86,4	–45,9/–39,8			A1	1 400	3 100	
R-449A	R-134a/125/1234yf/32 (26/25/25/24)	87,4	–46,0/–39,9			A1	1 400	3 200	
R-450A	R-1234ze(E)/134a (58/42)	108,7	–23,4/–22,8			A1	570	1 600	
R-451A	R-1234yf/134a (89,8/10,2)	112,7	–30,8/–30,5			A2L	140	390	
R-451B	R-1234yf/134a (88,8/11,2)	112,6	–31,0/–30,6			A2L	150	430	
R-452A	R-1234yf/32/125 (30/11/59)	103,5	–47,0/–43,2			A1	2 100	4 000	

Table A.3. Data summary for azeotropic refrigerant blends

Refrigerant Designation	Refrigerant Composition (Mass %)	Molecular Weight	Normal Boiling Point (°C)	ATEL/ODL (kg/ m³)	LFL (kg/m³)	Safety Class	GWP 100 Year	GWP 20 Year	ODP
R-500	R-12/152a (73,8/26,2)	99,3	-33,6/-33,6	0,12	NF	A1	1 700	8 100	0,5
R-501	R-22/12 (75,0/25,0)	93,1	-40,5/-40,3	0,21	NF	A1	3 900	6 700	0,2
R-502	R-22/115 (48,8/51,2)	111,6	-45,3/-45,0	0,33	NF	A1	4 600	5 600	0,1
R-503	R-23/13 (40,1/59,9)	87,2	–88	ND	NF	A1	13 000	11 000	0,6
R-504	R-32/115 (48,2/51,8)	79,2	–57	0,45	NF	A1	4 100	4 200	0,1
R-507A	R-125/143a (50,0/50,0)	98,9	-47,1/-47,1	0,53	NF	A1	4 300	6 700	
R-508A	R-23/116 (39,0/61,0)	100,1	-87,4/-87,4	0,23	NF	A1	12 000	9 200	
R-508B	R-23/116 (46,0/54,0)	95,4	-87,4/-87,0	0,2	NF	A1	12 000	9 400	
R-509A	R-22/218 (44,0/56,0)	124	-40,4/-40,4	0,38	NF	A1	5 800	6 100	0,01
R-510A	R-E170/600a (88,0/12,0)	47,2	-25,2/-25,2	0,087	0,056	A3	3,3	9,8	
R-511A	R-290/152a (95,0/5,0)	44,8	-42,18/-42,1	0,092	0,038	A3	12	44	
R-512A	R-134a/152a (5,0/95,0)	67,2	-24,0/-24,0	0,092	0,124	A2	210	710	
R-513A	R-1234yf/134a (56/44)	108,4	-29,2			A1	600	1 700	

About the UNEP DTIE OzonAction Programme

Under the Montreal Protocol on Substances that Deplete the Ozone Layer, countries worldwide are taking specific, time-targeted actions to reduce and eliminate the production and consumption of man-made chemicals that destroy the stratospheric ozone layer, Earth's protective shield.

The objective of the Montreal Protocol is to phase out ozone depleting substances (ODS), which include CFCs, halons, methyl bromide, carbon tetrachloride, methyl chloroform, and HCFCs. One hundred ninety seven governments have joined this multilateral environmental agreement and are taking action.

The UNEP DTIE OzonAction Branch assists developing countries and countries with economies in transition (CEITs) to enable them to achieve and sustain compliance with the Montreal Protocol. With our programme's assistance, countries are able to make informed decisions about alternative technologies, ozone-friendly policies and enforcement activities.

OzonAction has two main areas of work:

- Assisting developing countries in UNEP's capacity as an Implementing Agency of the Multilateral Fund for the Implementation of the Montreal Protocol, through a Compliance Assistance Programme (CAP).
- Specific partnerships with bilateral agencies and Governments.

UNEP's partnerships under the Montreal Protocol contribute to the realisation of the Millennium Development Goals and implementation of the Bali Strategic Plan.

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The Division works to promote:

> sustainable consumption and production,
> the efficient use of renewable energy,
> adequate management of chemicals,
> the integration of environmental costs in development policies.

The Office of the Director, located in Paris, coordinates activities through:

> The International Environmental Technology Centre - IETC (Osaka, Shiga), which implements integrated waste, water and disaster management programmes, focusing in particular on Asia.
> Sustainable Consumption and Production (Paris), which promotes sustainable consumption and production patterns to contribute to human development through global markets.
> Chemicals (Geneva), which promotes sustainable development by catalysing global actions and building national capacities for the sound management of chemicals and the improvement of chemicals safety worldwide.
> Energy (Paris), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.
> OzonAction (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.
> Economics and Trade (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies.

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Multilateral Fund for the Implementation of the Montreal Protocol

Many of the alternative refrigerants to hydrochlorofluorocarbons (HCFCs) have particular characteristics in terms of toxicity, flammability and high pressure which are different from those used previously. It is therefore important that the refrigeration and air-conditioning industry adapts to both the technical and safety issues concerning these refrigerants. This publication provides an overview of the alternatives, their general characteristics and their application in the context of the safety issues. It provides guidance for National Ozone Units (NOUs) and other interested parties in developing countries on how they can advise and assist their national stakeholders in the selection and implementation of alternative refrigerants.

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