Manual for Refrigeration Servicing Technicians

Why you need this manual ▶
When to use this manual ▶
How to use this manual ▶

Introduction

Welcome to the Manual for Refrigeration Servicing Technicians. It is an e-book for people who are involved in training and organization of service and maintenance of refrigeration and air-conditioning (RAC) systems. It is aimed at people who are:

- Service and maintenance technicians
- Private company service/maintenance managers
- Private company managers involved in developing their service and maintenance policy
- Private company technicians trainers
- Educational establishment RAC trainers and course developers
- National Ozone Units (NOUs) responsible for servicing and maintenance regulations and programmes related to the Montreal Protocol.

Why you need this Manual

Over recent years, attention on the issue of ozone depletion has remained focused on the obligatory phasing out of ozone depleting substances (ODS). At the same time, awareness of climate change has increased, along with the development of national and regional greenhouse gas (GHG) emissions reduction targets. In order to achieve reduction in emissions of both ODSs and GHGs, attention has to be paid to activities at a micro-level. This includes reducing leakage rates, improving energy-efficiency and preventing other environmental impacts, by directing the activities of individuals, and influencing the design and maintenance of equipment.

The manual is written for those who have a relatively comprehensive level of knowledge and understanding of RAC systems and associated technology. The material within this manual may be used for the purpose of developing training resources or parts of training courses, as well as general guidance and information for technicians on issues that are closely related to the use and application of alternative refrigerants. Most training courses are likely to cover a range of topics associated with RAC systems, and as such, the material within this manual may contribute towards those elements that address refrigerant use and handling.

Read on to find out how ▶

When to use the manual

The overall theme of this manual is to encourage technicians to work with systems in a more environmentally-friendly manner, and to get the equipment itself to have a lower impact. However, the primary motivation for technician operations carried out on a particular system is typically cost-orientated, rather than considering the environmental impact. It is often not recognised that actions resulting in a lesser environmental impact are consistent with a lower long-term cost impact. Conversely, the types of actions that are the “cheaper” options tend to lead to greater costs in the long term, as well as a worse environmental impact.

For example:

- A system that leaks may be topped-up or repaired. Topping-up may have a lower immediate cost, whereas repairing the leak takes more time and therefore costs more. However, in the long-term, the repaired system is less likely to leak thus the costs cease, whereas repeatedly topping-up a system over months and years results in a very high accumulated cost. Obviously, preventing leakage and thus fewer journeys to the equipment and better resulting efficiency is much more desirable from an environmental perspective.
- A system that is designed to work efficiently and is well maintained may cost more to build, but the pay-back period is generally much shorter than the equipment’s lifetime. Similarly, the additional GHG emissions associated with constructing larger heat exchangers (for example) are minute compared to the reduction in GHG emissions from energy consumption that will be saved over the first year of operation.

So, when installing a new system or working on an existing system, the actions taken should ideally lead to the system operating with minimal impact on the environment. To achieve this, several aspects should be borne in mind:

- Reduce energy consumption by minimizing heat load and improving efficiency.
- Minimize leakage and other emissions whenever possible.
- Avoid the use of high global warming potential (GWP) refrigerants.

Read on to decide how you might use this manual to achieve this ▶

How to use this manual

The objectives on the page ▼ **When to use this manual** may be achieved through a variety of means, including those detailed within this manual and from other sources. When a technician arrives at a system to carry out activities that involve refrigerant handling, and as they begin their work, they must formulate a view as to how to deal with the system in hand.

The considerations as to what to do with the system may include:

Repair:
Whether to repair and refill with the same refrigerant.

Drop-in refrigerant change:
Whether to repair and drop-in with a new refrigerant, and if so, which refrigerant to use.

Retrofitting:
Whether to repair and retrofit with a new refrigerant, and if so, which refrigerant to use.

Redesign:
Whether to repair, and add refrigerant, but also carry out other improvements to improve the reliability and efficiency.

Replacement:
Whether to replace the entire system with a new one, and if so, which system and which refrigerant.

Read The Factors Affecting the Decision ▶

The Factors affecting the decision

The decision as to which approach to take is rarely an obvious one, and requires consideration of many aspects.

Type of refrigerant and its availability

If a system uses a chlorofluorocarbon (CFC) then it is likely to be difficult to obtain, or even prohibited. The same will apply to hydrochlorofluorocarbons (HCFCs) in the future.

Severity of leakage

For systems that have a history of high leakage, perhaps due to poor manufacture or construction, or being positioned in a vulnerable location, consideration should be given to replacing them, or redesigning/reinstalling the susceptible parts.

Charge of refrigerant

If a system has a small charge of controlled or less available refrigerant, then it may not be so problematic to retain it, whereas if the charge is large then it would be sensible to replace it.

Availability of alternative refrigerant

The choice of alternative refrigerant should ideally be a substance with zero ozone depleting potential (ODP) i.e. not a CFC or HCFC or a blend that contains either. It should have as low a GWP as possible.

Physical size of the system

If a system is very large, replacing it with a new system may require considerable cost.

Availability of similar (replacement) systems

If the system is particularly complex and a replacement is being considered, it should only be done provided a replacement system is easily available.

Availability of expertise associated with the type of system

Involved types of work or replacing parts or the entire system should only be done provided that sufficient expertise is available.

Degree of integration into application

Where a system is partially integrated into an application or a building, or is part of a much larger mechanical installation, it is likely to be much easier and more cost effective to carry out minimal work rather than trying to replace it with a new system.

Condition/state of equipment

For systems in a very poor condition, where perpetual maintenance and repairs are likely, then installation of a new system may be appropriate.

Age of system

If a system is very old and is using outdated technology and parts, it could be appropriate to replace it, whereas newer equipment may have modern design and already use suitable refrigerants.

Current level of reliability

If the reliability of the system and its components are poor, resulting in repeated service visits and losses of parts and refrigerant, then a replacement system may be the preferred option.

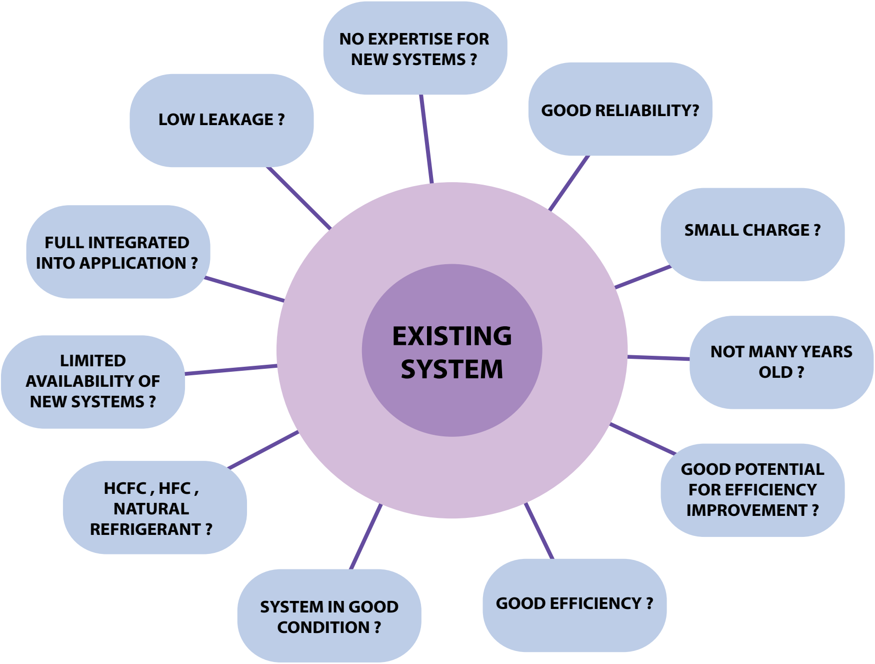
System efficiency and potential for efficiency improvement

If a system has a poor level of efficiency, it is necessary to consider whether there are viable operations that could be carried out to help improve the efficiency, but it is such that this is not possible, then adoption of a new system should be considered.

> The choice is often complex and a function of many different factors. Typically, the age of the equipment is a leading factor in terms of which conclusions are drawn in terms of how the equipment should be handled, for the reasons implied above.

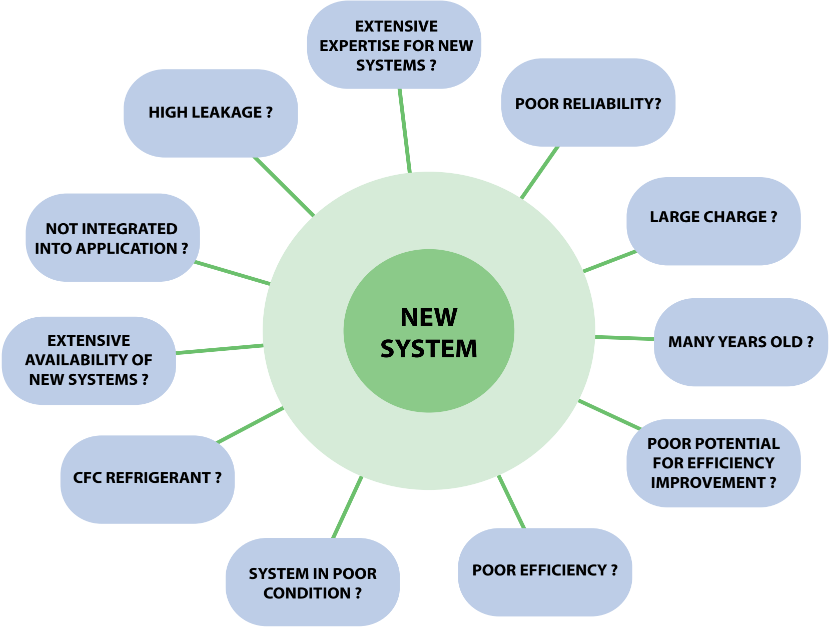
How to assess conditions

Here is an overview of conditions for the refill, drop-in, retro-fit and new system options, which includes considerations that should be given to how a system is handled.



Considering these factors, read the conditions below and then select the option you might choose

The conditions ▶



Condition	**Observation**			
Refrigerant type and availability	HFC, CO2, HC, NH3	CFC, HCFC	HCFC	CFC
Severity of leakage	low	low	medium	high
Charge of refrigerant	high	medium	medium	low
Alternative refrigerant availability	poor	good	good	good
Physical size of system	large	large	medium	small
Availability of similar systems	none	none	none	many
Availability of system expertise	none	some	some	much
Degree of integration	high	high	medium	low
Condition/state of equipment	good	good	fair	poor
Age of system	new	medium	medium	old
Current level of reliability	good	good	fair	poor
System efficiency	good	good	medium	poor
Efficiency improvement potential	good	good	medium	poor
Recommended action:	**Repair and refill**	**Drop-in**	**Retrofit**	**New system**

Characteristics of Selected Types of Equipment

Different types of equipment have certain characteristics associated with them, that may affect some aspects of the decision-making and some of these are listed in the Characteristics of Selected Types of Equipment sheet

Application example	System Type	Relative Charge	Integrated into Application
Domestic refrigeration	integral	small	low
Stand alone retail food display and vending	integral	small	low
Condensing unit refrigeration	remote	medium	medium
Large supermarket systems	distributed	large	medium
Cold storage	remote	large	medium
Industrial process refrigeration	all	medium, large	high
Refrigerated transport	remote	medium	high
Split and ducted air conditioners	remote	medium	medium
Portable & window air conditioner units	integral	small	low
Heat pumps	all	medium, large	medium
Chillers	integral	medium, large	medium
Mobile air conditioning (MAC)	Integral	small	high

Further information

The information within this manual was drawn from a variety of different sources. However, rather than providing a detailed reference list, each chapter is accompanied by a short list of publications for further reading. These publications cover a large amount of information on the topics addressed within this manual.

There are also a large number of textbooks on the subject of refrigeration engineering, and a selection of those is listed below. Amongst these, are addressed many of the topics covered within this manual, particularly related to servicing and maintenance practices:

Air Conditioning and Refrigeration, *by R Miller and M R Miller, 2006*

Modern Refrigeration and Air Conditioning, *by A D Althouse, C H Turnquist, and A F Bracciano, 2004*

Principles of Refrigeration, *by R J Dossat and T J Horan, 2001*

Refrigeration and Air Conditioning Technology, *by B Whitman, B Johnson, J Tomczyk, E Silberstein, 2008*

Refrigeration Equipment: A Servicing and Installation Handbook, *by A C Bryant, 1997*

More generally, there exist a large number of organizations who have Internet sites from where extensive information can be found related to the subjects of refrigeration and refrigerants.

A selection are:

- **www.ammonia21.com** - *related to the ammonia refrigeration industry*
- **www.ashrae.org**
American Society of Heating, Air-conditioning and Refrigeration Engineers
- **www.eurammon.com**
Eurammon - the European trade association for the use of natural refrigerants
- **www.hydrocarbons21.com**
Hydrocarbons21 - related to the hydrocarbon refrigeration industry
- **www.iiar.org** - *International Institute of Ammonia Refrigeration*
- **www.iifiir.org** - *International Institute of Refrigeration*
- **www.r744.com**
Everything R744 - related to the carbon dioxide refrigeration industry
- **www.refrigerantsnaturally.com**
Refrigerants, Naturally! - an organization of end-users involved in the adoption of natural refrigerants
- **www.unep.org/ozone/**
UNEP Ozone Secretariat – website of the Secretariat of the Vienna Convention and the Montreal Protocol: Ozone Secretariat
- **www.uneptie.org/ozonaction**
UNEP DTIE OzonAction – website of the OzonActon Branch as an implementing agency and clearinghouse function

Another form of reference information pertinent to the application of refrigeration systems and refrigerants is **standards**, which are usually a description of procedures or technical requirements that should enable individuals or companies to achieve equivalence in the activity under consideration.

For example, following refrigeration safety standards should ensure that two separate refrigerating systems achieve an equivalent level of safety, and following performance standards should ensure that two separate organizations would measure the same performance of the same system. Furthermore, they are intended to help practitioners avoid problems, errors and pitfalls that they may otherwise encounter if they did not follow the guidance of the standards.

Standards are published by a variety of different organizations. At a country level, national standardization bodies publish national standards (although in many cases these may be based on other countries' standards or international standards). European standardization bodies publish a European standard, which are typically adopted by national standardization bodies within European countries. Internationally, there are two main organizations which publish international standards.

The numbers of national, European and International standards that apply to the RAC sector are vast, and the reader should seek out the most relevant ones when and where necessary.

Here, a small selection of such standards is listed to provide an indication of what may be relevant to this subject area:

EN 378: 2008 – *Refrigeration systems and heat pumps, safety and environmental requirements;*

This is comprised of four parts

- **Part 1:** *basic requirements, classification and selection criteria*
- **Part 2:** *design, construction, testing, marking and documentation*
- **Part 3:** *Installation site and personal protection*
- **Part 4:** *Operation, maintenance, repair and recovery*

EN 13313: 2008 – *Refrigeration systems and heat pumps, Competence of personnel;* this addresses the level of competence that is necessary for engineers and technicians to carry out different activities

ISO 817: 2005 – *Refrigerants – designation and system classification;* this covers the R-numbering system for refrigerants and the means for their safety classification

ISO 5149: 1993 – *Mechanical refrigerating systems used for cooling and heating – Safety requirements;* this current version is rather dates, but it is currently under revision and is similar to EN 378

ISO 916: 1968 – *Testing of refrigerating systems;* this covers the determination of the technical performance of a refrigerating system (but not the functional duty of a complete installation or the performance of its individual components)

Other International and European standards, as well as various national standards also address the following subject matter:

Properties *of refrigerant and lubricants*

Performance testing *of systems including energy consumption (refrigeration, air conditioners, heat pumps, etc) and components*

Performance of refrigeration-related equipment *(such as recovery, recycling, vacuum equipment)*

Performance testing *of refrigerated display equipment, and refrigerated storage equipment*

Design, *construction and selection of system safety devices (such as pressure relief and pressure limiting devices)*

Safety design, *construction and selection of system components (such as vessels and pipes)*

Safety of appliances *(such as domestic refrigerators and freezers, commercial refrigerating equipment, air conditioners, dehumidifiers and heat pumps)*

Testing *of airborne noise levels of refrigeration, air conditioners, heat pump equipment*

Electrical safety *of refrigeration, air conditioners, heat pump equipment*

Such standards can be obtained from the relevant standardization organizations:

- **www.iso.org** - *International Standardisation Organisation*
- **www.cen.eu** - *Comité Européen de Normalisation*
- **www.iec.ch** - *International Electro-technical Commission*
- **www.cenelec.eu** - *Comité Européen de Normalisation Electrotechnique*

Choose your chapter

Throughout the lifetime of the equipment, a variety of activities are carried out by different personnel and accordingly, a range of knowledge is needed. The content of this manual is intended to provide a large portion of that, particularly for those who are involved in refrigerant handling. We have summarised the major activities involved during the start-of-life, operation and end-of-life stages of RAC equipment. For each of these activities, the most important chapters of this manual have been identified. Thus, any training course or technical guidance specifically for any one of these activities can be focused on the material within the corresponding chapters.

The primary objective of this manual is to provide the reader with the appropriate background information to enable him/her to gain an adequate level of understanding related to the key topics addressed. The diagram on the next page summarizes the contents of this manual.

CHAPTER 1
ENVIRONMENTAL IMPACT

sets the overall context for the manual, being the environmental impact of refrigerants and thus the introduction of alternative refrigerants

CHAPTER 2
REFRIGERANTS

provides a broad overview of most of the issues associated with refrigerants.

CHAPTER 3
REFRIGERANTS MANAGEMENT

covers a variety of important aspects related to the handling and management of refrigerants, with the primary focus on maintaining good quality refrigerant and avoiding emissions and wastage.

CHAPTER 4
SERVICING PRACTICES

covers methods and techniques that are used when working on systems, primarily during servicing exercises.

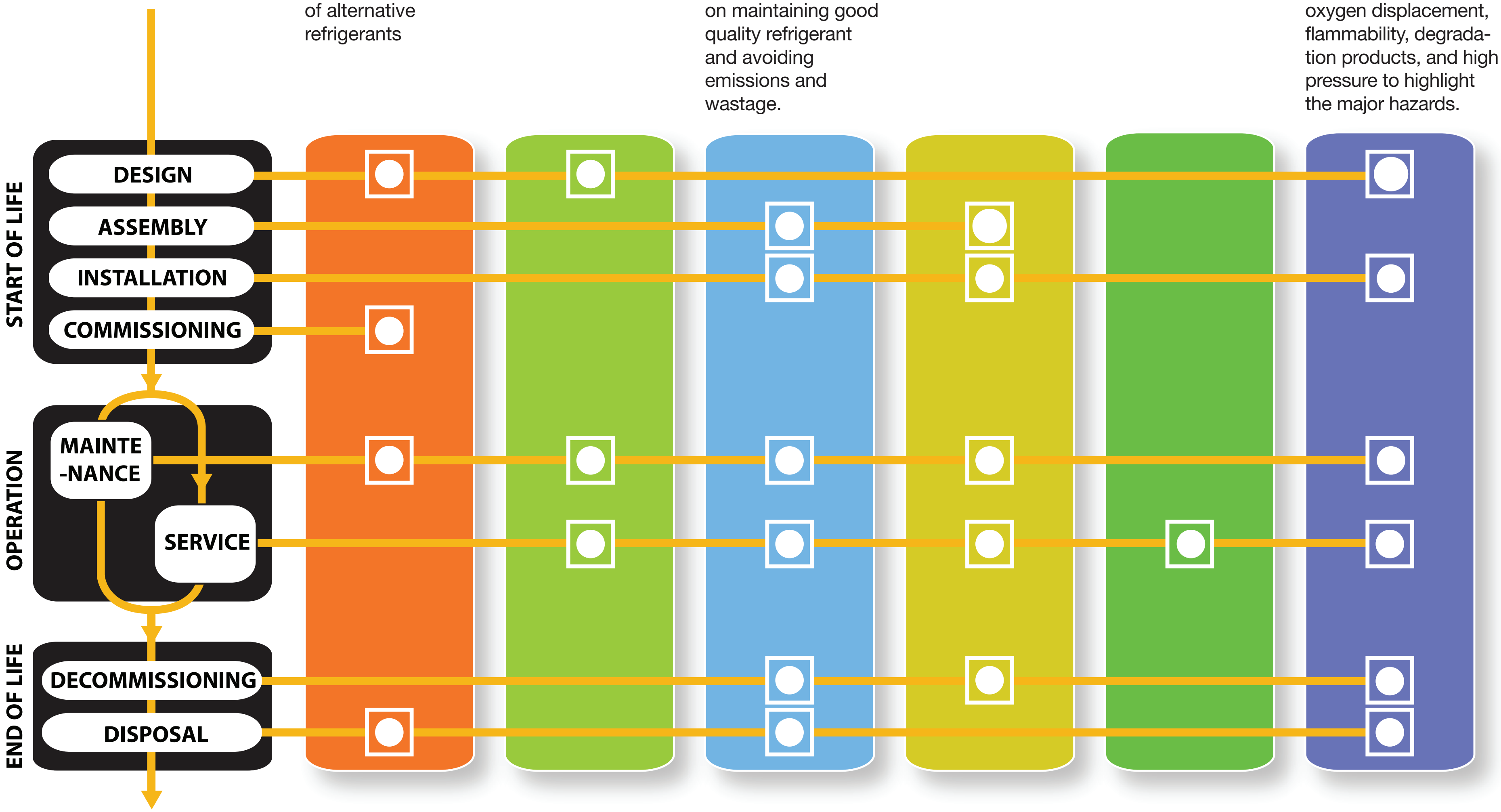
CHAPTER 5
RETROFITTING

addresses the approach and working procedures for changing refrigerants within an existing system.

CHAPTER 6
SAFE REFRIGERANT HANDLING

covers the relevant safety with refrigerants. There is a general description of the safety implications of refrigerants, including toxicity, oxygen displacement, flammability, degradation products, and high pressure to highlight the major hazards.

Click on any of the chapter bars to visit that section



		CHAPTER 1	CHAPTER 2	CHAPTER 3	CHAPTER 4	CHAPTER 5	CHAPTER 6
START OF LIFE	DESIGN	●	●				●
	ASSEMBLY			●	●		
	INSTALLATION			●	●		●
	COMMISSIONING	●					
OPERATION	MAINTE-NANCE	●	●	●	●		●
	SERVICE		●	●	●	●	●
END OF LIFE	DECOMMISSIONING			●	●		●
	DISPOSAL	●		●			●

1

Environmental impact of refrigeration and air conditioning (RAC) systems

Content

1

Environmental Impact

Summary

Initially the ozone layer is described and the impact that certain refrigerants have on it. The concept of global warming is also described and the impact of some refrigerants, and the energy-related impact associated with the operation of refrigeration systems are discussed. The primary motivation for the introduction of alternative refrigerants, namely the Montreal Protocol and latterly the Kyoto Protocol are emphasized.

The reader should be able to:

- **Identify the main environmental problems related to RAC installations**
- **Identify the role of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants in ozone layer depletion**
- **Identify how RAC contributes to global warming**
- **Identify the measures of the Montreal Protocol and the schedule for refrigerants phase-out.**

1.1. Introduction

Refrigeration, air conditioning and heat pump applications represent the major consumer of halogenated chemical substances used as refrigerants; it is also one of the most important energy sector users in our society today. It is estimated that, on average, for developed countries, the RAC sectors are responsible for 10-20% of electricity consumption.

The economic impact of refrigeration applications is significant; estimates indicate 300 million tonnes of continually refrigerating goods, with huge annual electricity consumption, and about US$ 100 billion in equipment investments, where the estimated value of the products treated by refrigeration are about four times this sum. This is one of the reasons why economic impacts of the elimination of refrigerant chemical substances such as CFCs and in the near future HCFCs have been hard to calculate.

Although HCFCs had been used since the 1930s, because of their relatively low ozone depleting potential (ODP), they were not at first included in the controls for ODS. As such, they were used within mixture of other chemical compounds to enable the easy replacement of CFCs. It was, however, acknowledged at the time that these chemicals were transitional since their production and consumption was also to be phased out under the Montreal Protocol.

About The Ozone Layer ▶

About the Montreal Protocol ▶

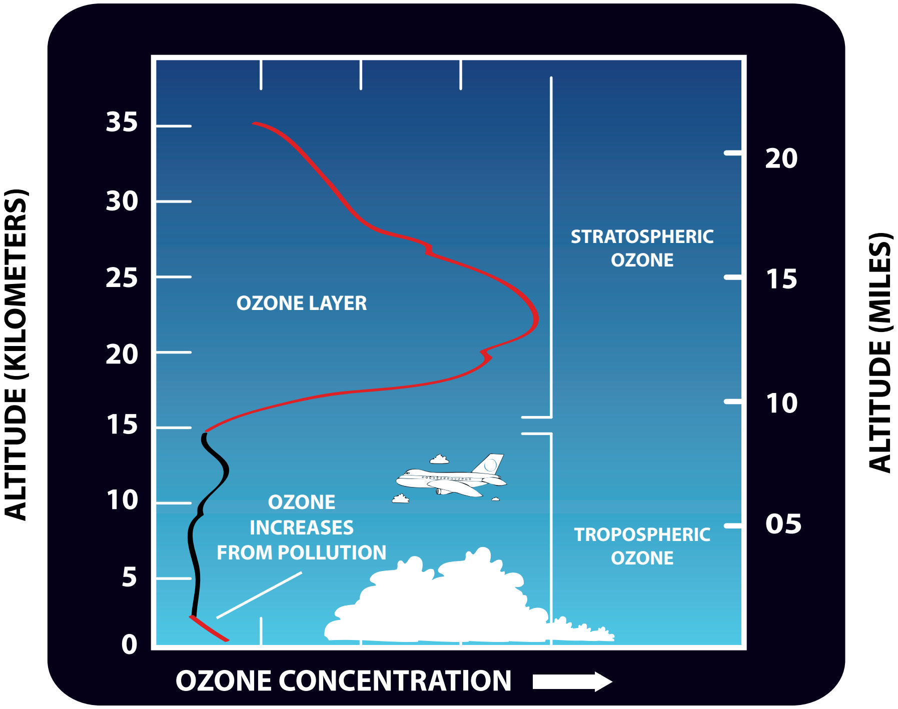
The ozone layer

As the sun's radiation approaches the planet's surface it can be scattered, reflected, or absorbed, intercepted and re-emitted. This is where the ozone layer comes into its own by scattering and reflecting harmful high energy ultraviolet radiation. Variations in temperature and pressure divide the Earth's atmosphere into layers and the mixing of gases between the layers happens very slowly. That is why this 90% of the ozone stays in the upper atmosphere. This stratospheric ozone contains 90% of all ozone gas on the Earth but it is spread thinly and unevenly.

Life on earth has been safeguarded because of a protective layer in the atmosphere. This layer, composed of ozone, acts as a shield to protect the earth against the harmful ultraviolet radiation from the sun. Ozone is a form of oxygen with three atoms (O3) instead of two (O2). Through natural atmospheric processes, ozone molecules are created and destroyed continuously. Ultraviolet radiation from the sun breaks up oxygen molecules into atoms which then combine with other oxygen molecules to form ozone. Ozone is not a stable gas and is particularly vulnerable to destruction by natural compounds containing hydrogen, nitrogen and chlorine.

Near the earth's surface (the troposphere) ozone is an increasingly troublesome pollutant, a constituent of photochemical smog and acid rain. But safely up in the stratosphere, 11 to 48 km above the earth's surface, the blue, pungent-smelling gas is as important to life as oxygen itself. Ozone forms a fragile shield, curiously insubstantial but remarkably effective.

The distribution of ozone in the atmosphere is illustrated in Figure 1.1.



Distribution of ozone in atmosphere.

1. The exosphere (2400km))	The sunlight still contains very high-energy photons, which can heat gas particles in the exosphere up to 2,500 degrees C during the day.
2. The ionosphere	Most high energy photons are absorbed here leading to a few air molecules becoming electrically charged.
3. The ozone layer	This thin layer at the top of the stratosphere absorbs most of the ultra-violet (UV) light. Too much UV light can cause damage to living things so the ozone layer is very important in protecting life on Earth.
4.The stratosphere (50km)	**Ozone depletion relies on the clouds in the stratosphere: Polar stratospheric clouds** (**PSCs**), also known as **nacreous clouds**, are CLOUDS in the winter polar STRATOSPHERE at altitudes of 15,000–25,000 metres (50,000–80,000 ft). They are implicated in the formation of OZONE HOLES; [1] their effects on ozone depletion arise because they support chemical reactions.
5. The troposphere (8-15 km).	The troposphere contains most of the air molecules, nearly all the water vapour so all of the clouds are in this layer. All these particles mean that a lot of sunlight is scattered. Shorter wavelengths (violet and blue) are scattered more than longer wavelengths, making the sky appear blue.
6. Absorption of radiation emitted by the Earth	The Earth emits a lot of long wavelength radiation from its surface and much of this is absorbed and scattered in the troposphere. Greenhouse gases such as carbon dioxide and water vapour are responsible for most of this absorption, making the temperature around the Earth higher.

This ozone filter efficiently screens out almost all the harmful ultraviolet rays of the sun; the ozone layer absorbs most of the dangerous UV-B radiation (radiation between UV-A which is allowed through and UV-C which is mainly captured by oxygen, as indicated in Figure 1.2). Any damage that is done to the ozone layer will lead to increased UV-B radiation. Increases of UV-B radiation have been clearly observed in areas experiencing periods of intense ozone depletion.

Any increased UV-B that reaches the earth's surface has a potential to cause considerable harm to the environment and to life on earth. A small decrease in the ozone layer could significantly increase the incidence of skin cancer, and could lead to an acceleration of the rarer but more virulent form of cancer known as coetaneous malignant melanoma. Increased UV-B could lead to increased incidents of eye damage, including cataracts, deformation of the eye lenses, and presbyopia. Eye cataracts, the leading cause of blindness in the world, are expected to increase considerably.

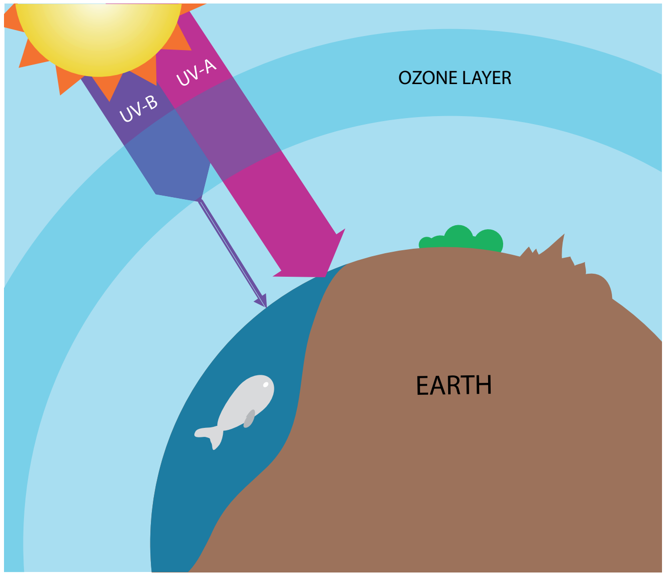


Figure 1.2. Radiation from the sun

UV rays are dangerous to human beings, animals and plants because they burn. They can penetrate our skin and eyes and weaken our bodies' immune system. That is why we should avoid long periods in the sun. To get the minimum daily dose of vitamin D only 15 minutes in the sun per day is enough. If we stay more than that, we might get sunburnt if no protection is used. Repeated sunburns and frequent tanning can cause premature ageing of the skin and, at worst, skin cancer such as melanoma (because of UV-A and UV-B). For the eyes the UV-B rays can cause a cataract (clouding of the eye lens). Most of the serious health problems appear only many years later.

CATEGORY	WAVELENGTHS (nanometres)	REACTIONS IN & WITH STRATOSPHERE	EFFECT UPON HUMANS, PLANTS ETC.
UV-A:	315/320 - 400 nm	Not significantly absorbed by the stratospheric ozone layer.	10-15% of 'burning': possible connection with the formation of skin cancers. Responsible for 'tanning' & skin ageing.
UV-B:	280 – 315/320 nm	Absorbed by ozone in the stratosphere. Ozone absorbs UV radiation without being reduced; the overall result being to convert UV radiation to heat.	85 – 90 % 'burning'; involved with both malignant & benign cancerous growths. Also linked to eye cataracts. Effects on growth of plants and marine life. Strong radiation kills also plankton in the water which is the main food supply for fishes.
UV-C:	200 - 280 nm	Highly absorbed by oxygen molecules: involved with formation of ozone.	Not thought to be significant, mainly because of its efficient absorption at high-altitudes.

Exposure to increased UV-B radiation could also suppress the body's immune system.

Immunosuppression by UV-B occurs irrespective of human skin pigmentation. Such effects could exacerbate the poor health situations of many developing countries.

Increased UV-B radiation could also cause decreased crop yields and damage to forests. It could affect ocean life causing damage to aquatic organisms, parts of the marine food web, which may lead to a decrease in fish higher up the food chain. Materials used in buildings, paints, packaging and countless other substances could be rapidly degraded by increased UV-B.

Depletion of stratospheric ozone could aggravate the photochemical pollution in the troposphere resulting in an increase of ozone at the surface of the earth where it is not wanted. Earth and inhabitants, therefore, have an enormous stake in preserving the fragile ozone layer shield.

Global consensus supports the theory that chlorine and bromine containing man-made chemicals emitted into the atmosphere are responsible for the depletion of ozone in the stratosphere. The larger part of these compounds, called ODS, consists of CFCs, HCFCs and halons (used as fire extinguishing agents), which are most effective in ozone depletion. CFCs have been used for years as refrigerants, solvents or blowing agents. ODS are classified considering how harmful they are for the ozone layer using a parameter called ozone depleting potential (ODP).

ODP is a relative index indicating the extent to which a chemical product may cause ozone depletion. The reference level of 1 is the potential of R11 and R12 to cause ozone depletion. If a product has an ODP of 0.5, a given weight of the product in the atmosphere would, in time, destroy half the amount of ozone that the same weight of R11 would destroy. ODP is calculated from mathematical models which take into account factors such as the stability of the product, the rate of diffusion, the quantity of depleting atoms per molecule and the effect of ultraviolet light and other radiation on the molecules.

The ozone layer and the Montreal Protocol

UNEP has been concerned about the protection of the ozone layer since its inception in 1972. In March 1985, the Convention for the Protection of the Ozone Layer was signed in Vienna. The Convention provided for future protocols and specified procedures for amendment and dispute settlement. In September 1987, agreement was reached on specific measures to be taken and the Montreal Protocol on Substances that Deplete the Ozone Layer was signed. Under the Protocol, the first concrete step to protect the ozone layer was taken, a 50% reduction in the production and consumption of specified CFCs by the year 1999.

Even as the nations adopted the Protocol in 1987, new scientific findings indicated that the Protocol's control measures were inadequate to restore the ozone layer. In addition, developing countries expressed concern over the vague language both regarding technology transfer to developing countries and regarding financial assistance. As a result of the Second Meeting of the Parties in London (1990), the Montreal schedules were adjusted so that the five CFCs (R11, R12, R113, R114 and R115) and the three halons would be phased out by the year 2000. Methyl chloroform was to be controlled and to be phased out in 2005. Figure 1.3 shows the CFC phase-out schedules for Article 5 and Non-Article 5 countries.

CFCs (ANNEX A/I) PRODUCTION/CONSUMPTION REDUCTION SCHEDULE

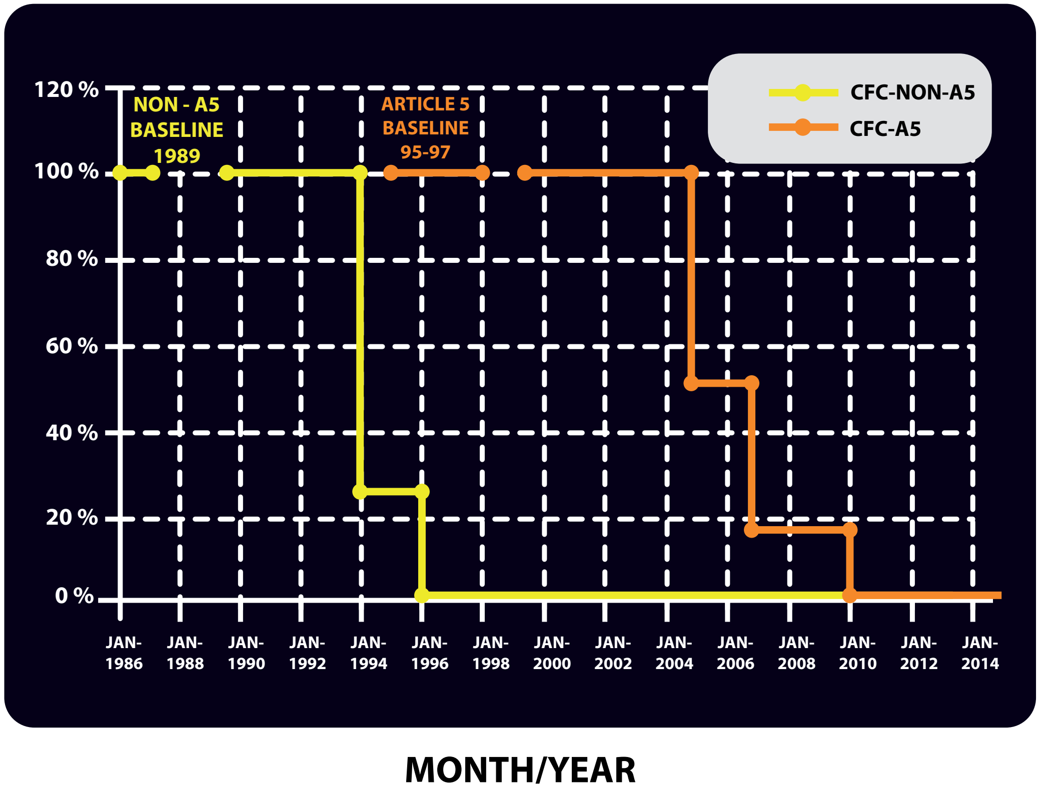


Figure 1.3 Article 5 and Non-Article 5 countries phase-out schedules of Annex A Group I CFCs

The UNEP Assessment Panels did a substantial amount of work in 1991. These Panels consider the science, the effects and the technology that is in place to replace and phase out the controlled chemicals.

On the basis of these reports the parties to the Montreal Protocol discussed again a tightening of the control schedules.

Achieving the goals of the Montreal Protocol depends on widespread cooperation among all the nations of the world. It is not enough that the developed nations, which accounted in 1986 for 85% of the consumption of ODS, participate in the Protocol. The participation of developing countries, which consumed only 15% in 1986, is also vitally important. HCFC consumption in developing countries has been growing at a much higher rate than in the developed world.

As long ago as 1987, developing countries were given incentives to conform with the Protocol in the form of a grace period of 10 years for implementation and technical assistance (Articles 5 and 10 in the Protocol). However, by 1989 many of the larger developing nations indicated that the provisions were inadequate. They argued that it was not they that were responsible for depleting the ozone layer. And as they are just beginning to develop economically and to use the low cost CFC technology acquired from the developed countries, they require help with the costs. If they are to bind themselves to strict schedules for adopting new technologies, they need to be given the new technologies and the finance necessary to adopt them. Negotiations on this issue resulted in the establishment of a new financial mechanism in London, 1990, through a new Article 10 in the Montreal Protocol.

The mechanism includes a Multilateral Fund and other multilateral, regional and bilateral co-operation. The Fund has now operated since 1991; under the Fund, UNEP OzonAction is responsible for information dissemination, training and networking. This manual is part of UNEP's work programme related to training on good practices in refrigeration in developing countries.

What is your countries protocol status from

▶ **http://ozone.unep.org/Ratification_status/list_of_article_5_parties.shtml**

Contact your National Ozone Units/Officers available on

▶ **http://www.uneptie.org/ozonaction/information/contacts.htm**
to find out actions being taken by your government.

Although having considerably lower ODP than CFCs, many HCFCs have high global warming potentials (GWP), of over 2000 times that of carbon dioxide (CO2).

The reasons for the phasing out **Effects of Ozone Depletion** ▶

For the impacts on climate change and global warming **Global Warming** ▶

Key dates in refrigeration development, a summary of what is happening and deadlines before different refrigerants become illegal to use.

Timeline Activity ▶

Effects of ozone layer depletion on the environment

With the loss of the shield from ultraviolet radiation, serious damage can result on all living organisms. The severity of the situation is augmented by the fact that each one percent depletion of ozone results in up to two percent increased exposure to ultraviolet radiation.

Plant and marine life could be adversely affected by increased exposure to ultraviolet radiation caused by depletion of the ozone layer. The sensitive ecosystem of the oceans may be adversely affected. The phytoplankton and larvae of many species that live from the surface of the ocean down to several metres below the surface could well be sensitive to increased exposure to ultraviolet radiation. Increased exposure results in reduced productivity, which means less plant life and fewer fish harvested from the seas.

The Global Solar UV Index, developed by the World Health Organization in collaboration with UNEP and the World Meteorological Organisation, is a tool to describe the level of UV radiation at the Earth's surface. It uses a range of values from zero upwards, taking into account all the factors to indicate the potential for adverse health effects due to UV radiation. The higher the value, the greater the amount of dangerous UV rays.

UV factors	High UV radiation
Time of the day	Between 10 am to 4 pm
Time of the year	Summer or hot season
Location	Especially close to the equator and poles
Elevation	Altitude above sea level
Reflection	Sand, snow, water and ice
Weather	No dark clouds in front of the sun

Activity

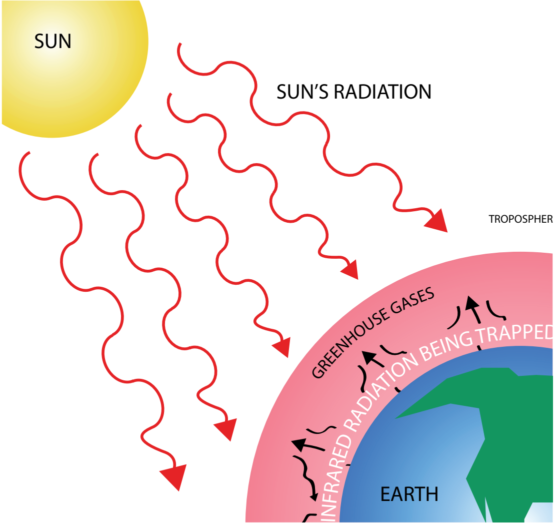
Fortunately there are many easy ways to protect ourselves from these dangerous rays. Use that information to write out a four point action plan.

- **During the hot** season avoid the sun between 10 am and 4 pm when the UV Index is the highest.
- **Search for a shade** when you're outside. Under a tree there might be up to 60% less radiation than in a sunny place.
- **Cover your skin and eyes.** Wear long sleeves, trousers, a hat or something to cover your head and sunglasses to protect your eyes.
- **Use sunscreen.** If you want to go swimming, avoid the midday hours and use sunscreen for the whole body as the water reflects the rays efficiently and increases the radiation. Also while wearing a long-sleeved shirt use some sunscreen on your hands or other parts that are not covered. Sunscreen should also be used often; if you put it once and stay in the sun for hours that is not enough to well protect your skin. Also every time you go swimming you should add sunscreen afterwards.

Global warming

The earth's temperature is maintained by a balance between heating from solar radiation flowing in from the sun, and cooling from infrared radiation emitted by the earth's warm surface and atmosphere escaping back to into space. The sun is the earth's only external source of heat. When solar radiation, in the form of visible light, reaches the earth, some is absorbed by the atmosphere and reflected from clouds and land (especially from deserts and snow). The remainder is absorbed by the surface which is heated and in turn warms the atmosphere. The warm surface and atmosphere of the earth emit invisible infrared radiation. While the atmosphere is relatively transparent to solar radiation, infrared radiation is absorbed in the atmosphere by many less abundant gases. Though present in small amounts, these trace gases act like a blanket, preventing much of the infrared radiation from escaping directly to space. By slowing the release of cooling radiation, these gases warm the earth's surface.

This process is illustrated here:



The concept of global warming

In a greenhouse, glass allows sunlight in but prevents some infrared radiation from escaping. The gases in the earth's atmosphere which exert a similar effect are called "greenhouse gases" (GHGs). Of the man-made greenhouse gases, the most important are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and the halocarbons (CFCs, HCFCs and HFCs).

Different gases absorb and trap varying amounts of infrared radiation. They also persist in the atmosphere for differing time periods and influence atmospheric chemistry (especially ozone) in different ways. For example, a molecule of R12 has about the same effect on radiation as 16,000 CO2 molecules. A molecule of methane has approximately 21 times the effect of CO2; but its lifetime is far shorter. The GWP is an index which compares the warming effect over time of different gases relative to equal emissions of CO2 (by weight). A table of the ODP and GWP of various refrigerants is included in Chapter 2. HFCs do not have chlorine, and in this way, don't destroy the ozone layer, but they do contribute to global warming. For this reason, they are in the group of gases controlled by Kyoto Protocol. These gases are: CO2, CH4, N2O, HFCs, perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Scientific measurements have shown that in the last century, the Earth's average near-surface atmospheric temperature rose 0.6 ± 0.2 °C, mostly attributable to human activities increasing the concentration of CO2 and other greenhouse gases in the atmosphere. Moreover, a global temperatures increase by between 1.4 and 5.8 °C between 1990 and 2100 has been predicted by the models and disseminated by the Intergovernmental Panel on Climate Change (IPCC).

The greenhouse warming effect causes an increase in global temperatures and consequently potentially catastrophic effects, such as rising sea level, changes in the amount and pattern of precipitation, increasing the frequency and intensity of extreme weather events, higher or lower agricultural yields, glacier retreat, and so on. These are the reasons why the international community has decided to control the emissions of GHGs through the Kyoto Protocol signed in 1997 and entered into force in 2005.

Direct global warming of refrigerants

The halocarbons, and among them the main refrigerants, absorb the infrared radiation in a spectral range where energy is not removed by CO2 or water vapour, thus causing a warming of the atmosphere. In fact these halocarbons are strong GHGs since their molecules can be thousands of times more efficient at absorbing infrared radiation than a molecule of CO2. CFCs and HCFCs have also a significant indirect cooling effect, since they contribute to the depletion of stratospheric ozone that is a strong UV radiation absorber, but this effect is less certain and should vanish with the reduction of the ozone hole. The direct warming potential of a molecule is proportional to its radiative effect and increases with its atmospheric lifetime. The direct global warming effect of a given mass of substance is the product of the GWP and the amount of the emissions: this explains why CO2 has a much greater overall contribution to global warming than halocarbons, since the total mass of CO2 emitted around the world is considerably more massive than the mass of emitted halocarbons.

Direct emissions of GHGs may occur during the manufacture of the GHG, during their use in products and processes and at the end of their life. Thus, the evaluation of their emissions over all their life, cycle is necessary. It is noteworthy that at present a large amount of halogenated refrigerants is in banks (i.e. CFC, HCFC and HFC that have already been manufactured but have not yet been released into the atmosphere such as contained in existing equipment, products and stockpiles, etc.) It is estimated that in 2002, the total amount of refrigerants (CFC and HFC) banked in domestic refrigeration, i.e. the sum of refrigerant charge contained in all refrigerators in operation or wasted, amounted to 160,000 tonnes. Despite the fall in the production of CFCs, the existing bank of CFCs, as refrigerant in all RAC applications and including the amount contained in foams, is over 1.1 million tonnes and is therefore a significant source of potential emissions. Banks of HCFCs and HFCs are being established as use increases. The management of CFC and HCFC banks is not controlled by the Montreal Protocol or taken into account under the United Nations Framework Convention on Climate Change (UNFCCC). The emission of these banks could give a significant contribution to global warming in the future.

Energy-related contribution to global warming

When considering the global warming impact of RAC equipment, one should address both the “direct” emissions, and the energy-related emissions. When these two contributions are added together, it provides and overall appreciation of the greenhouse gas impact of the equipment as a whole. The direct emissions are those of the refrigerant itself, for example, when the refrigerant leaks out, or when it is released during servicing or disposal.

The energy-related contribution is represented by the emissions of GHGs (mainly CO2) that arise from the production of electricity from, for example, fossil fuels. Over the entire life cycle of the RAC equipment, considerable amounts of electricity will be consumed, and in many countries, this is mainly generated through the burning of high-carbon content fuels, such as coal, oil and gas. In certain countries which rely heavily on hydro-electricity or other renewable energy resources (such as solar, wind, geothermal, and biomass), or nuclear power, there are minimal emissions of CO2 per kWh of electricity consumed. In countries that use carbon-intensive electricity production, emissions can be around 1 kg of CO2 per kWh. In these countries, the energy used is often the dominant contribution to equipments' GHG emissions. Therefore, it is important to also improve and maintain the efficiency of RAC equipment over its entire lifetime.

Certain concepts are often used to evaluate the overall lifetime GHG impact of RAC systems. These include a variety of names: Total Equivalent Warming Impact (TEWI), Life Cycle Climate Performance (LCCP), and Life Cycle Warming Impact (LCWI), amongst others. Essentially, all these concepts are the same: they add the total equivalent GHG emissions from different sources together, over the lifetime of the equipment. The purpose of doing this is often used to compare different technologies, and more constructively, to identify which aspects of the equipment could be most effectively optimised to help reduce its global warming impact. Lastly, it is of utmost importance to carry out such evaluations with attention to detail, since there are myriad assumptions involved, and as such it is easy to draw erroneous conclusions.

The Earth has a natural temperature control system. Certain atmospheric gases are vital in this system and are known as greenhouse gases. The Earth's surface becomes warm and as a result of incoming solar radiation and then emits infrared radiation. The greenhouse gases trap some of the infrared radiation thus warming the atmosphere. Naturally occurring greenhouse gases include water vapour, carbon dioxide, ozone, methane and nitrous oxide: together they create a natural greenhouse effect. Without this phenomenon the Earth's average temperature would be more than 30°C (60 °F) lower throughout the year.

Global warming might also slow down the ozone layer's recovery; despite the temperature rise in the troposphere, the air might even cool down in the stratosphere, which is favourable to the depletion of the ozone layer. The heat budget is dynamic – it is changing. For example: at the time of the dinosaurs there was more carbon dioxide in the atmosphere, trapping more heat, creating a higher planetary temperature. This is an example of a feedback system.

Activity

Affect	**Increase Earth's Temperature**	**Decrease Earth's Temperature**
Cutting down forests will:	√	
A major volcanic eruption will:	√	√ (May also offer some cooling as particles in the atmosphere reflect the sun's rays)
Burning fossil fuels leading to increased carbon dioxide in the atmosphere will:	√	
The addition of CFCs will:	√	
The addition of HCFCs will:	√	
The addition of HFCs will:	√	

Timeline activity

An overview of refrigerant development, phase out CFC and Phase out HCFC are given here:

19th Century

Refrigeration technology using the thermodynamic vapour compression cycle technology was first developed in the middle of the 19th Century. The technology used four basic components (compressor, condenser, evaporator and device expansion) and a working fluid, called a refrigerant. Since then, the RAC industry has evolved significantly, and has been present in many social sectors.

1930s

CFC and HCFC refrigerants were developed and have been used in the 1930s and 1940s.

1970s

During the 1970s CFC and HCFC refrigerants were found to be directly connected to a global environmental problem: the depletion of the ozone layer.

1987

CFC and HCFC are scheduled to be eliminated by the Montreal Protocol, an international agreement established in 1987. As well as contributing to the depletion of the ozone layer, CFCs and HCFCs are strong greenhouse gases, thus contributing to the global warming process. Since the establishment of Montreal Protocol, the refrigeration industry has been searching substitutes to CFCs and HCFCs refrigerants. At the same time, the industry has been developing ways to conserve these refrigerants, making the installations more leak-tight, adopting procedures for recovery and treatment of refrigerants for re-use, and converting installations to use zero ozone depleting substances (ODS) and low-global warming refrigerants. These procedures are now part of the so-called good practices of RAC servicing, and this manual has the objective of summarise them, helping technicians to deal with the upcoming challenges within the field of RAC.

2006

Global HCFC production was 34,400 ODP tonnes and approximately 75% of global HCFC use was in air-conditioning and refrigeration sectors. The main HCFC used is R22 or chlorodifluoromethane.

2007

At the 20th anniversary meeting of the Montreal Protocol on Substances that Deplete the Ozone Layer, in Montreal, agreement was reached to adjust the Montreal Protocol’s schedule to accelerate the phase-out of production and consumption of HCFCs. This decision will result in a significant reduction in ozone depletion, with the intention of simultaneously reducing the global warming impact. In addition to the HCFC accelerated phase-out schedules, the 2007 Meeting of the Parties of the Montreal Protocol approved a decision to encourage Parties to promote the selection of alternatives to HCFCs that minimise environmental impacts, in particular impacts on climate, as well as meeting other health, safety and economic considerations (Decision XIX/6: Adjustments to the Montreal Protocol with regard to Annex C, Group I, substances or so-called HCFCs).

Here are the schedules for HCFC phase-out schedules for Article 5 (developing) countries and Non-Article 5 countries:

Article 5 countries HCFC phase-out schedules
(production and consumption)

Level	Year
Baseline	Average of 2009 and 2010
Freeze	2013
10% reduction (90% of baseline)	2015
35% reduction (65% of baseline)	2020
67.5% reduction (32.5% of baseline)	2025
Total phase-out	2030
2.5 % of baseline averaged over ten years (2030-2040) allowed, if necessary, for servicing of refrigeration and air-conditioning equipment until 2040	2030-2040

Non-Article 5 countries HCFC phase-out schedules
(production and consumption)

Level	Year
Baseline	1989 HCFC consumption + 2.8% of 1989 consumption
Freeze	1996
35% reduction (65% of baseline)	2004
75% reduction (25% of baseline)	2010
90% reduction (10% of baseline)	2015
Total phase-out	2020
0.5 % of baseline restricted to servicing of refrigeration and air-conditioning equipment until 2030	2020-2030

Alternative refrigerants and regulations

Hydrofluorocarbon (HFC) refrigerants were developed in the 1980s and 1990s as alternative refrigerants to CFCs and HCFCs. HFCs do not contain chlorine, and therefore do not destroy the ozone layer. They do, however, contribute to global warming; HFCs are greenhouse gases and as such they are in the group of gases included within the Kyoto Protocol. Several regions and countries in the world are adopting regulations to contain, prevent and thereby reduce emissions of the fluorinated greenhouse gases covered by the Kyoto Protocol.

Examples of regulation:

European ▶

USA ▶

European

One example is regulation (EC) no 842/2006 of the European Parliament. It applies to several HFC compounds, among them the R134a, and R404A.

According to this Regulation, for stationary refrigeration, air conditioning and heat pump units over 3 kg charge (6 kg if hermetic), operators must:

- Prevent leakage, and repair any leaks as soon as possible
- Arrange proper refrigerant recovery by certified personnel during servicing and disposal
- Carry out regular leak checks (e.g. at least once every three months for applications with 300 kg or more of fluorinated gases) by certified competent staff
- Maintain records of refrigerants and of servicing
- Provide labelling of equipment containing fluorinated gases
- Prohibit of placing on the market certain equipment containing fluorinated gases such as non-refillable containers.

For non-stationary equipment (e.g., mobile units on trucks) and any other products containing fluorinated gases, operators must ensure that appropriately qualified personnel are used to recover gases, as long as this is feasible and not excessively expensive.

Other European measures regarding the use of HFCs are covered by the Directive 2006/40/EC, relating to emissions from air-conditioning systems in motor vehicles, which bans fluorinated gases with a GWP higher than 150 (such as R134a) as of 2011 for new models of cars.

USA

Another case of regulations concerning the use of HFC compounds are the measures adopted by the California Air Resources Board in 2007, to reduce the HFC emissions from mobile vehicle air conditioning (MVAC) systems. These measures will control HFC releases from MVAC servicing, requiring leak tightness test, repair to smog check, enforce the federal regulations on banning HFC release from MVAC servicing, dismantling, and require using low-GWP refrigerants for new MVAC.

Mobile Vehicle Air Conditioning manufacturers are testing alternative refrigerants to meet the long-term needs of automotive manufacturers. Currently there are two alternatives under consideration: R744 (carbon dioxide) and R1234yf (an unsaturated HFC). Both have low GWP, are of lower toxicity, and whilst R744 is non-flammable, R1234yf has a lower flammability classification. These new alternatives are still in the testing and development phase, and it is not clear whether either one or both will be adopted for MVAC systems.

With the continued environmental pressure on refrigerants, technological innovations have helped in the consideration of “natural refrigerants” (ammonia, hydrocarbons, carbon dioxide) as a safe and economic options for RAC applications in many areas. Because of smaller environmental impacts and for being more appropriate in terms of sustainable technological development perspective, refrigeration systems with natural refrigerants could have an important role in the future as technical solution in many applications.

The way forward

Changing refrigerant options and efficiency goals are likely to drive further innovations in air conditioning and refrigeration equipment. Technical options are being developed to lower refrigerant charges in equipment, thereby decreasing refrigerant emissions, and cooperating for the responsible use of all alternatives. Due to technological development and adoption of sustainability policies, it is predicted an increase of natural refrigerant applications. Use of indirect systems (applying heat transfer fluids in secondary systems) is growing since it helps also to reduce charge sizes, to enable use of sealed systems, and to facilitate application of flammable alternatives.

Contrary to non-Article 5 countries, the demand for service refrigerants in most Article 5 countries will consist of CFCs and HCFCs, a tendency driven by long equipment life and with the costs of field conversion to alternative refrigerants, and the availability of such alternatives. One of the main concerns will be maintaining adequate supplies of HCFCs. Refrigerant conservation programmes to be established for CFCs in Article 5 countries will mostly be government sponsored and regulatory in nature. As in many non-Article 5 countries, they may include restrictions on the sale, use, and end-of-life disposal requirements that mandate recovery and recycling of refrigerants. These programmes will be expanded in countries without such requirements.

Further reading

UNEP DTIE OzonAction – *Ozone Protection, Climate Change & Energy Efficiency, Centro Studi Galileo / UNEP, 2007*

▸ **www.unep.fr/ozonaction/information/mmcfiles/4824-e-ozoneclimenerg.pdf**

Ozone Secretariat, Refrigeration – *reports of the Air Conditioning and Heat Pumps Technical Options Committee (RTOC)*

▸ **www.ozone.unep.org/teap/Reports/RTOC/**

UNEP DTIE OzonAction – *Protecting the Ozone Layer, Volume 1, Refrigerants, UNEP, 2001*

▸ **www.unep.fr/ozonaction/information/mmcfiles/2333-e.pdf**

International Panel on Climate Change - *IPCC special report on Safeguarding the Ozone Layer and the Global Climate System: Issues related to Hydrofluorocarbons and perfluorocarbons, IPCC / TEAP, 2005*

▸ **www1.ipcc.ch/ipccreports/sroc.htm**

European Commission Environment - *web section on fluorinated greenhouse gases*

▸ **http://ec.europa.eu/environment/climat/fluor/index_en.htm**

2

Refrigerants

Content

2

Refrigerants

2.1. Section objectives

This chapter provides a broad overview of most of the issues associated with refrigerants. This includes the criteria normally applied to their selection (for example, thermodynamic properties and safety characteristics), an overview of the various types of refrigerants and how they are identified. Particular attention is paid to the characteristics of refrigerant blends. Although not normally considered to be a refrigerant, the topic of refrigeration oils or lubricants is discussed since it effectively becomes part of the working fluid during system operation and thus requires special attention also.

The information provided here should help the reader
to be able to:

- Identify refrigerant characteristics
- Recognise the classification of refrigerants
- State the main refrigerant groups
- Identify the proper refrigerant for each refrigeration or air-conditioning system
- State the main characteristics for the most commonly-used refrigerant
- Identify the suitable lubricant for each refrigerant.

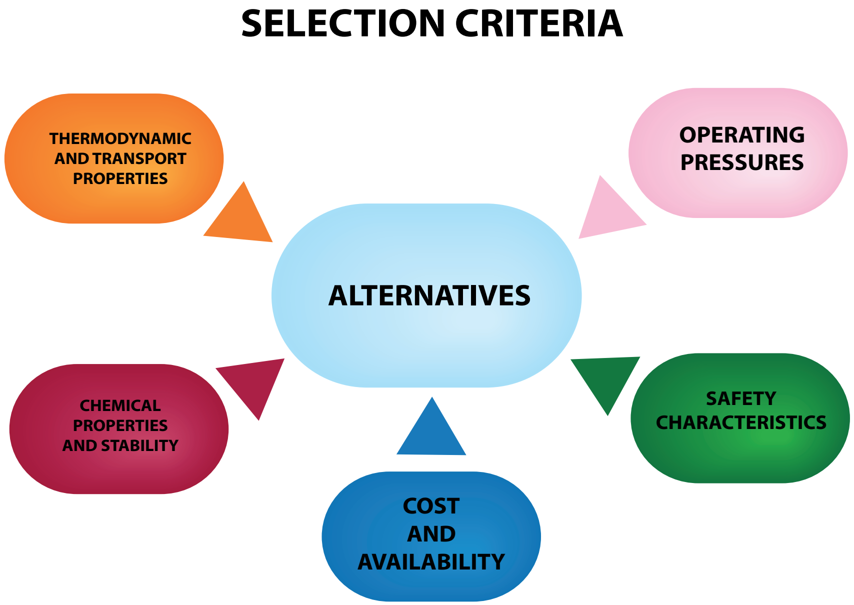
Selecting the refrigerant

Originally when the modern refrigerating system concept was developed in the middle of the 19th Century, a small number of fluids were used as the working fluid, or “refrigerant”. These included ammonia (NH3, R717), carbon dioxide (CO2, R744), sulphur dioxide, methyl chloride and ethyl ether. However, because of the combination of toxicity, flammability and pressure issues, these refrigerants were largely replaced with to a “new” group of fluorinated chemicals which exhibited little reactivity, low-toxicity and no flammability. However, during the 1980s, it was found that these chemicals contributed to the depletion of the ozone layer, which lead to the development of the Montreal Protocol in 1987.

The Montreal Protocol requires the cessation of the consumption and production of all chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) and since its introduction, the refrigeration and air conditioning (RAC) industry has been engaged with the chemical community to establish substitutes for ozone depleting refrigerants. Throughout this time a large number of refrigerants have been introduced worldwide, of which some are long term alternatives, and others are “transitional” substances. With the increasing attention paid to the issue of global warming and climate change, there is now a stronger push towards adopting alternative refrigerants with low or no global warming potential (GWP), as well as zero ozone depleting potential (ODP).

With the continued attention on replacement refrigerants, coupled with the ever growing market for RAC, there are now several hundred refrigerants that are currently commercially available. Such a diversity of refrigerants and their variety of different characteristics can create difficulties in handling and servicing practices for many RAC technicians. This section aims to introduce an overview of refrigerants and their characteristics, classifications, applications, identification and lubricants.

There are usually two situations that necessitate refrigerant selection, the first being for manufacture of systems, and the second being equipment servicing. For manufacturing RAC equipment, the refrigerant selection process is theoretically complex, involving the consideration of huge number parameters.



Chemical properties and stability

The stability of a refrigerant is linked to the way it behaves in the presence of other substances, particularly within the refrigerating system. It is important that the refrigerant will not react with, or act as a solvent with, any of the materials within the system. These include metals used for pipes and other components, compressor oils and associated additives, plastic motor materials, elastomers in valves and fittings, and desiccants within filter dryers. This should also be considered with respect to the small quantities of contaminants such as moisture and air.

In general CFCs, HCFCs, hydrofluorocarbons (HFCs) and HCs are compatible with most materials (since most components are designed for these refrigerants). However, many components are designed using proprietary mixtures and additives, so there is always a possibility of incompatibility with certain materials if an unspecified refrigerant is used. Carbon dioxide has some compatibility problems with certain elastomers, which is why only dedicated components for R744 should be used with this refrigerant.

Ammonia is not compatible with many materials, such as copper, copper alloys and many electrical wiring insulation materials. Therefore construction metals inside ammonia systems are normally limited to carbon steel and stainless steel.

In all cases, component manufacturers should be consulted to check that their materials are compatible with a non-standard refrigerant.

Operating pressures

It is important to consider the likely operating pressures in both the suction and discharge sides of the system. Ideally, a refrigerant is chosen that will have an evaporating pressure above atmospheric pressure under normal operating conditions, so as to avoid air and moisture being drawn into the system in the event of a leak. Thus, a refrigerant should be chosen with a normal boiling point (NBP) that is lower than the anticipated evaporating temperature. A selected refrigerant should also have a condensing pressure that does not exceed the pressure that the system components are designed for, as this can have safety implications.

Thermodynamic and transport properties

The most important performance criteria for a refrigerating system are cooling (or heating in the case of heat pumps) capacity and efficiency, or coefficient of performance (COP). **These performance characteristics are influenced by a number of properties, including:**

- saturation pressure-temperature characteristics
- critical temperature
- latent heat
- density
- viscosity
- thermal conductivity
- specific heat capacity

It is important to consider the likely operating pressures in both the suction and discharge sides of the system. Ideally, a refrigerant is chosen that will have an evaporating pressure above atmospheric pressure under normal operating conditions, so as to avoid air and moisture being drawn into the system in the event of a leak. Thus, a refrigerant should be chosen with a normal boiling point (NBP) that is lower than the anticipated evaporating temperature. A selected refrigerant should also have a condensing pressure that does not exceed the pressure that the system components are designed for, as this can have safety implications.

The capacity and COP are mainly dictated by the design and control of the system itself (compressor, heat exchangers, piping, etc), although the properties of the refrigerant play a part in this. The COP can be affected by the compression ratio (which is dictated by the saturation pressure-temperature characteristic), heat exchanger performance and pressure losses around the system, which are all influenced by latent heat, density, viscosity, thermal conductivity, specific heat.

For a given evaporating and condensing temperature, the cooling (or heating) capacity of a system is strongly influenced by the latent heat and density of the gas entering the compressor. For conventional systems, a fairly high critical temperature is preferred (at least 20K above the condensing temperature), unless the system is specially designed for operation near or above the critical temperature, such as with R744 systems.

Safety characteristics

Refrigerant are classified in terms of two general safety criteria: toxicity and flammability.

Toxicity: Both acute (short-term) and chronic (long-term) toxicity are considered as they affect human safety during handling and servicing with refrigerants, and for occupants in refrigerated or air conditioned spaces. The acute-toxicity exposure limit (ATEL) is the maximum recommended refrigerant concentration intended to reduce the risks of acute toxicity hazards to humans in the event of a refrigerant release. For chronic toxicity, the threshold limit value-time weighted average (TLV-TWA) is the time -weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

Flammability: Refrigerant flammability can affect the safety of people and property mainly during handling and servicing activities, and it influences the design of equipment. The flammability of a refrigerant is judged according to the lower flammability limit (LFL), which is the lowest concentration of the refrigerant mixed in air, required for it to be able to be ignited. Flammability is also considered according to the refrigerants' heat of combustion (HOC), which is the amount of energy released when it burns.

According to various international and national safety standards, refrigerants may be allocated one of six safety classifications according to its toxicity and flammability. This classification consists of two alpha-numeric characters (e.g. A2); the capital letter corresponds to toxicity and the digit to flammability. The toxicity classification is determined by a refrigerants' TLV-TWA, such that it may be lower toxicity "A" or higher toxicity "B". There are no refrigerants that are non-toxic.

The flammability classification may be no flame propagation "1", lower flammability "2" or higher flammability "3".

These classifications are shown in this table:

LOWER TOXITY	HIGHER TOXITY	
A3	B3	HIGHER FLAMMABILITY
A2	B2	LOWER FLAMMABILITY
A1	B1	NO - FLAME PROPAGATION

Safety Classifications according to ISO 817, EN 378 and ASHRAE 34 standards

Environmental parameters

Whenever a gas is released into the environment it has some impact. The most important impacts related to refrigerants are ozone depletion and global warming.

They are discussed in detail in

Chapter 1 ▶

Cost and availability

The cost (or retail price) of refrigerants varies widely, with HCFCs tending to be cheaper, and HFC blends more expensive. Similarly, the most widely used HCFCs (for example, R22) and the most common HFCs (e.g. R134a) tend to be most widely available. Hydrocarbon (HC) refrigerants tend to be less widely available, and ammonia is normally sourced from specialist suppliers.

In reality, many of these parameters will already have been addressed, for example, by refrigerant retailers, and through the availability of components. Whilst there are several hundred refrigerants currently available, this catalogue of products will have been filtered down to a more manageable selection.

Most refrigerant retailers will stock around 20 different refrigerants, whilst manufacturers of components (compressors, valves, heat exchangers, etc) often limit their range to five to 10 refrigerants, particularly for non-industrial applications. Often the predominant selection criteria tend to be: the choice of operating pressures, safety characteristics and whether the refrigerant has a high or low GWP.

In terms of selection for equipment servicing, the selection depends upon whether the refrigerant currently in use is restricted or not. If it is not restricted, then the same refrigerant as indicated on the nameplate on the equipment should be chosen. If the named refrigerant is restricted (i.e. due to it being unavailable because of regulations), then a similar set of considerations need to be applied as detailed above. The following section outlines the types of refrigerants that are available.

Types of refrigerants

Refrigerants can be divided in two main groups:

synthetic (basically halocarbon fluids: CFCs, HCFCs and HFCs) and **non-synthetic** (hydrocarbons, carbon dioxide, ammonia, water, air – so-called natural refrigerants).

Synthetic ▶

Natural ▶

Synthetic refrigerants

Refrigerators from the late 1800s until 1929 used the higher toxicity gases - ammonia, methyl chloride, and sulphur dioxide - as refrigerants. Several fatal accidents occurred in the 1920s because of methyl chloride leakage from refrigerators. A collaborative effort began between three American corporations to search for a less dangerous method of refrigeration.

In 1928, CFCs and HCFCs were invented as substitutes for the higher toxicity and flammable refrigerants. CFCs and HCFCs are a group of aliphatic organic compounds containing the elements carbon and fluorine, and, in many cases, other halogens (especially chlorine) and hydrogen. Most CFCs and HCFCs tend to be colourless, odourless, non-flammable, non-corrosive substances. Because CFCs and HCFCs have low toxicity, their use eliminated the danger posed by refrigerator leaks. In just a few years, compressor refrigerators using CFCs became the standard for almost all home kitchens. In subsequent years, they were introduced in a series of products, including R11, R113, R114 and R22, that helped the expansion of the RAC industry and applications. With the advent of the Montreal Protocol, HFC refrigerants were developed during the 1980s and 1990s as alternative refrigerants to CFCs and HCFCs.

Three groups could be considered:

Those with ozone depleting potential ▶

Those without ozone depleting potential ▶

Heat transfer fluids ▶

More about the classification and use of different refrigerants:

Using Refrigerant Blends – issues and concepts ▶

Those with ozone depleting potential

Chlorofluorocarbons

CFCs consist of chlorine, fluorine, and carbon. The most common refrigerants in this group are R11, R12 and R115 (within the blend R502). As mentioned above, they have been in widespread use since the 1930s, in nearly all applications, including domestic refrigeration, commercial refrigeration, cold storage, transport refrigeration and vehicle air conditioning. Because they contain no hydrogen, CFCs are chemically very stable, and tend to have good compatibility with most materials and traditional lubricants such as mineral oils. Across the range of CFCs, they have a variety of pressure-temperature characteristics, thus covering a fairly wide range of applications. Their thermodynamic and transport properties are generally good, thereby offering the potential for good efficiency. Their good stability also results in lower toxicity and non-flammability, thus usually achieving an A1 safety classification. However, because they contain chlorine, CFCs are damaging to the ozone layer (section 1), and due to their long atmospheric life, the CFCs have a high ODP. Similarly, they are strong greenhouse gases with high GWP. However, they are not controlled by the Kyoto Protocol because they are controlled and are being eliminated by the Montreal Protocol. Traditionally, CFCs have been very cheap and widely available, although with their current phase-out, prices will rise considerably and availability will lessen.

Hydrochlorofluorocarbons

HCFCs consist of hydrogen, chlorine, fluorine, and carbon. The most common refrigerants in this group are R22, R123 and R124 (within various blends). As mentioned above, they have been in widespread use since the 1930s, in nearly all applications, including commercial refrigeration, cold storage, transport refrigeration, stationary air conditioning and chillers. Because they contain hydrogen, HCFCs are theoretically less chemically stable than CFCs, but nevertheless tend to have good compatibility with most materials and traditional lubricants such as mineral oils. Across the range of HCFCs, there are a variety of pressure-temperature characteristics. Their thermodynamic and transport properties are typically very good, thereby offering the potential for very good efficiency. Although some HCFCs have an A1 safety classification, due to their less stable nature, some HCFCs have A2 (low-toxicity, lower-flammability) and B1 (higher toxicity, non-flammable) safety classifications. As with CFCs, because of the chlorine content, they are damaging to the ozone layer (Chapter 1), although with a relatively low ODP. Similarly, they are strong greenhouse gases with high GWP. Again, they are not controlled by the Kyoto Protocol because they are controlled and are being eliminated by the Montreal Protocol. Currently, HCFCs are very cheap and widely available, although with the forthcoming accelerated phase-out, prices will rise considerably and availability will lessen.

Hydrofluorocabons (HFCs)

HFCs consist of hydrogen, fluorine, and carbon. The most common refrigerants in this group are R134a, R32, R125 and R143a (mostly within blends, such as R404A, R407C and R410A). They have been in large scale use since the 1990s, in nearly all applications that have traditionally used CFCs and HCFCs, including domestic and commercial refrigeration, cold storage, vehicle air conditioning, transport refrigeration, stationary air conditioning and chillers.
HFCs are generally chemically very stable, and tend to have good compatibility with most materials. However, they are not miscible with traditional lubricants, so other types of synthetic oils must be used. Across the range of HFCs, there are a variety of pressure-temperature characteristics. Their thermodynamic and transport properties range from fairly to very good, thereby offering the potential for good efficiency. Although some HFCs have an A1 safety classification, some have A2 (low-toxicity, lower-flammability) safety classifications. Unlike CFCs and HCFCs, they contain no chlorine, and are thus not damaging to the ozone layer (Chapter 1). However, due to their long atmospheric lifetime, they are typically strong greenhouse gases with high GWP. They are controlled by the Kyoto Protocol. Currently, HFCs carry a moderate price, with the blends being more expensive. Although numerous countries are developing legislation to control the use and/or emissions of HFCs, many are widely available, and will continue to be so for the foreseeable future.

Those without ozone depleting potential ▶
Heat transfer fluids ▶
Using Refrigerant Blends – issues and concepts ▶

Those with zero ozone depleting potential

There are three other sub-categories of synthetic refrigerants that have zero ODP and play a part in RAC:

Perfluorocarbons

They represent another group of fluorocarbons which contains five different fluids. One of these (R218) is occasionally used in refrigerant blends. Generally PFCs are very stable, but as a result have very high GWP.

Unsaturated HFCs

Whilst conventional HFCs are saturated, there are a small number of unsaturated HFCs, known as olefins. Generally, there are highly unstable, but recently a small number have been identified which are sufficiently stable to be used as refrigerants, and have low-toxicity and low flammability and low GWP. The two receiving most interest are R1234yf and R1234ze; the former is being considered for use in MVAC systems, but it is unlikely that they will be applied as refrigerant in other sectors for several years.

Hydrofluoroethers

This group of fluorinated chemicals tends to be fairly stable and amongst them have a fairly wide range of boiling points, although they tend to be lower pressure fluids. They have been considered as use as refrigerants, but to date have not achieved market acceptance for various reasons.

Those with ozone depleting potential ▶

Heat transfer fluids ▶

Using Refrigerant Blends – issues and concepts ▶

Natural refrigerants

Various hydrocarbons, ammonia and carbon dioxide belong to a group named "natural refrigerants". All natural refrigerants exist in material cycles present in the nature even without human interference. They have zero ODP and zero or negligible GWP. Evolutions and technological innovations have helped in the consideration of "natural refrigerants" as a safe and economic solution for applications in many sectors. Because of minimal environmental impacts and for being more appropriated in a sustainable technological development perspective, refrigeration systems with natural refrigerants could have an important role in the future in many applications.

Ammonia (NH3, R717)

Ammonia contains nitrogen and hydrogen, and is widely used within many industries. It has been used widely as a refrigerant since the late 1800's, and is currently in common use in industrial refrigeration, cold storage and food process cooling, and more recently is being used for commercial refrigeration and chillers. R717 is chemically stable, but will react under certain conditions, for example when it is in contact with carbon dioxide, or water and copper. Otherwise, compatibility in steel systems and correctly chosen oils is good. The pressure-temperature characteristic of R717 is broadly similar to that of R22. However, it's thermodynamic and transport properties are excellent, leading to potentially highly efficient systems. Due to its higher toxicity and lower flammability, it has a B2 safety classification. Unlike the fluorinated gases, it has no impact on the ozone layer and has a zero GWP, so it is controlled by neither the Kyoto Protocol nor the Montreal Protocol. R717 is very cheap and widely available from specialist retailers.

Hydrocarbons (HCs)

Hydrocarbons contain hydrogen and carbon, and are widely used within many industries. The most commonly used for refrigeration purposes are isobutane (C4H12, R600a) and propane (C3H8, R290), propylene (C3H6, R1270), and blends thereof. Within industrial applications, a variety of other HCs are widely used. In general, HCs had been widely used a refrigerant since the late 1800s until 1930s, and has been re-applied since the early 1990s. Apart from industrial applications, HCs have been used in domestic refrigeration, commercial refrigeration, air conditioners and chillers. HCs are chemically stable, and exhibit similar compatibility to the CFCs and HCFCs. Across the range of HCs, there are a variety of pressure-temperature characteristics. They also have excellent thermodynamic and transport properties, leading to potentially very efficient systems. Due to their higher flammability, all HCs have an A3 safety classification. As with R717, they have no impact on the ozone layer and have a negligible GWP, so are controlled by neither the Kyoto Protocol nor the Montreal Protocol. R600a and R290 are fairly cheap but availability is disparate, depending upon the country.

Carbon dioxide (CO2, R744)

Carbon dioxide contains carbon and oxygen, and is widely used within many industries. It had been extensively applied as a refrigerant since the mid-1800s, but this also ceased with the advent of the CFCs and HCFCs. From the later 1990s, its has re-emerged as a refrigerant and its use is currently increasing within industrial refrigeration, cold storage, commercial refrigeration and hot-water heat pumps, amongst others. R744 is chemically stable, and does not react under most conditions, and is compatible with many materials. The pressure-temperature characteristic of R744 are different from most conventional refrigerants, in that it operates at pressures, for example, approximately seven times higher than R22, which necessitates the system to be designed with special consideration to high pressures. In addition, it has a low critical temperature, such that when ambient temperatures exceed about +25°C, a special system design is required. Otherwise, it's thermodynamic and transport properties are excellent, leading to potentially highly efficient systems within cooler climates. Due to its lower toxicity and non-flammability, it has an A1 safety classification. Unlike the fluorinated gases, it has no impact on the ozone layer so is not controlled by the Montreal Protocol. However, despite it having a GWP of 1, it is included within the Kyoto Protocol, but its use it not restricted as a result of this. R744 is very cheap and widely available from specialist retailers.

Refrigerant numbering

Chemical names of typical refrigerants are generally long and complex. In order to create a more simple way to designated refrigerants a method of identifying them by number was developed. IIR's note on classification of refrigerants that describes the basic rules for adopting the number of the refrigerant (see www.iifiir.org/en/doc/1034.pdf). The classification is based on the standard ASHRAE 34 and makes it possible to name all refrigerants used in a clear and internationally recognised way by classifying them according to their chemical composition. Basically an identifying number is assigned to each refrigerant. It consists of a prefix made up of letters and a suffix made up of digits. The prefix is composed of the letter R (for refrigerant). Examples: R22, R134a, R600a, R717. Blended refrigerants, whether they are zeotropic or azeotropic, always being with R4xx or R5xx, respectively.

Refrigerant blends characteristics and pros and cons:

Refrigerant blends ▶

Lubricants properties and choices:

Lubricants ▶

Once you have explored these characteristics the next button introduces refrigerants and their appropriate use:

Using Refrigerant Blends ▶

Refrigerant blends

Although refrigerants can be one single substance, they can also be a mixture of two or more substances, and these are normally referred to as “blends”. Refrigerant blends have been formulated to provide a match to certain properties and characteristics of the refrigerants originally used (i.e. in the case of retrofit blends), or to achieve a particular set of properties for other reasons. Most commercially available blends have between two and five components. These components may be HCFCs, HFCs and/or HCs and PFCs. The individual component refrigerants in a blended refrigerant do not have identical physical characteristics; they have different densities, different viscosities and different evaporation and condensation temperatures at a given pressure. With most blends, the components within the mixture change their composition in the liquid and vapour phases as the blend boils or condenses; these are known as zeotropes. These have an R-number designation, R4xx. Less commonly, the individual components in certain blends interact such that the vapour phase and liquid phase have the same composition at a given pressure; these blends are called azeotropic mixtures. These have an R-number designation, R5xx.

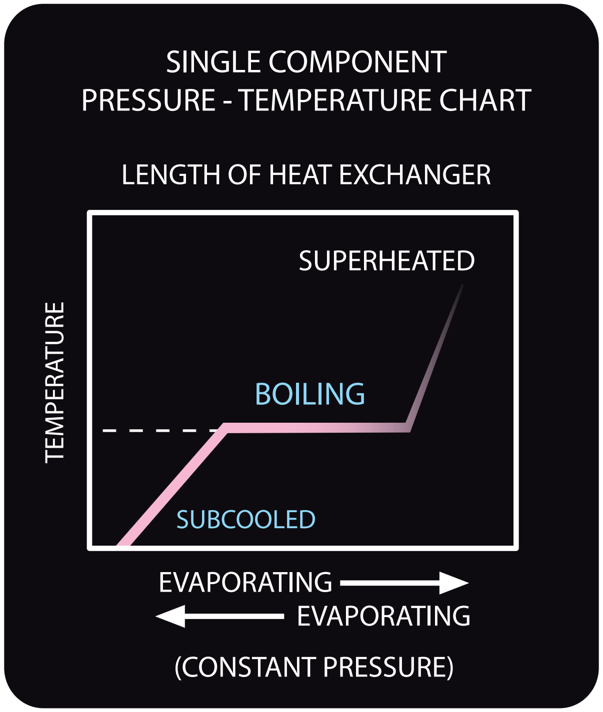
There are two types of blend:

- **Azeotropic** ▶
- **Zeotropic** ▶

Azeotropic Blends

An azeotropic blend is a mixture of usually two substances, which behaves as if it were a pure fluid. When heat is added to or removed from an azeotropic refrigerant blend, the composition (mole fraction) of the vapour and the liquid remain essentially unchanged throughout the complete process. In other words, in a blend of 50% of fluid A and 50% of fluid B, for every molecule of fluid A that vaporises or condenses, a molecule of fluid B does the same.

An azeotropic blend behaves like a single refrigerant when condensing or evaporating, i.e., the temperature remains constant at a given pressure, as shown in this figure:



Condensation and evaporation of an azeotropic blend

Historically, the commonly used ozone depleting substance (ODS) blends were R500 (mixture of R12 and R152a) and R502 (mixture of R22 and R115). More recently, an azeotropic blend using only HFCs has been found, R507A (mixture of R125 and R143a).

Zeotropic blends

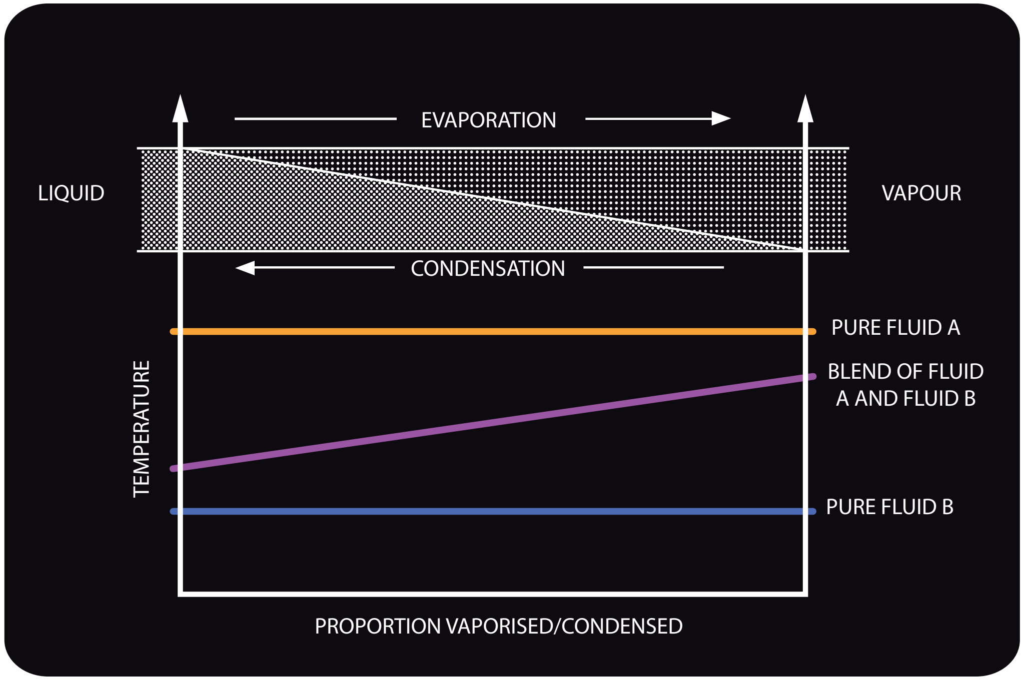
A zeotropic blend is a mixture of refrigerants whose different volatilities are seen when observing the performance of a refrigeration cycle. For example, a change in the molar composition and/or a change in saturation temperature during boiling or condensation; in this way, it does not behave like a single refrigerant when condensing or evaporating.

Two different situations arise, depending upon the type of system.
Direct expansion system:

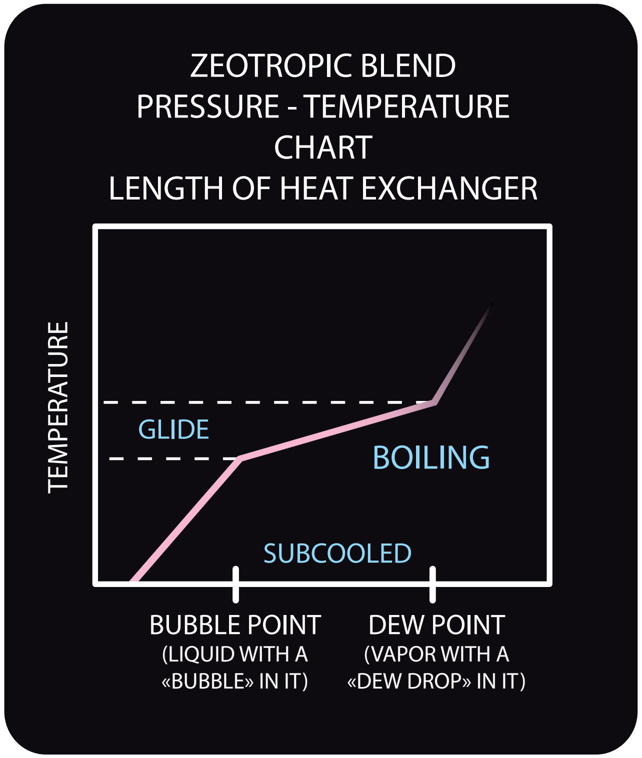
- **Flow-boiling** occurs in the evaporator and flow-condensation in the condenser. Fluid A boils or condenses at a different rate than fluid B, and because the liquid composition of fluid A and fluid B changes, whilst the pressure remains the same, the saturation temperature along the heat exchanger varies.
- **Flooded system:** Pool-boiling occurs in the evaporator and film-condensation in the condenser. Fluid A boils or condenses at a different rate from fluid B, which results in an accumulation of the most volatile fluid in the condenser and the less volatile fluid in the evaporator. Whilst the phase-change process occurs at a constant temperature, there is essentially a short-circuiting of the refrigerant, which results in a loss in performance.

The next illustration shows action of a zeotropic mixture of refrigerant components, fluid A and fluid B, as it flows through a heat exchanger tube. In the case of a pure fluid, the temperature of the refrigerant remains the same as the liquid vaporises, or the vapour condenses. However, with a zeotropic blend, as the refrigerant vaporises, the saturation temperature rises, or as the vapour condenses, the saturation temperature falls. The refrigerant is at the bubble temperature when it is just a pure liquid (e.g. when it is just evaporating) and is at the dew temperature when it is just a pure gas (e.g. when it is just condensing).

The range of temperature between the dew point and bubble point is called the temperature glide. This is illustrated here:



Behaviour of a zeotropic blend with changing temperature



Condensation and evaporation of a zeotropic blend

Prior to the Montreal Protocol, zeotropic mixtures were rarely used, perhaps the only example being R400 (a mixture of R12 and R114). In the search for alternatives for CFCs, and latterly, for alternatives for HCFCs, a large number of zeotropic mixtures have been formulated. Some of the HFC and HC based zeotropic blends to replace CFCs and HCFCs are: R404A, R407C, R410A and R436B.

Using Refrigerant Blends – issues and concepts

The following graphic allows you to consider different concepts and issues relating to the use of refrigerant blends.

Temperature glide ▶

Composition ▶

Flammability ▶

When considering these factors combined there are pros and cons for blends.

Pros and cons for blends ▶

Temperature glide

The characteristic called "temperature glide" refers to the temperature range over which components in a blended refrigerant boil or condense at a given pressure. A pure substance (like water) at a constant pressure will go through a complete phase change at a constant temperature. Conversely, a zeotropic blended refrigerant must proceed through a temperature range in order to complete the phase change process. The name temperature glide refers to this range of temperature. Similarly, if a zeotropic refrigerant was left to boil off within a bucket, the temperature at which it would start to boil would be the bubble-point temperature, and eventually the last few drops would be boiling off at the dew-point temperature. However boiling and condensation in "flooded" type evaporators and condensers will not normally exhibit any temperature glide because they are constantly being replenished with new refrigerant. Thus the refrigerant is seen to change phase at a single temperature - the bubble-point in an evaporator and dew-point in a condenser.

Composition

The specific characteristic of zeotropic blends, i.e., the liquid and vapour composition, is different at most given temperature and pressure. This causes concerns relating to composition changes in the refrigerant supply chain, including liquid removal from containers for multi-component refrigerant mixtures in the manufacturer plant, and refrigerant transfers to smaller containers by dealers. A study conducted by the Air Conditioning and Refrigeration Institute (ARI) in USA indicates "refrigerant mixtures can have composition changes during the handling procedures that lead to out-of-specification composition". The refrigerant transfer and equipment charging by technicians, and refrigerant equipment leakage could also change the composition. The change of the composition will affect the performance to some extent. Accordingly, ARI and Deutsches Institute für Normung (DIN) sets composition tolerances for specific blends, for example, ARI composition tolerances for R410A (R32/R125) are +0.5, -1.5% for R32, and +1.5, -0.5% for R125.

Flammability

Several of the blends use flammable refrigerants as one of the components, and some blends just use a mixture of hydrocarbons. Therefore, some safety concerns are raised for their application. Some regions and countries set a limitation in specific equipment for such kinds of blends or even forbid their use. In developed countries, the HCFC based blends for replacement of R12 were not widely used for the manufacturing of new equipment or retrofitting of existing equipment partly due to its ODP value, flammability and servicing complications. Also, the retrofitting of appliances is not practiced in developed countries mainly because of the availability of recycled CFC for servicing and high retrofitting cost due to higher labour charges compared to new equipment cost.

Pros and Cons of refrigerant blends

Pros of refrigerant blends:

- The refrigerant blends provide another way to assist the country in complying with the CFCs phase-out provision under the Montreal Protocol whilst not harming the interests of the end users.
- The refrigerant blends (if the main components are either R22/ R152a/HCs) can be cheaper than R134a and other alternatives; they tend to be widely available.
- The HCFC based refrigerant blends as mentioned above aimed to replace R12 can mostly be used with mineral oils and can provide acceptable performance in retrofitted equipment.

Cons of refrigerant blends:

- HCFC-based blends are an interim CFC replacement solution.
- Due to the non-azeotropic and possible flammable characteristics, the servicing procedure especially charging would be complicated and the technicians should be informed to follow proper handling procedures.
- It is more difficult to estimate the amount of superheat and sub-cooling when commissioning or servicing a system.
- Leakage from heat exchangers and subsequent re-filling will lead to a gradual change in composition, thereby resulting in a change in performance and operating characteristics over time.
- The introduction of more refrigerants in the market might confuse the technicians, causing more cases of cross-contamination in running the refrigeration system.
- Even though the short-term impact on the performance of the equipment might not be noticed by the equipment owner, it is believed the cross-contamination of a refrigerant/lubricant will reduce the equipment's energy efficiency and its performance, and shorten the operational life of the equipment.
- More blends will also complicate the recovery/recycling programme due to the cross-contamination, as equipment with the blends might not be properly labelled or the technicians may just ignore the label.
- Some blends are advertised to replace R134a, so it might cause backward retrofitting from R134a to HCFC-based blends.

Lubricants

Today, almost as many new lubricants are on the market as there are refrigerants. Compressor manufacturers always specify oil type and fill each model of compressor accordingly. One of the most common mistakes whilst servicing is not checking which is the appropriate lubricant for the serviced system; this could cause damage to the system due to non-compatibility with refrigerant and system components. In hermetic systems, the lubricant is in intimate contact with the electrical motor windings. The oil must therefore provide good, material compatibility and have high thermal stability properties.

Although the majority of the lubricant remains in the compressor, a small amount will be circulated into the rest of the refrigerant circuit. The lubricant must be able to resist both the high temperatures at the compressor discharge valves and the low temperatures at the expansion device. It must be sufficiently soluble with the refrigerant itself in order for it to be returned back to the compressor, so that over time, it does not become starved of oil, which could lead to mechanical failure. There properties are discussed next.

Properties

The properties of a good refrigeration lubricant are:

- **Low wax content.** Separation of wax from the refrigeration oil mixture may plug refrigerant control orifices
- **Good thermal stability.** It should not form hard carbon deposits and spots in the compressor, such as in the valves of the discharge port
- **Good chemical stability.** There should be little or no chemical reaction with the refrigerant or materials normally found in systems
- **Low pour point.** This is the ability of the oil to remain in a fluid state at the lowest temperature in the system
- **Good miscibility and solubility.** Good miscibility ensures that the oil will be returned to the compressor, although a too high solubility may result in lubricant being washed off the moving parts
- **Low viscosity index.** This is the ability of the lubricant to maintain good oiling properties at high temperatures and good fluidity at low temperatures and to provide a good lubricating film at all times.

Categories

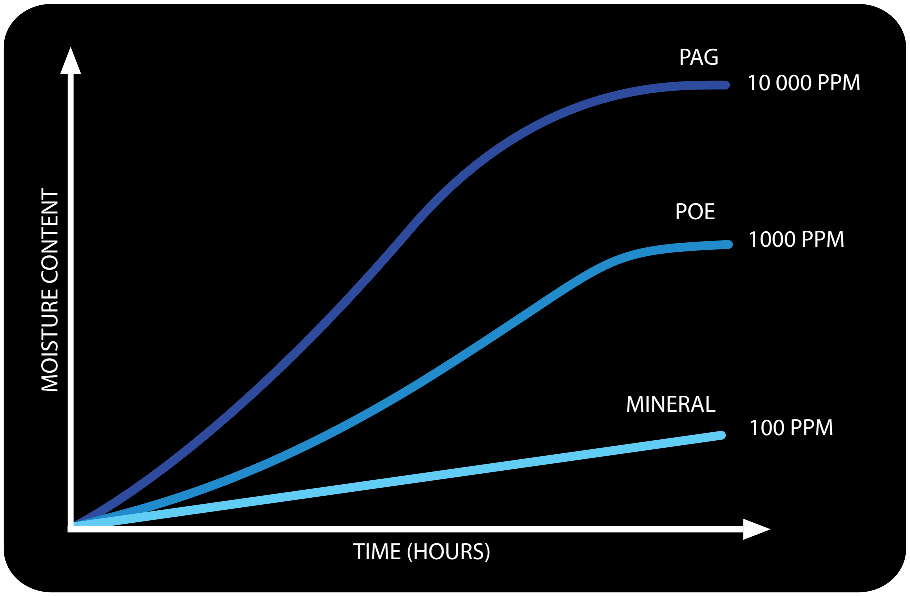
Basically there are six main categories of refrigeration lubricants:

- mineral oils (MO)
- alkyl benzene oils (AB)
- polyol ester oils (POE)
- poly alpha olefin oils (PAO)
- poly alkyl glycol oils (PAG)

Traditionally, CFC refrigerants have been used with mineral and alkyl benzene oils for the lubrication of compressors. This is now undergoing change, with the introduction of HFC refrigerants, which are immiscible with the traditional mineral oils, and need the use of synthetic oils for miscibility and oil return.

Characteristics

An important characteristic of many of the synthetic lubricants, such as POE and PAG oils, is that they are more hygroscopic than mineral oils as shown in the diagram below. They saturate at approximately 1000 ppm from atmospheric moisture, compared to about 100 ppm for mineral oils. The POE lubricants are considerably less hygroscopic than PAG lubricants. This diagram shows lubricant compatibility for some refrigerants.



Hygroscopy of POE and mineral lubricants

Refrigerant	**Appropriate Lubricant**				
	Mineral Oil (MO)	**Alkyl benzene (AB)**	**Polyol Ester (POE)**	**Poly alpha oelfin (PAO)**	**Poly alkyl glycol (PAG)**
CFC-11	✓	×	☐	☐	×
CFC-12	✓	✓	☐	☐	×
R-502	✓	✓	☐	☐	×
HCFC-22	✓	✓	☐	☐	×
HCFC-123	✓	✓	☐	☐	×
HFC-134a	×	×	✓	×	☐
HFC-404A	×	×	✓	×	☐
HFC-407C	×	×	✓	×	☐
HFC-410A	×	×	✓	×	☐
HFC-507A	×	×	✓	×	☐
HC-600a	✓	☐	✓	✓	☐
HC-290	✓	☐	✓	✓	☐
R-717 (NH_3)	✓	☐	×	✓	☐
R-744 (CO_2)	☐	☐	✓	✓	✓

✓: Good Suitability ☐: Application with limitations ×: Not Suitable

Chapter 4 of this manual presents information about the problems moisture can create in a system, and how to deal with them.

Refrigerants and applications

Application	Traditional refrigerants	Retrofit / drop-in refrigerants		New system refrigerants
		Transitional	Longer term	
Domestic refrigeration	R12	R401A, R401C, R405A, R406A, R414A, R414B, R415B	R426A, R430A, R435A, R436A*, R436B*, R437A	R134a, R600a*
Stand alone retail food display and vending	R12	R401A, R401C, R405A, R406A, R409A (HT), R414A, R414B, R415B, R416A (HT), R420A (HT)	R426A, R429A (HT), R430A, R435A, R436A*, R436B*, R437A (LT)	R600a*, R134a, R423A, R435A, R436A*, R436B*, R510A
	R22, R502	R408A (HT), R411A, R411B, R412A, R415A, R418A	R290*, R417A, R419A (HT), R422B, R422D, R424A, R431A, R438A	R290*, R404A, R407A/B/D/E, R421A, R421B, R427A, R433A/B/C, R507A, R744
Condensing Units	R502	R408A (HT), R411A, R411B, R412A, R415A, R418A	R417A, R419A (HT), R422B, R422D, R424A, R431A, R438A	R404A, R407A/B/D/E, R421A, R421B, R427A, R433A/B/C, R507A, R744
Large Supermarket Systems	R22 R502	R408A (HT), R411A, R411B, R412A, R415A, R418A	R417A, R419A (HT), R422B, R422D, R424A, R431A, R438A	R404A, R407A/B/D/E, R421A, R421B, R427A, R433A/B/C, R507A, R744, Indirect systems (using R290*, R1270*, R717*)
Cold Storage	R502 R22 R717	R408A (HT), R411A, R411B, R412A, R415A, R418A	R417A, R419A (HT), R422B, R422D, R424A, R431A, R438A	R404A, R407A/B/D/E, R421A, R421B, R427A, R433A/B/C, R507A, R744, Indirect systems (using R290*, R1270*), R717*

The chart presents an overview of main alternative refrigerants to CFCs and HCFCs in diverse RAC applications.

For each application, there are four lists of refrigerants:

- **Traditional refrigerants**, what would usually have been used prior to the Montreal Protocol.
- **Retrofit / drop-in refrigerants**, are refrigerants that have been developed, or can be used in existing systems that contained the traditional refrigerants, and typically contain some HC component so that they are soluble with existing mineral oils.

  These have been divided into two further categories:

  - **Transitional refrigerants** that comprise some HCFCs, and are therefore still controlled by the Montreal Protocol, and should only considered for short-term use in systems that contained CFCs.
- **Long-term refrigerants** that do not comprise any ozone depleting substances, and can be considered to be unrestricted.
- **New system refrigerants**, which include refrigerants that are also not restricted by the Montreal Protocol and are expected to be applicable for the long term.

Application	Traditional refrigerants	Retrofit / drop-in refrigerants		New system refrigerants
		Transitional	Longer term	
Industrial Process Refrigeration	R22 R502 R717 R290/ R1270	R408A (HT), R411A, R411B, R412A, R415A, R418A	R417A, R419A (HT), R422B, R422D, R424A, R431A, R438A	R404A, R407A/B/D/E, R421A, R421B, R427A, R433A/B/C, R507A, R744, Indirect systems (using R290*, R1270*), R717*
Refrigerated Transport	R12	R401A, R401C, R405A, R406A, R409A (HT), R414A, R414B, R415B, R416A (HT), R420A (HT)	R426A, R429A (HT), R430A, R435A, R436A*, R436B*, R437A (LT)	R134a, R423A, R435A, R436A*, R436B*, R510A*
	R502, R22	R408A (HT), R411A, R411B, R412A, R415A, R418A	R290*,R417A, R419A (HT), R422B, R422D, R424A, R431A, R438A	R404A, R407A/B/D/E, R421A, R421B, R427A, R433A/B/C, R507A, R744, R290*, R1270*
Split and ducted air conditioners	R22	R408A, R411A, R411B, R412A, R415A, R418A	R290*,R417A, R419A, R422B, R422D, R424A, R431A, R438A	R407A/C/D/E, R421A, R427A, R433A/B/C, R290*, R1270*, R410A
Portable and window units	R22	R408A, R411A, R411B, R412A, R415A, R418A	R290*,R417A, R419A, R422B, R422D, R424A, R431A, R438A	R407A/C/D/E, R421A, R427A, R433A/B/C, R290*, R1270*, R410A
Heat Pumps	R22	R408A, R411A, R411B, R412A, R415A, R418A	R290*,R417A, R419A, R422B, R422D, R424A, R431A, R438A	R407A/C/D/E, R421A, R427A, R433A/B/C, R744, R290*, R1270*, R410A
Chillers	R11 R123	None	None	R236ea, R236fa, R245fa
	R12	R401A, R401C, R405A, R406A, R409A, R414A, R414B, R415B, R416A, R420A	R426A, R429A, R430A, R435A	R134a, R423A, R435A
	R22	R408A, R411A, R411B, R412A, R415A, R418A	R290*,R417A, R419A, R422B, R422D, R424A, R431A, R438A	R407A/C/D/E, R421A, R427A, R433A/B/C, R744, R290*, R1270*, R410A
Mobile air conditioning (MAC)	R12	R401A, R401C, R405A, R406A, R409A, R414A, R414B, R415B, R416A, R420A	R426A, R429A, R430A, R435A, R436A*, R436B*	R134a, R744

A number of additional observations are made:

- Many of the blends in the "longer term" and "new system" lists contain HFCs and PFCs, which are included in the Kyoto Protocol, and are being legislated against in several European counties.
- Flammable refrigerants – indicated with an asterisk (*) must be handled appropriately, that is, systems are designed and maintained according to safety rules. If they are used as a drop-in refrigerant, the technician must ensure that the conversion has been done according to the appropriate safety rules.
- The initials "(HT)" and "(LT)" imply that the refrigerant is more suited to high temperature (eg, chilled food) or low temperature (eg. frozen food), respectively.
- In addition to the refrigerants listed, there are many other products on the market that do not have an R-number. Similarly, many of the refrigerants listed are marketed under trade names, rather than the R-number.
- Systems using carbon dioxide systems need to be designed with particular respect to its thermodynamic characteristics.

Properties of most common refrigerants

These are properties of refrigerants mostly used:

Refrigerant	Chemical type	Molecular mass	NBP (°C)	Pressure at 35°C (kPa)	Critical temp (°C)	Safety class	ODP (MP)	GWP (100)
R11	CFC	137.7	23.7	149	198	AI	1	4750
R12	CFC	120.9	-29.8	846	112	AI	1	10890
R22	HCFC	86.4	-40.8	1355	96.1	AI	0.055	1810
R114	CFC	170.9	3.6	292	145.7	AI	1	10040
R123	HCFC	152.9	27.8	131	183.7	BI	0.02	77
R134a	HFC	102.0	-26.1	887	101.1	AI	0	1430
R152a	HFC	66.1	-24	794	113.3	A2	0	124
R290	HC	44.1	-42.1	1218	96.7	A3	0	3
R401A	HCFC/HFC	94.4	-32.9	961	107.3	AI	0.04	1180
R401B	HCFC/HFC	92.8	-34.5	1024	105.6	AI	0.04	1290
R402A	HCFC/HFC/HC	101.6	-48.9	1733	75.8	AI	0.02	2790
R402B	HCFC/HFC/HC	94.7	-47	1635	82.9	AI	0.03	2420
R403A	HCFC/PFC/HC	92.0	-47.7	1649	87	AI	0.04	3120
R403B	HCFC/PFC/HC	103.3	-49.2	1715	79.6	AI	0.03	4460
R404A	HFC	97.6	-46.2	1629	72	AI	0	3920
R407C	HFC	86.2	-43.6	1414	86	AI	0	1770
R409A	HCFC	97.4	-34.4	977	109.3	AI	0.05	1590
R409B	HCFC	96.7	-35.6	1024	106.9	AI	0.05	1560
R410A	HFC	72.6	-51.4	2071	71.4	AI	0	2090
R413A	PFC/HFC/HC	104.0	-33.4	1067	96.6	A2	0	2050
R417A	HFC/HC	106.8	-39.1	1315	87.1	AI	0	2350
R500	CFC/HFC	99.3	-33.6	980	102.1	AI	0.74	8070
R502	CFC/HCFC	111.6	-45.3	1464	81.5	AI	0.33	4660
R600a	HC	58.1	-11.7	465	134.7	A3	0	4
R717	NH3	17.0	-33.3	1351	132.3	B2	0	0
R744	CO2	44.0	-54.4	>7300	31	AI	0	1
R1270	HC	42.1	-47.6	1469	91.1	A3	0	2

Further reading

US Environmental Protection Agency - *Significant New Alternatives Policy (SNAP) Program*

- **www.epa.gov/ozone/snap/index.html**

UNEP DTIE OzonAction - *Fact Sheet No. 16 on Refrigerant Blends*

- **www.uneptie.org/ozonaction/information/mmcfiles/4766-e-16blends.pdf**

UNEP DTIE OzonAction - *HCFC Help Centre : Refrigerant blends containing HCFCs, UNEP*

- **www.uneptie.org/ozonaction/topics/hcfcblends.htm**

UNEP DTIE OzonAction – *Refrigeration & Air-Conditioning*

- **http://www.uneptie.org/ozonAction/topics/refrigerant.htm**

UNEP DTIE OzonAction – *Protecting the Ozone Layer, Volume 1, Refrigerants, UNEP, 2001*

- **www.unep.fr/ozonaction/information/mmcfiles/2333-e.pdf**

International Institute of Refrigeration – *Classification of Refrigerants based on American standard ANSI/ASHRAE 34 published in 2001*

- **www.iifiir.org/en/doc/1034.pdf**

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) Proklima - *Natural Refrigerants: Sustainable Ozone- and Climate-Friendly Alternatives to HCFCs, GTZ Proklima, 2008*

- **http://www.gtz.de/de/dokumente/en-gtz-proklima-natural-refrigerants.pdf**

or

- **www.gtz.de/en/themen/umwelt-infrastruktur/23898.htm**

3

Refrigerants Management

Content

3 Refrigerant Management

Summary

This chapter covers a variety of important aspects related to the handling and management of refrigerants, with the primary focus on maintaining good quality refrigerant and avoiding emissions and wastage. Specific topics include: the good handling and use of cylinders, and issues related to the re-use and proper disposal of refrigerants. In addition, the concept of refrigerant conservation is explained, with practical measures for all stages of refrigerant use, such as containment within systems, proper recovery and recycling methods and reclamation. The reader should be able to:

- Describe how to correctly handle refrigerants
- Describe the ways to promote refrigerant conservation
- Identify refrigerant emissions
- Describe how to perform refrigerant recovery and recycling activities

3.1. Management plans

Refrigerant management has been done in two levels: at a country government level and at installation/application level. Strategies for refrigerant management have been developed at a country level as an action of the Montreal Protocol implementation in developing countries by UNEP and other implementing agencies in conjunction with National Ozone Units (NOUs) and other governmental institutions.

The Multilateral Fund (MLF) assistance to Article 5 countries in the refrigeration servicing sector started in 1991 when projects for training service technicians and recovering and recycling chlorofluorocarbon (CFC) refrigerants were first approved. In 1997 these standalone projects were replaced by *Refrigerant Management Plans (RMP).* Refrigerant management is an approach to optimising the use of available refrigerants in the existing equipment and minimising the demand for virgin refrigerants for servicing through technical and regulatory measures. This is aiming to allow the appropriate operation of the equipment throughout its lifecycle at reducing harmful impact to the environment resulting from the emission of refrigerants.

The conditions and resources allocated for the RMPs have been adjusted from time to time. After the RMPs, projects called *Terminal Phase-out Management Plans (TPMP)* have been developed. Under a TPMP, a country receives funding for a full phase-out of CFC consumption on the understanding that no further funding will be requested.

The majority of the RMPs and TPMPs are carried out in low-volume consuming countries (LVC) with 75%–100% of the CFCs consumption in the servicing sector. Since 2007 with the approval of the acceleration of the *phase-out of hydrochlorofluorocarbons (HCFCs),* the Multilateral Fund for the Implementation of the Montreal Protocol is supporting the development of HCFC phase-out management plans (HPMPs) in developing countries.

Refrigerant management plans for CFCs (RMP)

An RMP is a comprehensive strategy to phase out the use of ozone depleting refrigerants used to service and maintain refrigeration and air conditioning systems. It may include actions to reduce ODS consumption and emissions, reduce the need for further servicing by controlling new installations and restricting imports of equipment that depend on ODS for their functioning, and promote retrofitting and replacement of existing equipment. Regulations, economic incentives and disincentives, training, and public awareness activities are some of the tools used to achieve these goals.

The successful implementation of RMPs requires the coordination of activities in different ODS-using sectors, including:

- Manufacturing
- Servicing
- End-users sectors
- Regulatory and trade controls
- Economic incentives and disincentives
- Training on good practices in refrigeration for service technicians
- Training for customs officers
- Establishing recovery and recycling programmes
- Public awareness campaign.

Terminal phase-out management plan for CFCs (TPMP)

The TPMP contains the Compliance Strategy and Action Plan for the elimination of the use of the CFCs controlled under Annex A Group I of the Montreal Protocol, until their final phase out on 1st January 2010. It also contains follow up actions, to ensure the necessary compliance monitoring and reporting.

HCFC phase-out management plan (HPMP)

The HPMP includes undertaking a comprehensive survey of the refrigeration and air conditioning sector and all sectors and sub-sectors that use HCFC. It describes the overall strategy that will be followed by the country to meet the complete phase-out of HCFCs. This includes policy instruments to reduce supply of HCFCs, and a plan for implementation of alternatives for new and existing equipment and products. The HPMP needs to take into account the climate impact of the alternatives, and should be coordinated with chemical management and energy policies.

To implement a strategy for refrigerant management in a country, it is essential to develop actions at field installations level. Technicians in developing countries have a very important role helping their countries to implement plans to phase-out CFC and HCFC refrigerants, and also to decrease emissions of hydrofluorocarbon (HFC) refrigerants.
This can only be achieved with the adoption of good practices in refrigerant management, in handling and working with refrigerants. This is the role of refrigeration and air conditioning (RAC) technicians, and this is the focus of this manual.

In the end, one can say that we should apply to refrigerants a general concept that starts to be used in waste management is the 4R principle: Reduce the use, Recovery, Recycling and Reuse. This can be achieved through technology development, making systems more hermetic and with lower refrigerant charge and through good practices on refrigerant management. The last is refrigeration technicians' task and this section provides some guidance on that. We start with handling of refrigerants.

Handling of refrigerants

Below are presented some aspects of the management of refrigerant cylinders. Specific considerations about safety and care precautions concerning the manipulation and direct contact with refrigerant itself are presented in **Chapter 6** ▶

Refrigerant cylinders

Refrigerants are packed in both disposable and returnable (refillable) shipping containers, commonly called “cylinders”. Disposables are manufactured in sizes from 0.5 litres to 22 litres capacity (corresponding to approximately 0.5 to 25 kg of CFC, HCFC or HFC refrigerant). They are considered pressure vessels, and in most countries therefore are subject to national regulations.

Containers are designed for pressurised and liquefied gases, and are labelled accordingly. Some refrigerants are gases at atmospheric pressure and room temperature, and are therefore transported and stored as liquefied compressed gases in pressurised cylinders. Other refrigerants are liquids at room temperature and contained in drums, barrels or other standard containers.

Numerous regulations are in force worldwide for the manufacture, handling and maintenance of pressurised containers. Cylinders are manufactured to specifications established by countries regulatory authorities.

There are different types of cylinder:

- **Disposable and non-refillable cylinders** ▶
- **Refillable cylinders** ▶
- **Recovery cylinders** ▶

Normally, each cylinder is equipped with a safety-relief device that will vent pressure from the cylinder before it reaches the rupture point, in the event of, say, overheating. When temperatures increase, the liquid refrigerant expands into the vapour space above the liquid causing the pressure to rise gradually as long as a vapour space is available for expansion. However, if no vapour space is available due to an overfilled cylinder and no pressure-relief valve is available, the liquid will continue to expand with no room for the expanding liquid and will result in extremely high pressures with the consequence of the cylinder rupturing. When the cylinder ruptures, the pressure drop causes the liquid refrigerant to flash into vapour and sustains explosive behaviour. The rupture of a refrigerant cylinder containing liquid refrigerant that flashes into vapour is far worse than the rupture of a compressed-air cylinder of the same pressure. The next pages include information on cylinder management plans.

Disposable and non-refillable cylinders

Available on the market are a type of cylinder called "non-refillable" or "disposable" cylinders. These are sometimes used where the supply infrastructure is less comprehensive, and it is less costly for refrigerant suppliers who may expect their cylinders to become lost. From both an environmental and safety perspective, the use of disposable cylinders is considered to be very bad practice.

These containers are generally discharged after use, resulting in a lot of refrigerant being released to the atmosphere. Furthermore, there are often attempts to re-use these cylinders (for example, through brazing new valves onto them to enable re-filling with refrigerant), despite such practices being forbidden. Also, they tend to be manufactured from thinner metal than the conventional, re-usable cylinders, rendering them more susceptible to rusting and mechanical damage over time. As such, their use is not recommended under any circumstances.

In fact they are already prohibited in many countries, such as the European Union member states and Australia and Canada. Other countries are also working to implement similar rules. Mandating the use of returnable, refillable containers was implemented as a key measure to reduce GHG emissions by eliminating the possibility of the eventual release of the residual product that unavoidably remains in disposable refrigerant containers. These regulations had support from the major refrigerant manufacturers and industry trade associations.

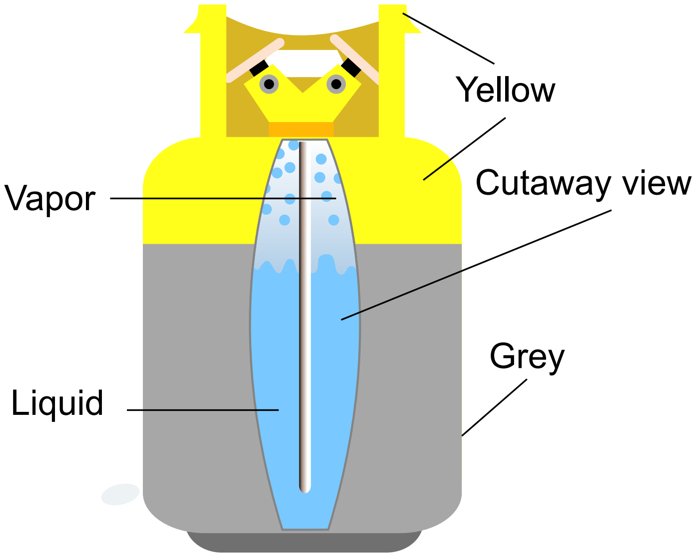
If a disposable cylinder has been used, before disposing of it, it should be properly emptied. This requires the remaining refrigerant to be recovered until the pressure has been reduced to pressure of approximately 0.3 bar (absolute). The container's valve must be closed at this time and the container marked as empty. The container is then ready for disposal. It is recommended that the cylinder valve should then be opened to allow air to enter, and the cylinder should be rendered useless (with the valve still open) by breaking off the valve or puncturing the container. This will avoid misuse of the container by untrained individuals. Used cylinders can be recycled with other scrap metal. Never leave used cylinders with residual refrigerant outdoors where the cylinder can rust. An abandoned cylinder will eventually deteriorate and could potentially explode.

Refillable cylinders

Refillable cylinders are the standard receptacles available for the storage and transportation of smaller quantities of refrigerant. They normally range in size from about 5 litres to 110 litres (approximately 5 to 100 kg of CFC, HCFC or HFC refrigerant). The cylinders are normally constructed from steel and have a combination valve, with separate ports for refrigerant removal, refrigerant filling and a pressure relief device. The port for refrigerant filling is normally locked so that only the refrigerant supplier can gain access. Some cylinders also have two separate removal ports: one for liquid and another for vapour, if the cylinder is fitted with a dip-tube. There is usually a metal collar around to the top of the cylinder to protect the valve from mechanical damage. Both the cylinder itself and the valve are usually subject to national regulations for their design, fabrication, and testing.

Recovery cylinders

Recovery cylinders are specifically intended for refrigerant that have been removed from refrigeration systems. The recovered refrigerant can then be re-used or sent for reclamation or disposal. The construction of the cylinders is normally very similar to a conventional refillable cylinder, except for two differences: one is that the cylinder valve has the refrigerant filling port enabled, so that refrigerant can be easily fed into the cylinder, and the second being the external marking. The cylinder shoulder and upper part is normally painted yellow, with the remainder of the cylinder body painted grey colour code is also applied to cylinder to indicate the type of recovered refrigerant, as shown in the illustration.



Recovery Cylinder

It is important to ensure that the recovery cylinder is only ever used for one type of refrigerant. This rule should be followed for two reasons: first, if different refrigerants are mixed, it may not be possible to separate them again for re-used, and secondly, mixing two or more refrigerants can result in a pressure that exceeds the pressure of either of the refrigerants added into the cylinder.

For refrigeration technicians using recycling machines, it is suggested that the refrigeration technician utilise a ‘CLEAN’ recovery cylinder for recycled refrigerant and a ‘DIRTY’ recovery tank for recovered, but not recycled refrigerant. Marking the recovery tanks as clean and dirty will avoid contamination of otherwise clean refrigerant by putting clean refrigerant into a recovery tank that once held dirty refrigerant.

Management:
Cylinder inspections and re-testing

The use of the various refrigerants in cylinders that are exposed to the environment, is reason for concern, as previously discussed. Although the interior of these cylinders must be void of moisture, the exterior cannot avoid it. Thus, corrosion can and does occur, as well as mechanical damage due to mishandling. These are but a few of the reasons why the cylinders must be inspected and re-tested at particular intervals. The intervals differ by country, but the date for the next inspection or testing is usually indicated on the cylinder. It should then be returned to the refrigerant supplier. Similarly, the valves should be periodically examined, especially the relief valve. Check to be sure that nothing is obstructing the relief valve and that no visual deterioration or damage has occurred. If any damage is visible, empty the cylinder and have the tank repaired. Never use a cylinder with a faulty pressure-relief valve or with obvious structural impairments.

Elements of the refrigerant management strategy should include:

- **Refrigerant conservation** ▶
- **Refrigerant emissions** ▶
- **Containment** ▶
- **Refrigerant recovery and recycling** ▶
- **Identification of refrigerants** ▶

Refrigerant conservation

Refrigerant conservation is part of a refrigerant management strategy. It is an effort to extend the lifetime of used refrigerant by establishing methods to contain, recover, recycle, and reclaim for the purpose of reuse and minimising emissions to the environment. Containment is important not only to protect the environment, preventing refrigerant emissions, but also to ensure proper functioning and efficiency of air-conditioning and refrigeration systems. Cooling systems are designed as sealed units to provide long term operation with a fixed charge of refrigerant. Conservation is affected by the design, installation, service and disposal of the refrigerating system. Guidelines and standards are being developed and updated in several countries with consideration to environmental matters and improved conservation.

Refrigerant emissions

Refrigerant emissions to the atmosphere often occur without identification of the cause. However, the identification of the sources of refrigerant leaks is necessary to limit emissions.

Refrigerant emissions occur because of the following:

- **Tightness degradation** due to temperature variations, pressure cycling, and vibrations that can lead to unexpected leaks
- **Component failures** from poor construction or faulty assembly
- **Losses due to refrigerant handling** during maintenance (e.g. charging the system), and servicing (e.g. opening the system without previously recovering the refrigerant)
- **Accidental losses** (e.g. natural disasters, fires, explosions, sabotage, and theft)
- **Losses at equipment disposal** that is due to venting, rather than recovering refrigerant at the end of the system’s life

When designing, installing and servicing refrigeration systems, technicians should keep these causes in mind, and work on systems in ways that avoid them occurring.

Containment

Containment is the general concept of retaining the refrigerant within the equipment by having leak-proof joints and seals, pipelines, etc, and handling the refrigerant in a manner that minimises refrigerant releases.

Leak detection is a basic element of containment and must take place in manufacturing, commissioning, maintenance and servicing of refrigerating and air-conditioning equipment, as it allows measuring and improving conservation of refrigerants.

There are three general means of identifying whether refrigerant may be leaking from a system:

a) Global methods - such as fixed refrigerant detectors, which indicate that there is the presence of refrigerant, but they do not actually locate a leak. They are useful at the end of manufacturing and each time the system is opened up for repair or retrofit.

b) Local methods - where a technician uses gas detection equipment to manually pinpoint the location of the leak. This is the usual method used during servicing.

c) Automated performance monitoring systems – which indicate that a leak exists by alerting operators to changes in equipment performance. This can indicate that there is a deficit of refrigerant within the system.

It is important to recognise the difference between “refrigerant detection” and “leak detection”: refrigerant detection is the identification of the presence of refrigerant, and leak detection is the identification of the location where refrigerant is, or could be, emitted from. Thus, refrigerant detection is normally required for detecting leaks, but it requires the technician to manually search for the leak source.

Refrigerant recovery and recycling

The need to adopt refrigerant conservation has led the industry to develop a specific terminology which is used in this section.

According ISO 11650 standard, these definitions are:

- **Recovery** means to remove refrigerant in any condition from a system and store it in an external container. Practical aspects of recovery procedures, and examples of refrigerant recovery operations in refrigeration equipment and systems how this might be done.

Recovery methods ▶

- **Recycling** means to extract refrigerant from an appliance and clean it using oil separation and single or multiple passes through filter-driers which reduce moisture, acidity, and particulate matter. Recycling normally takes place at the field job site.

Recycling of refrigerant ▶

There is also potential to reclaim refrigerants as outlined in:

Refrigerant recovery and recycling equipment ▶

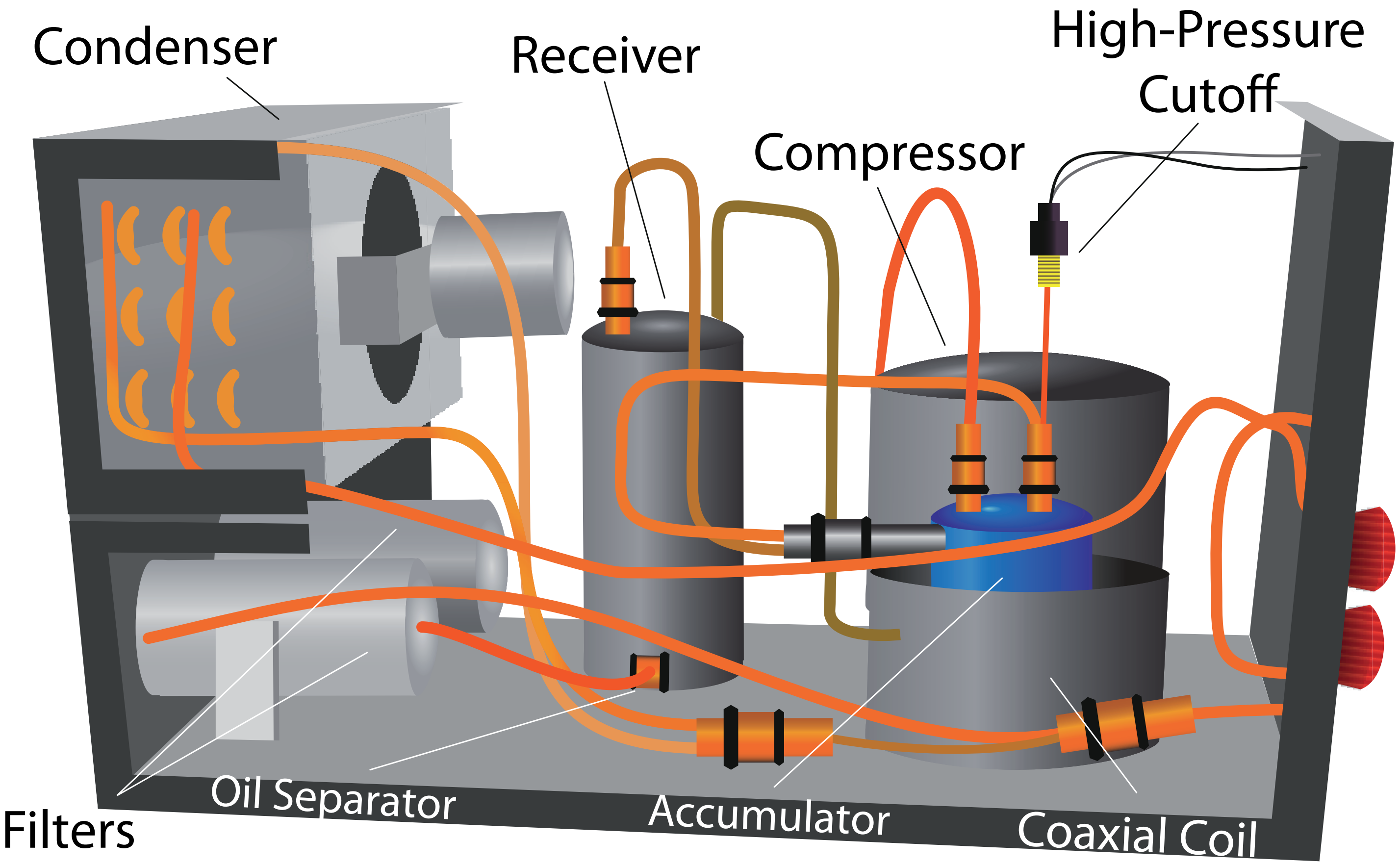
Information on testing refrigerants for recycling and reuse can be found in:

Identification and testing of refrigerants ▶

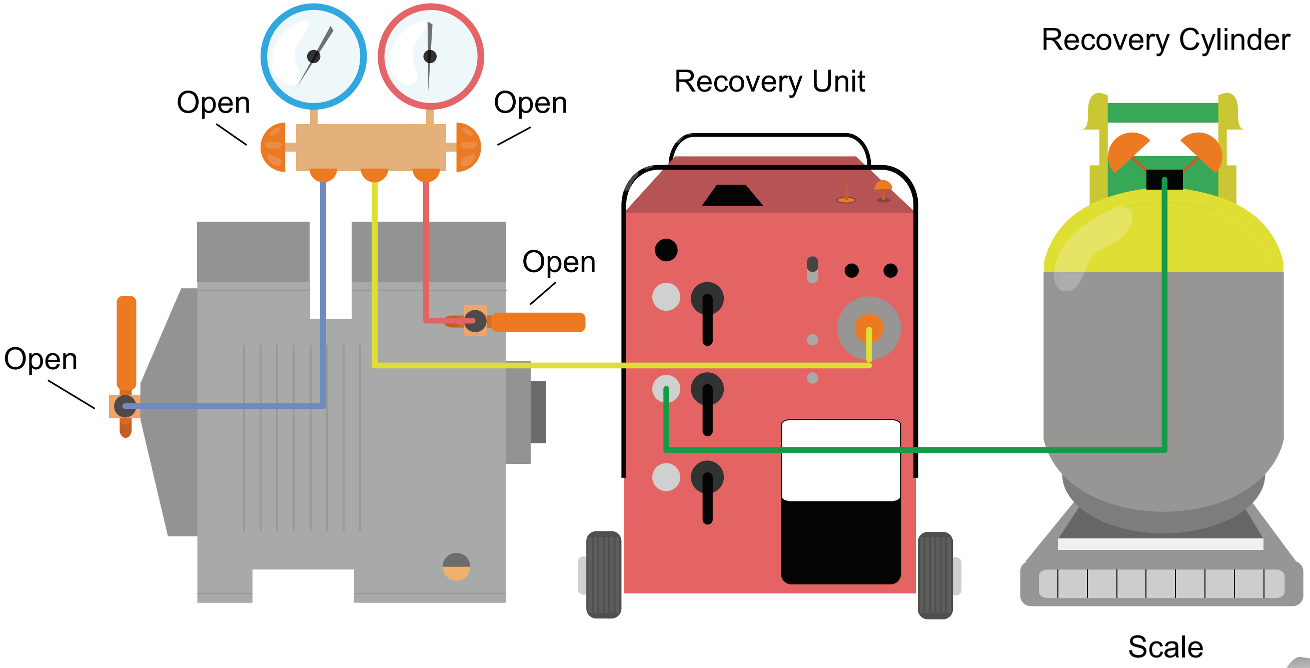
Recovery methods

Since a recovery unit will remove more refrigerant from a system than any other practicable method, its use should be regarded as the norm and not the exception. Recovery units are being more widely used due to their increasing availability. It is important to use appropriate equipment considering the characteristics of the refrigeration or air conditioning system and the technical specifications of the recovery unit regarding mainly capacity of the unit, rate of recovery, and type of refrigerant that can be recovered. As with vacuum pumps, recovery units will work much more efficiently if connection hoses are kept as short and as large in diameter as possible. However, not being able to get a recovery unit close to a system is not an acceptable excuse for not using one. If long hoses have to be used, all that will happen is that recovery will take longer. **There is no longer any acceptable reason or excuse for releasing refrigerants into the atmosphere.**

These images show a typical configuration and the main components of a recovery unit.



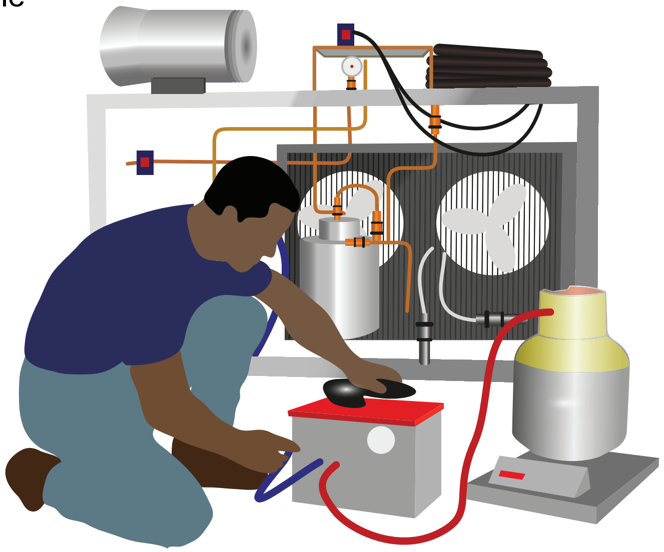
Configuration and the main components of a recovery unit



Refrigerant recovery unit

Using recovery units

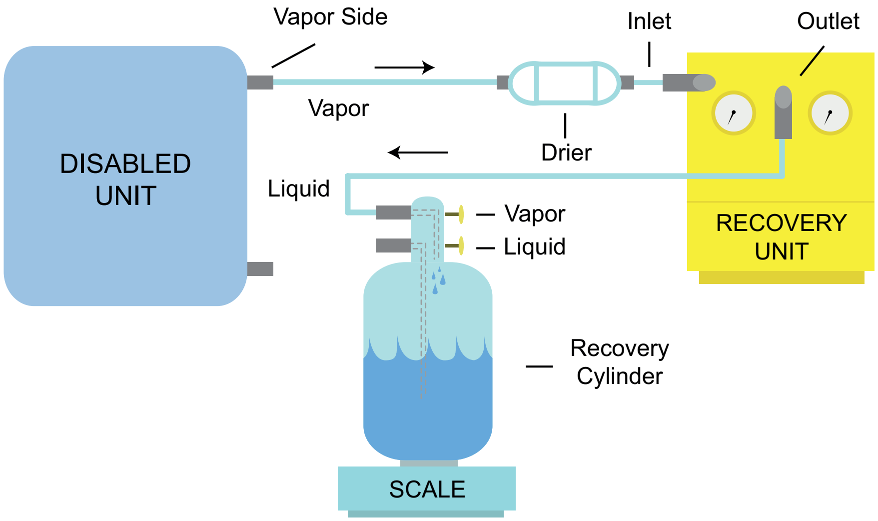
Recovery units are connected to the system by available service valves or line tap valves or line piercing pliers as shown in the image. Some of them can handle refrigerants in vapour phase and others in both vapour and liquid phases by throttling the liquid before it enters the compressor. For vapour-only recovery machines, it must be ensured that the compressor does not suck in liquid refrigerant as this will cause serious damage. Many have onboard storage vessels.



Connection of a recovery unit to a refrigeration system

Vapour transfer

The refrigerant charge can be recovered in vapour recovery mode as shown in this diagram.



Vapour recovery mode

On larger refrigeration systems this will take appreciably longer than if liquid is transferred. The connection hoses between recovery units, systems and recovery cylinders should be kept as short as possible and with as large a diameter as practicable.

Liquid transfer

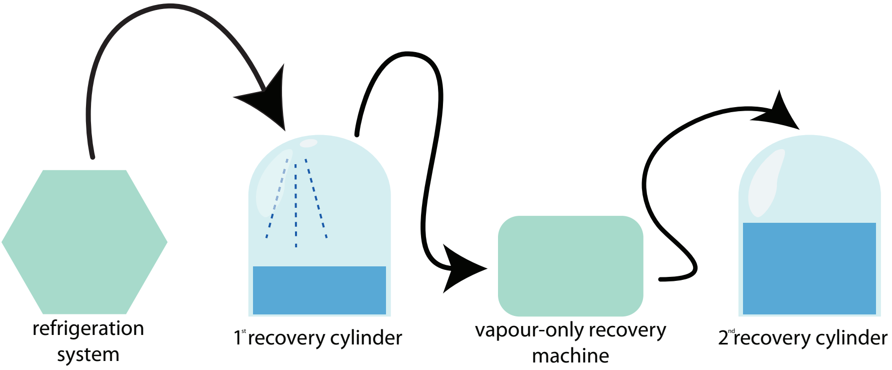
Until recently, it was unheard of to recover direct liquid. But with the use of oil-less compressors and constant pressure regulator valves, it's become the preferred method of recovery by most recovery equipment manufacturers. Oil-less recovery equipment has an internal device to flash off the refrigerant. Oil-less compressors will tolerate liquid only if metered through a device like a CPR (crankcase pressure regulating) valve. Don't attempt to use the liquid recovery method unless your unit is designed to recover liquid.

Liquid recovery is performed the same way as standard vapour recovery. The only difference is that you will connect to the high side of the system. Recovering liquid is ideal for recovering large amounts of refrigerant.

If the recovery unit does not have a built-in liquid pump or is otherwise not designed to handle liquid, then liquid can be removed from a system using two recovery cylinders and a recovery unit. The recovery cylinders must have two ports and two valves, one each for liquid and one each for vapour connections. Connect one cylinder liquid port directly to the refrigeration system at a point where liquid refrigerant can be decanted. Connect the same cylinder vapour port to the recovery unit inlet. Use the recovery unit to draw vapour from the cylinder, thereby reducing the cylinder pressure, which will cause liquid to flow from the refrigeration system in to the cylinder. Take care as this can happen quite quickly.

The second cylinder is used to collect the refrigerant from the recovery unit as it draws it from the first cylinder. If the recovery unit has adequate onboard storage capacity this may not be necessary. Once the entire liquid refrigerant has been recovered from the refrigeration system, the connections can be relocated and the remaining refrigerant recovered in vapour recovery mode.

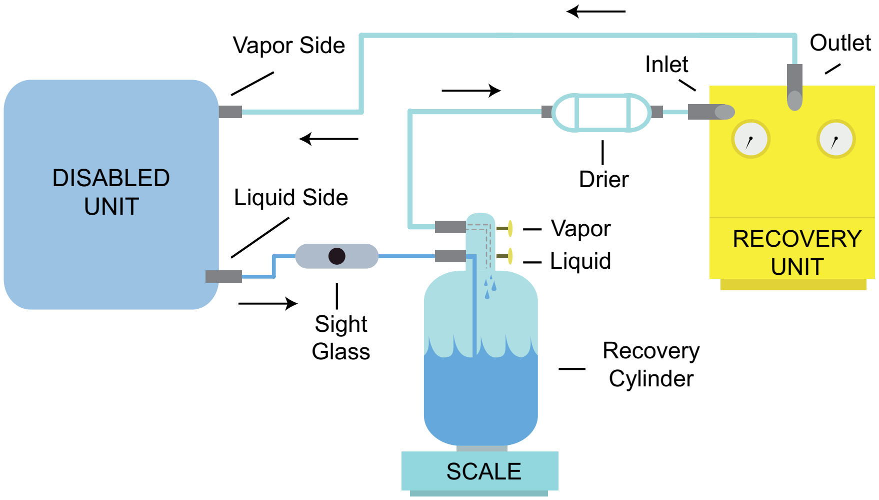
It may be found convenient to fit a liquid sight glass within the transfer line. Do not connect the liquid line to the transfer unit compressor otherwise it will be damaged. **The set-up of this scheme is illustrated here:**



Liquid recovery using a vapour only recovery machine and two recovery cylinders

Push and pull liquid recovery

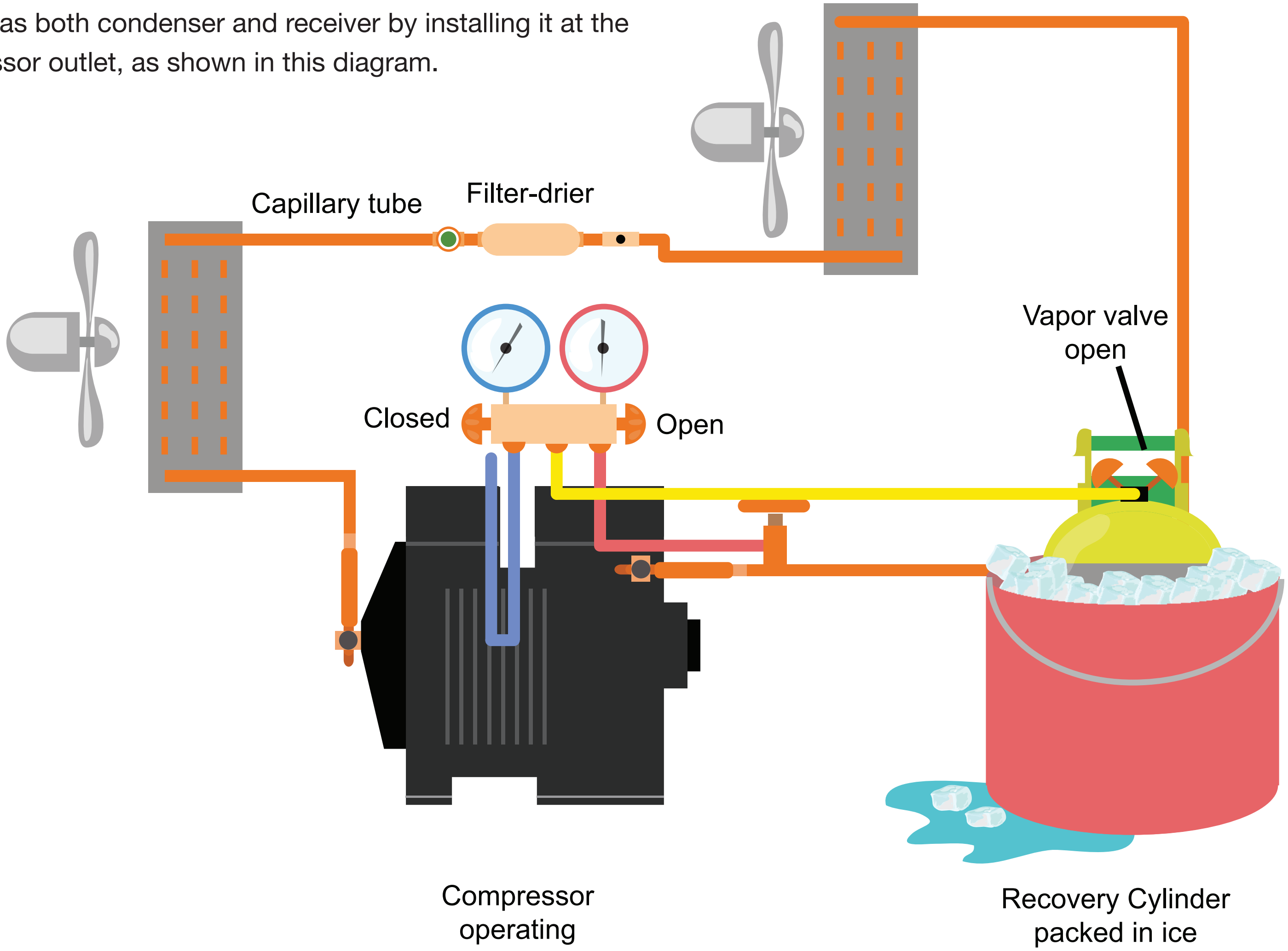
There is another method for liquid recovery; more common than that described previously, called the "push and pull" method. If you have access to a recovery cylinder, the procedure will be successful if you connect the recovery cylinder to the recovery units vapour valve, and the recovery cylinder liquid valve to the liquid side on the disabled unit as shown in the diagram. The recovery unit will pull the liquid refrigerant from the disabled unit when decreasing the pressure in the recovery cylinder. Vapour pulled from the recovery cylinder by the recovery unit will than be pushed back to the disabled unit's vapour side.



Push and pull recovery method

Using the system's own compressor

If the refrigerant in a system is to be removed and the system has a working compressor, it is possible to use the compressor to recover the refrigerant. It may be possible to pump the system down in the normal way and then decant the refrigerant into a cooled recovery cylinder, or it may only be possible to use the cooled recovery cylinder as both condenser and receiver by installing it at the compressor outlet, as shown in this diagram.



Using the compressor to recover the refrigerant

Recycling of refrigerant

Recovered refrigerant may be reused in the same system from which it was removed or it may be removed from the site and processed for use in another system, depending upon the reason for its removal and its condition, i.e., the level and types of contaminants it contains. There are many potential hazards in the recovery of refrigerants, and recovery and reuse need to be monitored carefully. Potential contaminants in refrigerant are acids, air, moisture, high boiling residues and other particulate matter. Even low levels of these contaminants can reduce the working life of a refrigeration system and it is recommended that recovered refrigerant should be checked before reuse.

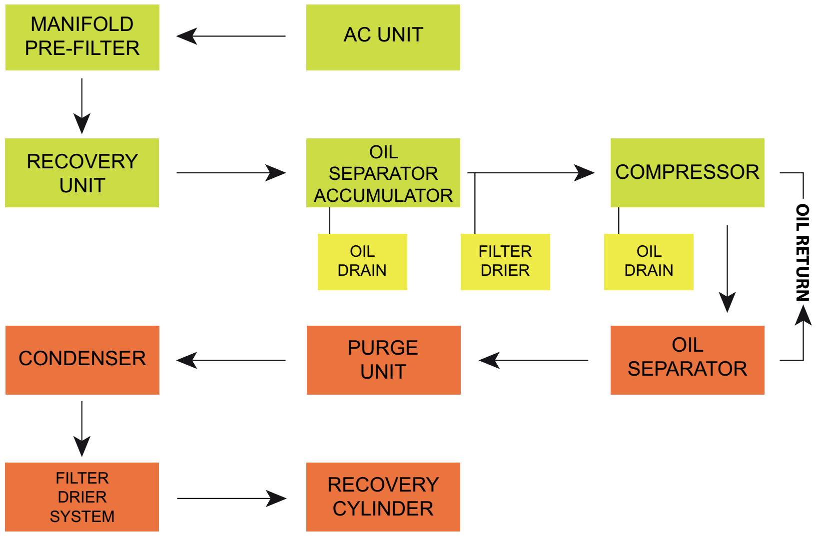
Refrigerant from a unit with a burnt-out hermetic compressor is reusable providing it has been recovered with a recovery unit incorporating an oil separator and filters and that it has been checked for acidity. To check the acid content of any reclaimed oil it is necessary to use a refrigeration-oil-test-kit. Usually it is only a matter of filling a test bottle with the oil to be tested and mixing it with the test liquid inside. If result shows purple: oil is safe. If liquid turns yellow this would show the oil is acidic - and refrigerant/oil should not be used in system. Such material should be sent for reclamation or destruction.

Refrigerant recycling

There are in the market several units that recovers, recycles, evacuates and recharges – all in one fast, continuous operation through one hook-up; these are called refrigerant recycling machines. If it is to be returned, the next issue is the condition of the refrigerant. When the oil is separated from the refrigerant, the vast majority of the contaminants are contained in it. Most refrigerant recycling machines utilise filter-driers to remove any other moisture and acid as well as particles. It is generally acceptable to return this refrigerant to the system.

The real problem occurs when there is a burnout in a hermetic compressor. A burnout is the result of electrical failure inside the compressor of the refrigeration system. This can be due to variety of factors. Contamination of the refrigerant in this situation can range from mild to severe. Two recycling standard methods are used by equipment on the market. The first is referred to as single pass, and the other is a multiple pass. There is equipment that provides operation in both methods.

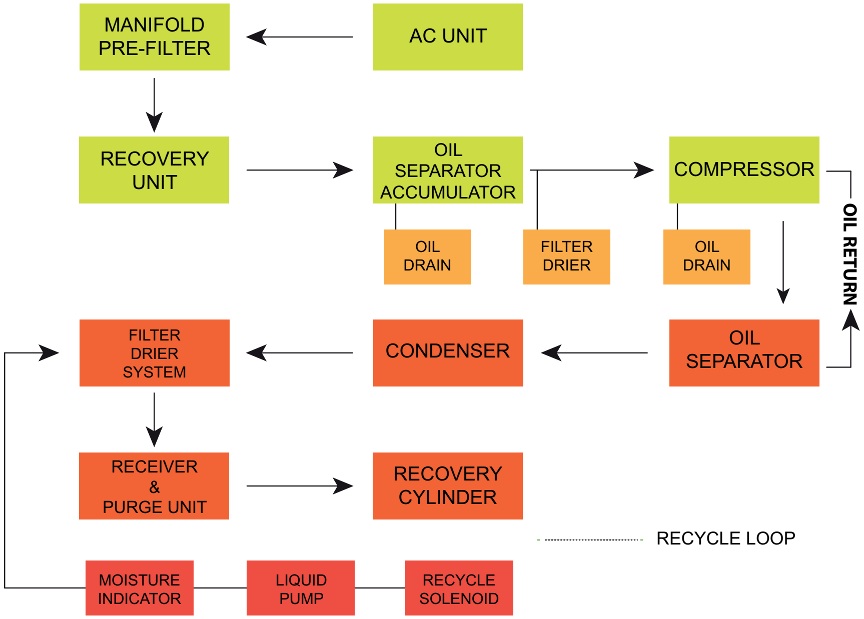
- **The single pass** recycling machines process refrigerant through filter-driers and /or distillation. It makes only one trip from the recycling process through the machine and then into the storage cylinder. This image shows a typical single pass system.



Typical single pass system

- **The multiple pass** method re-circulates the recovered refrigerant many times through filter-driers. After a certain period of time or number of cycles, the refrigerant is transferred into a storage cylinder. Multiple-passes method recycling takes longer, but depending on the refrigerant level of contamination and moisture it may be essential, for example, if it is particularly dirty.

This is shown in the diagram:



Typical multi-pass system

Refrigerant recovery and recycling equipment

The purpose of refrigerant recovery and recovery/recycling equipment is to help prevent emissions of refrigerant by providing a means of temporarily storing refrigerants that have been removed from systems undergoing service or disposal. Such equipment is used to temporarily store recovered refrigerant until the system undergoing repair is ready to be recharged or is prepared for disposal. Refrigerant recovery equipment may have the ability to store (recovery only) or the added capability of recycling (recovery and recycling) refrigerants. The temporary storage capability of the equipment prevents the release of refrigerants into the atmosphere that may otherwise exist if the refrigeration and air-conditioning equipment were opened to the atmosphere for servicing.

The use of refrigerant recovery and recycling equipment is an essential means of conserving refrigerant during servicing, maintenance, repair, or disposal of refrigeration and air-conditioning equipment. Refrigerant recovery and recycling equipment could be made available to service technicians in every sector. Note that due to incompatibility issues and the array of refrigerants used in different sectors, refrigerant recovery/recycling equipment intended for use with one type of air conditioning system, such as motor vehicle air conditioners, may not be adequate to service air-conditioning and refrigeration equipment in the domestic, unitary, or commercial refrigeration and air-conditioning sectors. The types of refrigerants used in these sectors vary and all recovery/recycling equipment is not capable of meeting the same requirements. This is very important to users to ensure that their recovery equipment is capable of handling the specific refrigerants that are used in the system. The specific identification of the equipment is important throughout its service, disposal or end-of-life.

Recycling equipment is expected to remove oil, acid, particulate, chloride, moisture, and non-condensable (air) contaminants from used refrigerants. The effectiveness of the recycling process can be measured on contaminated refrigerant samples according to standardized test methods, such as those within the standards ISO 12810 and ARI 700. Unlike reclaiming, recycling does not involve analysis of every batch of used refrigerant and, therefore, it does not quantify contaminants nor identify mixed refrigerants. Subsequent restrictions have been placed on the use of recycled refrigerant, because its quality is not proven by analysis.

A variety of recycling equipment is available over a wide price range. Currently, the automotive air-conditioning industry is the only application that prefers the practice of recycling and reuse without reclamation. Acceptance in other sectors depends on national regulations, the recommendation of the cooling system manufacturers, the existence of another solution such as a reclaim station, variety and type of systems, and the preference of the service contractor. Recycling with limited analysis capability may be the preference of certain developing countries where access to qualified laboratories is limited and shipping costs are prohibitive. For most refrigerants there is a lack of inexpensive field instruments available to measure the contaminant levels of reclaimed refrigerant after processing.

Refrigerant recovery equipment has been developed and is available with a wide range of features and prices. Some equipment with protected potential sources of ignition also exists for recovery of flammable refrigerant. Testing standards have been developed to measure equipment performance for automotive (SAE) and non-automotive applications (ISO). Although liquid recovery is the most efficient, vapour recovery methods may be used alone to remove the entire refrigerant charge as long as the time is not excessive.

Excessive recovery times should be avoided, since extended recovery time periods may limit the practical usage of recovery equipment on the majority of refrigeration or air-conditioning equipment that contain up to 5 kg of refrigerant. In order to reach the vacuum levels that are required in some countries for larger systems, vapour recovery will be used after liquid recovery. Performance standards for refrigerant recovery equipment are available for service of both motor vehicle air conditioners (e.g., SAE J1990), and stationary refrigeration and air-conditioning systems (e.g. ARI Standard 740). Adoption of such standards as a part of common service procedures could be adopted by regulating authorities.

Identification and testing of refrigerants

Is very important to know which refrigerant is in a system in order that correct refrigerant can be used when work is carried out on the system. Refrigerants may be identified by the following methods:

- Refrigerants stamped on unit data plate, thermostatic expansion valve, or compressor
- Standing pressure
- Refrigerant Identifier – a portable electronic device that allow the reliable identification or detection of percentage composition (not all) of CFCs, HCFCs, HFCs, hydrocarbons (HC) and air content.

In the case of hermetic systems that have not be opened (i.e., no sign of post-manufacture manipulation of the system, such as recent brazing or piercing valves), the first method is adequate. In other systems, the last method should ideally be used, since it is the most reliable. If a system has previously been broken into, it is possible that a retrofitted refrigerant may have been charged into the system. In this case, the marking on the name plates may not reflect this, and the standing pressure may be the same for the original and the new refrigerant.

Testing considerations include:

Test refrigerant for contamination ▶

Test oil contamination ▶

Checking of refrigerant cylinders ▶

Test refrigerant for contamination

Refrigerants can be tested for water/oil contamination and acidity with a test kit. With the change to alternative refrigerants, in many cases, has come need for new lubricants. Where retrofit procedures call for the removal of mineral-based oil and replacement with ester lubricants, it is necessary to reduce the mineral lubricant to a minimal level. These test kits provide simple methods of determining the level of residual mineral oil in an ester lubricant mixture.

Test oil contamination

It is possible to test the oil in some systems for acidity. Acid in the oil indicates that burnout or partial burnout has taken place, and/or that there is moisture in the system, which can cause a burnout.

To carry out an oil test it is necessary to remove a sample of oil from the compressor without undue release of refrigerant. The procedure for this will vary depending on the arrangement of shutoff valves and access to the oil available on the unit. For many hermetic compressors there will be neither shut off valves nor access. This image shows an example of a refrigerant testing kit.

Refrigerant testing kit

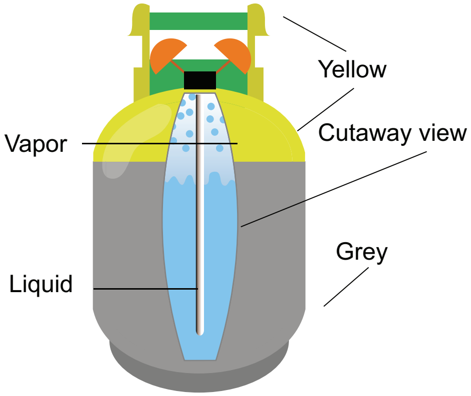
The refrigeration oil acid test kit is one-bottle (one step) test, and is the fastest way of determining if compressor oil is safe or acidic. If the test result in the mixture remaining purple, the oil is safe, whereas if it turns yellow, it is acidic. The ultra-sensitive colour change guarantees an accurate test.

Checking of refrigerant cylinders

Decanting refrigerants into service cylinders is a hazardous practice. It should always be carried out using the method prescribed by the refrigerant manufacturer.

Special care should be taken:

- Not to overfill the cylinder
- Not to mix grades of refrigerant or put one grade in a cylinder labelled for another
- To use only clean cylinders, free from contamination by oil, acid, moisture etc.
- To visually check each cylinder before use and make sure all cylinders are regularly pressure tested
- Recovery cylinders should have a specific indication depending on the country in order not to be confused with virgin refrigerant container
- Cylinders should have separate liquid and gas valves and be fitted with a pressure relief device, as shown in the diagram:



Cylinder with separate liquid and gas valves

Recognising Refrigerant cylinder colour codes

Refrigerant cylinders or drums are often colour coded. The colour code is normally a voluntary precaution followed by refrigerant suppliers. However, it should be noted that different colour codes are used in various parts of the world.

Refrigerant cylinder colour codes according to ARI (2008)

Colour	PMS number	Refrigerants
White	N/A	R12
Orange	21	R11, R404A
Yellow	109	R500
Yellow-Brown (Mustard)	124	R14, R401B
Yellow-Orange	128	R422A
Cream	156	R407B
Pinkish-Red (Coral)	177	R14, R401A
Red	185	HCs
Maroon	194	R245fa
Medium Purple (Purple)	248	R406A
Light Purple (Lavender)	251	R403B, R502
Dark Purple (Violet)	266	R113, R411A
Warm Red	292	R423A
Dark Blue (Navy)	302	R114, R506B
Blue-Green (Teal)	326	R411B, R507A
Deep Green	335	R124
Light Green	352	R22
Green	354	R417A

Colour	PMS number	Refrigerants
Lime Green	368	R407A
Green-Yellow	375	R422D
Yellow-Green (Lime)	381	R416A
Green-Brown (Olive)	385	R402B
Dark Grey (Battleship)	424	R116, R236fa
Light Blue-Grey	428	R23, R123
Light Brown (Sand)	461	R402A
Medium Brown (Tan)	465	R125, R409A
Dark Brown (Chocolate)	450	R407D
Medium Brown (Brown)	471	R407C
Rose	507	R410A,
Light Blue (Sky)	2975	R13, R134a
Medium Blue (Blue)	2995	R414B
Deep Blue	3015	R413A
Blue-Green (Aqua)	3268	R401C, R503
Green-Blue (Jungle Green)	3405	R427A
Beige	4545	R414A

Examples of colour-coded refrigerant cylinders

Examples of refrigerant recovery

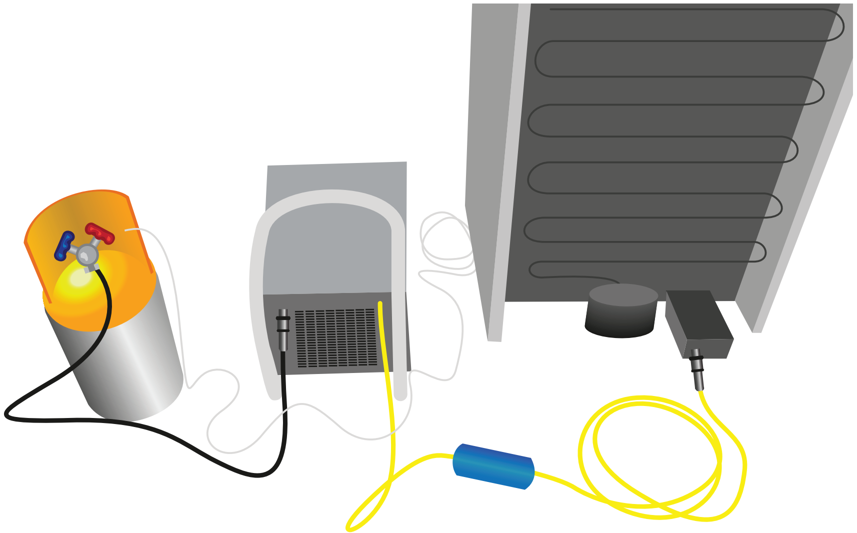
Now you have relevant download and read the briefing, attempt to apply the information to the following examples.

Domestic refrigerator ▶
Commercial cold room system ▶
Air-conditioning system ▶
Mobile air conditioning (MAC) system ▶

Recovery from a domestic refrigerator

It is possible to recover refrigerant from a hermetically sealed system, which has no service valve. A line-tap valve (piercing valve) should be fitted to the system, and a recovery unit used to remove the refrigerant from the unit via the line-tap as with the larger system. Line-tap valves should never be left permanently in place, but removed after use if placed on the process tube (if the equipment is going for disposal). Because of the small charge of refrigerant, only vapour recovery is needed.

It is recommended to install tap-valves on both and low pressure side, as shown here:



Recovery from a domestic refrigerator

Recovery from commercial cold room system

Liquid transfer

Connect the recovery cylinder's hose to the system's outlet stop valve on the condenser/receiver. To control liquid flow, install a sight glass to the hose and cylinder. From the recovery cylinder's vapour side, use a drier. Outlet/discharge side of the recovery unit goes to the system's high-pressure side at the inlet condenser or compressor high-pressure stop valve. All of the system's stop valves have to be opened, including the solenoid valves.
Run the recovery unit and keep an eye on the sight glass. When there is no more liquid transferred through the sight glass, and there is no icing left on the compressor shell, on the receiver or anywhere else, this indicates there is negligible amounts of refrigerant left in the system.

Vapour transfer

When liquid transfer is completed, connect the hoses from the recovery unit suction/inlet side to the compressor low or high-pressure side. For better recovery, connect hoses to both the high pressure side. For better recovery, connect hoses to both the high and low pressure sides using a service manifold. The recovery discharge/outlet side should be connected to the recovery cylinder's vapour side. Be sure that all service/shut off valves are open to avoid "locking" refrigerant into the system.

Recovery from air-conditioning system

Liquid transfer

Air-conditioning installations may have service stop valves installed in the pipe lines. When recovering refrigerant from such a system, liquid should be transferred first because the quantity can be rather large. The push-pull method is recommended.

The system's liquid pipe should be connected to the recovery cylinder's liquid side. The cylinder's vapour side should be connected to the recovery inlet (suction) side. The discharge side recovery unit should be connected to the suction pipe on the air conditioning system. If there are available valves on the systems receiver (on the high pressure side), the recovery unit discharge side could be connected here as well. Liquid flows now from the liquid side of the air-conditioning system and into in the cylinder. The recovery unit will keep the pressure inside the cylinder lower than in the air-conditioning system and keep up the liquid flow.

Vapour transfer

When liquid transfer is completed there will still be some refrigerant vapour left in the system. To transfer all refrigerant to the recovery cylinder, connect the suction hose from the recovery unit to the gas pipe on the air-conditioning system. Connect the recovery unit discharge outlet hose to the recovery cylinder's vapour side. Run the recovery unit until the suction gauge reads –0.7 bar (0.3 bar absolute) or lower.

Recovery from mobile air conditioning (MAC) system

Vapour transfer

MAC systems are normally equipped with service valves on the compressor's high and low-pressure sides. The refrigerant charge on such system is rather small and therefore only vapour transfer is required. Connect the hose from the recovery unit's suction/ inlet side to the air-conditioning system's compressor low-pressure side and the discharge hose to the vapour valve on the recovery cylinders. Run the recovery unit for 3 – 5 minutes. Connect another hose to the system's high-pressure side and complete the recovery. Run the recovery unit until pressure gauges reads –0.7 bar (0.3 bar absolute) or lower.

Refrigerant reclaiming

Reclamation means to reprocess used refrigerant, typically by distillation, to conditions similar to that of virgin product specifications. Reclamation removes contaminants such as water, chloride, acidity, high boiling residue, particulates/solids, non-condensable, and impurities including other refrigerants. Chemical analysis of the refrigerant shall be required to determine that appropriate specifications are met. The identification of contaminants and required chemical analysis shall be specified by reference to national or international standards for new product specifications. Reclamation typically occurs at a reprocessing or manufacturing facility. Commercial units are available for use with R12, R22, R134a, etc, and are designed for the continuous use required on a long run recovery recycling procedure.

Further reading

UNEP DTIE OzonAction - *Guidebook for Implementation of Codes of Good Practice Refrigeration Sector, 1998*

- www.unep.fr/ozonaction/information/mmcfiles/2174-e.pdf

UNEP DTIE OzonAction - *Training Manual on Good Practices in Refrigeration – Training Manual, 1994*

UNEP DTIE OzonAction - *Training Manual on Chillers and Refrigerant Management, UNEP 1994*

Ozone Unit of The Former Yugoslav Republic of Macedonia - *Manual for Refrigeration Service Technicians, 2006*

- www.ozoneunit.gov.mk/eng/doc/Training_manual_for_service_technicians.pdf

Stockholm Environment Institute - *Interlinked ODS Phase-Out Activities, 2005*

- www.sei.se/publications.html?task=view&catid=1&id=562

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) Proklima – *Training Manual on Good Practices in Refrigeration, GTZ Proklima, 2009*

- www.gtz.de/proklima

4

Servicing Practices

Content

4

Servicing Practices

Summary

This section will provide the technician with the ability to understand the causes of main operational problems presented by vapour compression refrigeration or air conditioning systems. It is important to understand how to avoid them through the adoption of good practices, and to be aware of the main precautions which should be taken when servicing installations and systems.

Methods and techniques that are used when working on systems, primarily during servicing exercises, are discussed. In particular, this includes the consideration of system cleanliness (moisture, acid, non-condensable), and the means for overcoming these problems, such as proper evacuation methods and system purging. To avoid such issues in the first place demands appropriate procedures associated with tightness testing (“leak testing”) and refrigerant charging, which are described.

Technicians have the important role of making the operation of RAC systems the most energy efficient and decreasing refrigerant emissions. This can only be achieved by the adoption of good practices. The section starts with the evaluation of the problems due to the presence of moisture and contaminants in the system, and how to avoid them through purging and evacuation, charging, and leak testing. The important measurement instruments and tools necessary to achieve good servicing practices are included.

A technician should be should be able to achieve the following servicing operations:

- Leak detection, purging and evacuation.
- Charging refrigerants.
- Identifying the servicing-specific tubing tools and techniques of sizing, un-rolling, cutting, bending, flaring, swaging, piercing, pinching and welding.
- Identifying the proper use of servicing instruments: manifold gauges, charging scales, and thermometers.

Avoiding contaminants

Before charging any system with refrigerant, precautions should be taken to avoid the presence of any type of contaminants in the system, so classifying contamination types in a refrigeration system is necessary to identify the proper servicing action required before charging any system with new refrigerant.

First, the identification of potential contaminants is outlined:

- **Moisture** ▶
- **Non-condensables** ▶

Moisture

Moisture causes several operating problems in RAC systems and understanding the basis of these problems is important. Basically, moisture can be classified as visible and invisible. “Visible” moisture is high concentration of water and can be seen with the eye, and is in liquid form. Occasionally, liquid water is found in systems but this is rather unusual. “Invisible” moisture is water in low concentrations and cannot be seen with the eye, since it is essentially dissolved in the refrigerant. It is important to remember that moisture can easily get into a system but it is difficult to get out.

The main situations and activities that can result in moisture entering the system are:

- when there is a leak in part of the system that experiences sub-atmospheric pressure (thus, drawing air into the system)
- during servicing and repair when the system is opened and exposed to the air and evacuation is not carried out properly
- when filters or lubricant are exchanged
- during charging with refrigerant and transfer hoses have not been purged properly.

The technician should be particularly aware of the possible introduction of moisture when carrying out these activities.

There will always be some moisture within any refrigerating system, and complete elimination is almost impossible. However, at very low concentrations the moisture is unlikely to cause any significant problem. On the other hand, if the moisture is present in higher concentrations, then a series of problems can arise. The “tolerable” concentration of moisture differs between refrigerants, oil types, operating temperatures and compressor designs. Nevertheless, in almost all systems – except for ammonia systems – the maximum concentration of moisture should not exceed around 10 ppm. Above these concentrations, the moisture can have negative effects on the system, such as reactions with the oil, causing the unit to malfunction and accelerating burn-out of hermetic compressors.

Recognising the presence of moisture

The presence of moisture within the system can be recognised by certain observations:

- The system will stop due to low suction pressure, and proceed to warm up. Since it is the formation of solid ice within the expansion device that has caused the blockage, the warming will result in the disappearance of the ice and thus the unit will work properly again. However, the process will occur again as the ice once again forms at the expansion device.
- Decreasing pressure, where the suction pressure steadily decreases over several hours – even to a vacuum. Then pressure suddenly becomes normal again. This abnormal cycle will keep repeating.
- If, during system shutdown, one warms the refrigerant control with a safe resistance heater (hot pad) or radiant heat bulb, the ice will melt. Should the system then begin to work properly, there is definitely moisture in the refrigerant.

These symptoms are explained by the following:

- The solubility of water in refrigerant reduces with temperature, so as the refrigerant passes through the expansion device, the dissolved moisture may become saturated water.

- If the temperature reaches below 0°C, the saturated moisture (water) within the expansion device can freeze and subsequently stop the refrigerant flow.
- As the expansion valve warms, due to the lack of refrigerant, the ice melts and moisture returns to the expansion valve and once more generates an intermittent cooling.
- Whether or not freezing actually occurs depends primarily upon the amount of moisture (water) and size of the ice particles formed.

Be aware of the risk of corrosion and its impacts

In addition to possible freezing, another serious problem – namely corrosion – can occur within the system due to the presence of moisture. Corrosion can create serious problems because often its effects are not apparent until serious damage has occurred. For example, moisture in the form of water alone can cause rust after a period of time. However, moisture plus the refrigerant create much more corrosion problems. Refrigerant such as R12 containing chlorine will slowly hydrolyse with water and form hydrochloric acids. This acid greatly increases the corrosion of metals.

The corrosion processes can be characterised as follows:

- Heat increases the rate of corrosion due to acids because at higher temperatures the acid-forming process is accelerated. This acid, of course, attacks all the materials it contacts, the rate of corrosion of the individual materials being determined by their corrosion-resistant qualities. Steel will generally corrode at lower moisture levels than copper or brass.
- Compressor lubricant presents another problem caused by moisture, particularly in the case of polyol ester (POE) and poly alkyl glycol (PAG) lubricants, used with hydrofluorocarbon (HFC) refrigerants. In fact, these types of lubricant have an affinity for moisture and will absorb it rapidly if left open to the atmosphere. Mineral lubricants do not mix with water in the same range as polyol ester lubricants.
- Water changed into acid emulsifies with lubricants, the two forming an intimate mixture of exceedingly fine globules. This effect is called “sludging” of the oil and greatly reduces its lubricating ability. Corrosion becomes troublesome from the operating standpoint when the metallic surface is eaten away and a solid, detachable product is formed. This formation is commonly known as “sludge”. Sludge exists as slimy liquids, fine powders, granular solids or sticky solids and causes a variety of problems. They can plug fine strainers, expansion valves and capillary tubes. And because they usually contain acids they corrode whatever they cling to, accelerating damage.

Eliminating moisture problems

To eliminate moisture problems it is necessary to take precautions and actions, which will ensure a moisture-free system. It is important to change the filter drier frequently. The most effective way to eliminate moisture from a system is through the use of a high vacuum pump to create a vacuum deep enough to evaporate and remove this moisture. The recommended level of evacuation is of 1 millibar absolute (100 Pa) to achieve the evacuation of moisture. This level of vacuum must be maintained for 10 minutes without the help of a vacuum pump.

Non-condensables

Gases in the system which do not liquefy in the condenser are contaminants and reduce the cooling capacity and system efficiency. The quantity of non-condensable gas that is harmful depends on the design and size of the refrigeration system and nature of the refrigerant. Their presence contributes to higher than normal discharge pressures and resultant higher discharge temperature. Higher temperatures speed up undesirable chemical reactions. Gases found in hermetic refrigeration units include nitrogen, oxygen, carbon dioxide (CO_2, R744), carbon monoxide, methane and hydrogen.

These non-condensable gases infiltrate sealed systems in the following manner:

- They are present during equipment manufacture or servicing and remain due to incomplete evacuation.
- They are desorbed from various system materials or are formed by decomposition of gases at elevated temperatures during system operation.
- They enter through low side (below atmospheric pressure) leakage points.
- They are formed from chemical reactions between refrigerants, lubricants and other materials during operation. Chemically reactive gases, such as hydrogen chloride, attack other components in the refrigerating system; in extreme cases, the refrigerating unit fails.
- They are introduced when connecting refrigerant hoses that have not been properly purged.

Whilst designing, installing and servicing systems, technicians should be aware of these routes to contamination, and adjust their behaviour accordingly.

Servicing RAC systems

The main concept and procedures of each operation is the same for all refrigeration and air-conditioning systems. They differ only in each system specific connectivity requirements or tools to be used.

Most of servicing activities to RAC systems –dealing with refrigerants – falls within the one of the following main operations:

- **Evacuation** ▶
- **Purging (cleaning)** ▶
- **Leak detection** ▶
- **Charging** ▶
- **Recovery** ▶

Evacuation

A refrigerating system must contain only the refrigerant in liquid or vapour state along with dry oil. All other vapours, gases, and fluids must be removed. Connecting the system to a vacuum pump and allowing the pump to run continuously for some time while a deep vacuum is drawn on the system can best remove these substances. It is sometimes necessary to warm the parts to around +50°C while under a high vacuum; in order to accelerate the removal of all unwanted moisture, heat the parts using warm air, heat lamps, or water. Never use a brazing torch. If any part of the system is below 0°C, the moisture may freeze and it will take a considerably longer time for the ice to sublimate to vapour during the evacuation process.

The equipment necessary to carry out the evacuation is:

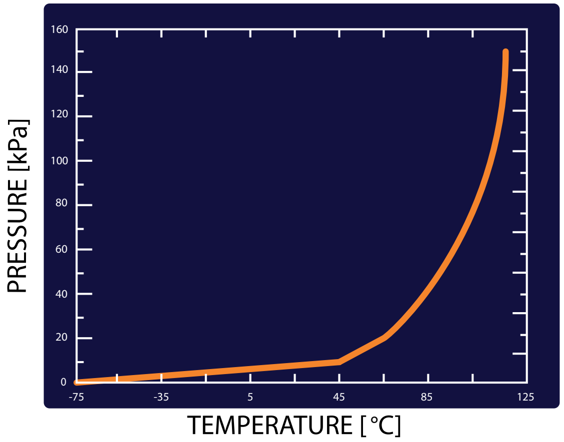
- vacuum pump
- manifold gauges

  two servicing valves (in the case system is not equipped with servicing valves)
- vacuum gauge.

It is essential to know that conventional manifold gauges have low sensitivity, particularly at lower pressures. As such, they are ineffective at determining whether or not a sufficient vacuum has been achieved. Therefore it is essential to ensure that a proper vacuum gauge (such as a Pirani gauge) is used.

To understand why system evacuation is very important for moisture elimination, it is useful to remember the concept of vacuum and the relationship between boiling temperature and pressure. For a pure substance, like water, the boiling temperature for a fixed pressure is called saturation temperature at this pressure, and the pressure at which the water evaporates at a fixed temperature is called saturation pressure at this temperature.

The relationship between these two thermodynamic properties (a natural law) is presented in the figure for water:



Saturation pressure and temperature curve for water

It can be seen in this figure that as the pressure reduces, the boiling temperature will be lower. If one wants to remove moisture in vapour phase from a refrigeration system, it is very important to lower the system pressure because this will facilitate the change of the moisture from liquid to vapour phase (through heat transfer from the surrounding environment) making its removal easier.

Always evacuate a system when:

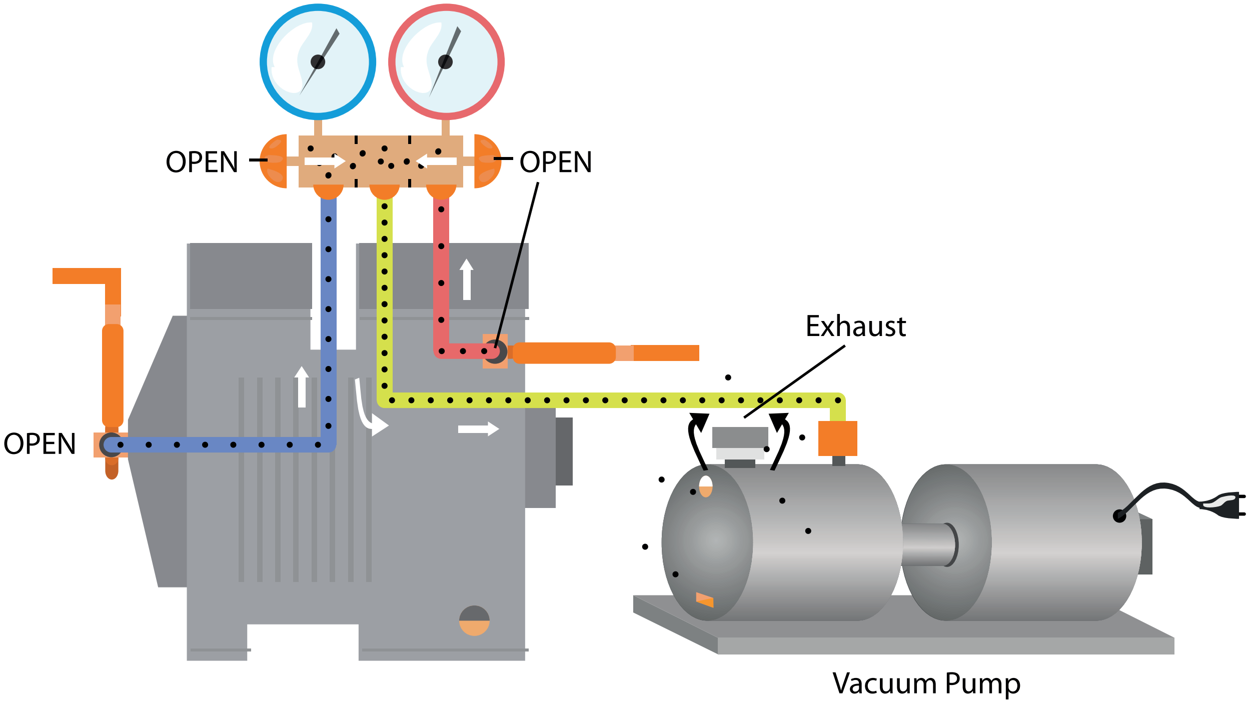
- replacing a circuit component (compressor, condenser, filter-drier, evaporator, etc.)
- whilst the system has no refrigerant
- if the refrigerant is contaminated
- after the lubricant is charged.

Procedures to perform evacuation

To evacuate and dehydrate a system, before filling with refrigerant, take the following steps:

1 - First, the system should be tightness tested (i.e., “leak tested”). This can be done by pressurising the system with oxygen free, dry nitrogen (OFDN). Shut off the supply of nitrogen and check the pressure over a period of time (a minimum of 15 minutes, but it depends upon the size of the system; a larger system requires more time). Keep checking the pressure gauge to see if the pressure reduces.

2 - If the pressure does fall, it is likely that the system has a leak, so leak searching and repair procedures must be carried out.



Vacuum pump connexion

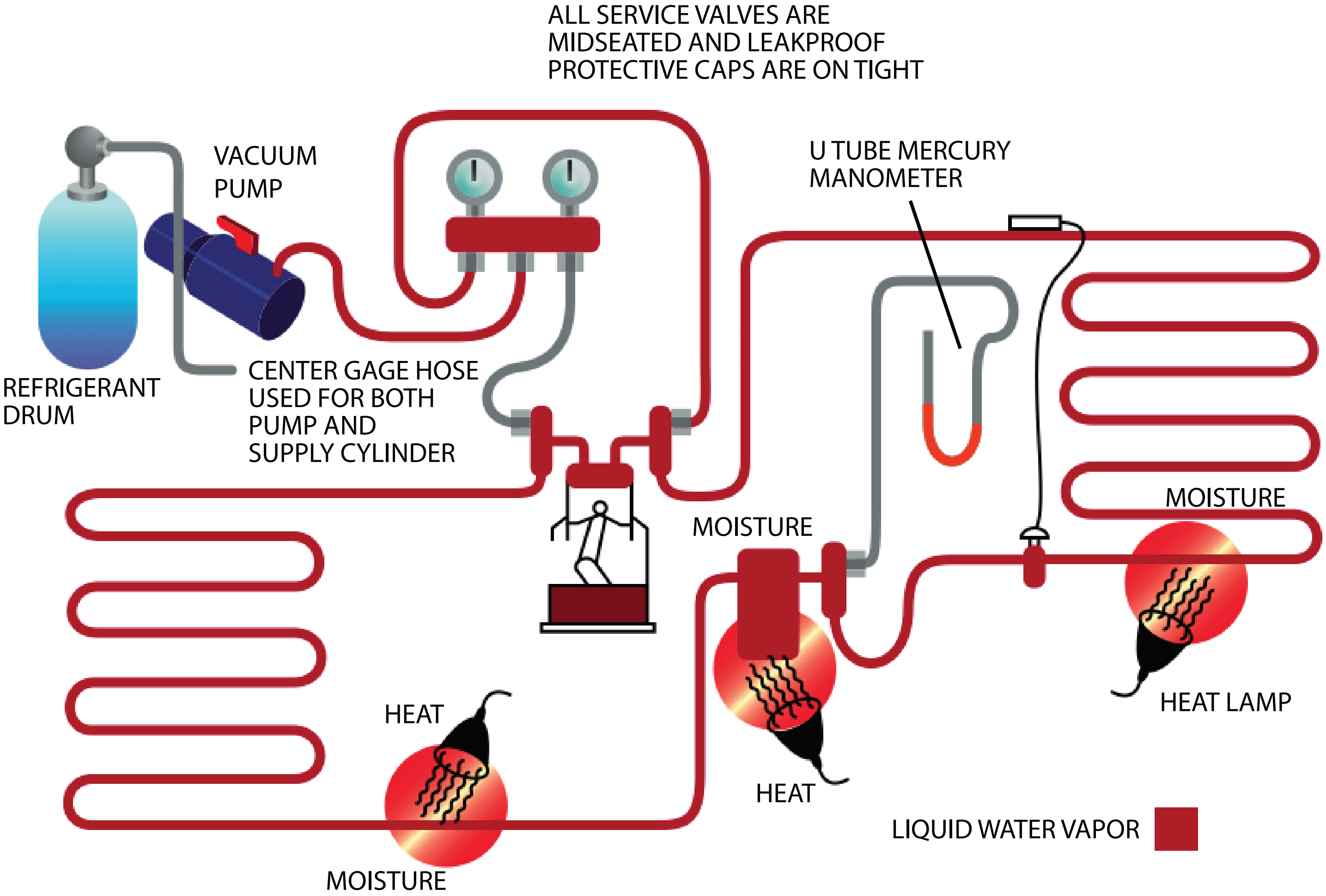
3 - When the system is confirmed to be leak-tight, release the OFDN and immediately connect a proper vacuum pump to both suction side and discharge the side of the compressor (see diagrams), and make sure the vacuum gauge is connected. Open all the valves, including solenoid valves, so there is no part of the circuit that is “locked” in.

4 - Switch on the vacuum pump and wait.

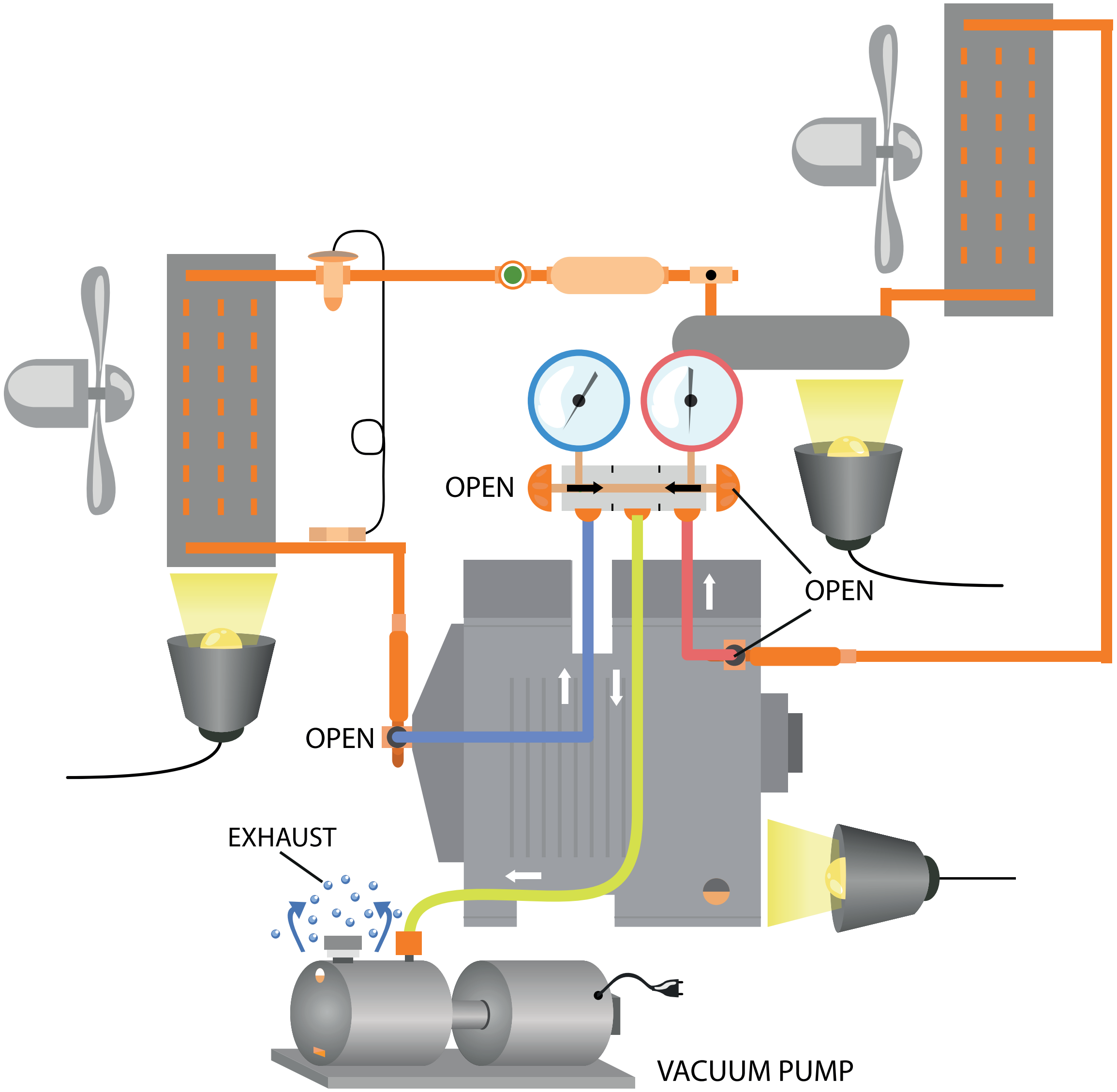
5 - When satisfactory vacuum has been reached (below 100 Pa abs.) stop the pump and leave it for an appropriate length of time (around half an hour for a small hermetic system, to several hours for a large site-installed system) to see if the vacuum gauge indicates an increase in internal pressure. If the pressure rises there could be two reasons for it: either there is a leak or moisture still in the system. In this case, the evacuation procedure should continue, but if a constant vacuum pressure is never achieved, then it is likely that a leak is present and the tightness test should be repeated.

6 - If the vacuum pressure remains constant over a period of time, the circuit is correctly evacuated; dry and free of leakage.

7 - For large systems where is expected excess of moisture content, apply indirect heat (using a heat lamp or hot air-blower, see the diagram) to the system tubing (applying heat to one side only will cause moisture condensation in the coolest part).



Refrigeration system evacuation



Moisture removal

8 - In case of closed solenoid valves in the system, air is usually trapped in-between valves where they should be opened manually if supplied with open screws, by applying direct electrical source to solenoid coil, or by using a service hand magnet.

9 - Charging of refrigerant can now begin, either direct to the high-pressure liquid side or charging into the suction side when the compressor is running.

Pressure units for vacuum

A variety of different units of measurement are employed for quantifying pressures, which can easily lead to confusion. The below Table 4.1 provides a conversion of certain units of pressure for standard atmospheric pressure, 1 bar, and the recommended highest level of vacuum (ideally, evacuation pressure should be below this). Note also that the pressures are indicated in absolute pressure, not gauge pressure.

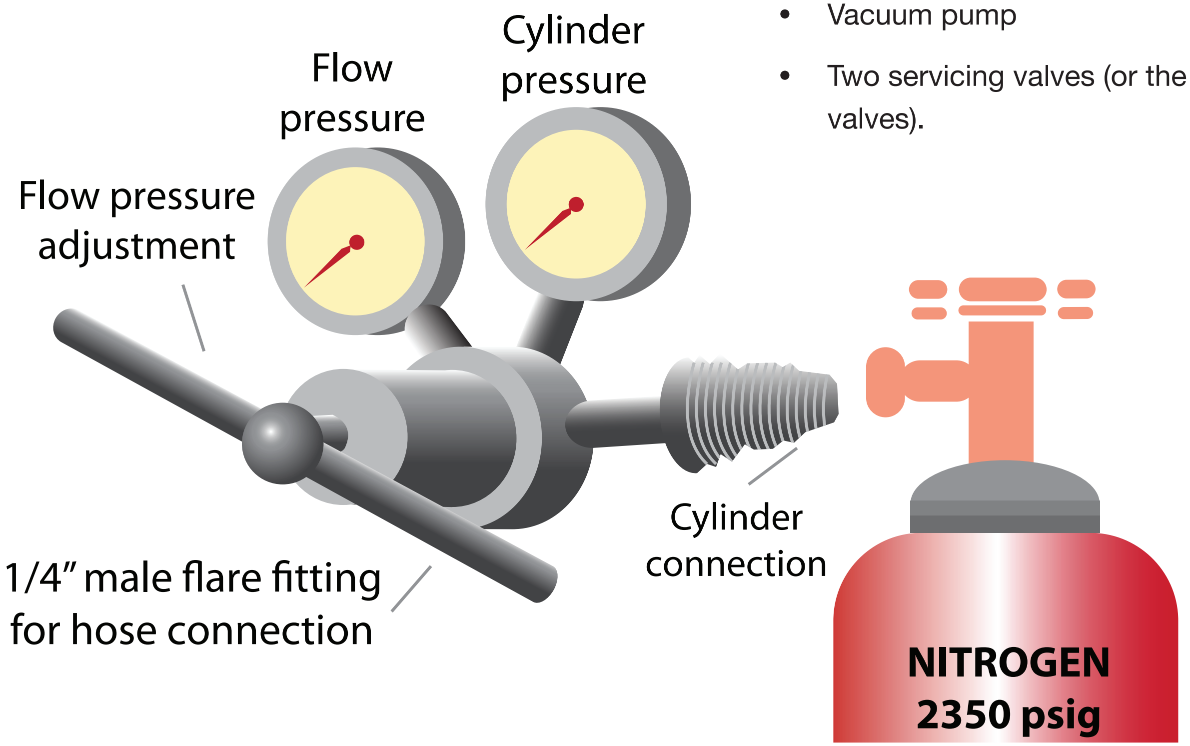
SI units	**Standard atmosphere**	**1 bar (absolute)**	**Preferred vacuum level (absolute)**
bar	1.01325 bar	1 bar	0.001 bar
kilo Pascal	101.3 kPa	100 kPa	0.10 kPa
micron	1013250 microns	1,000,000 microns	1000 microns
millibar	1013.25 mbar	1000 mbar	1 mbar
Pascal (Pa)	101325 Pa	100,000 Pa	100 Pa
Non-SI units:			
inch of mercury	30.5 in Hg	29.5 in Hg	0.030 in Hg
mm of mercury	760 mm Hg	750 mm Hg	0.75 mm Hg
Torr	760 Torr	750 Torr	0.75 Torr
pounds (force) per square inch	15.0 psi	14.5 psi	0.015 psi

Purging

The process of removing unwanted gases, dirt or moisture from the system is called purging. An inert gas such as nitrogen is introduced in the system to flow through the tubing, forcing unwanted contaminants out.

The following equipment is needed to perform purging:

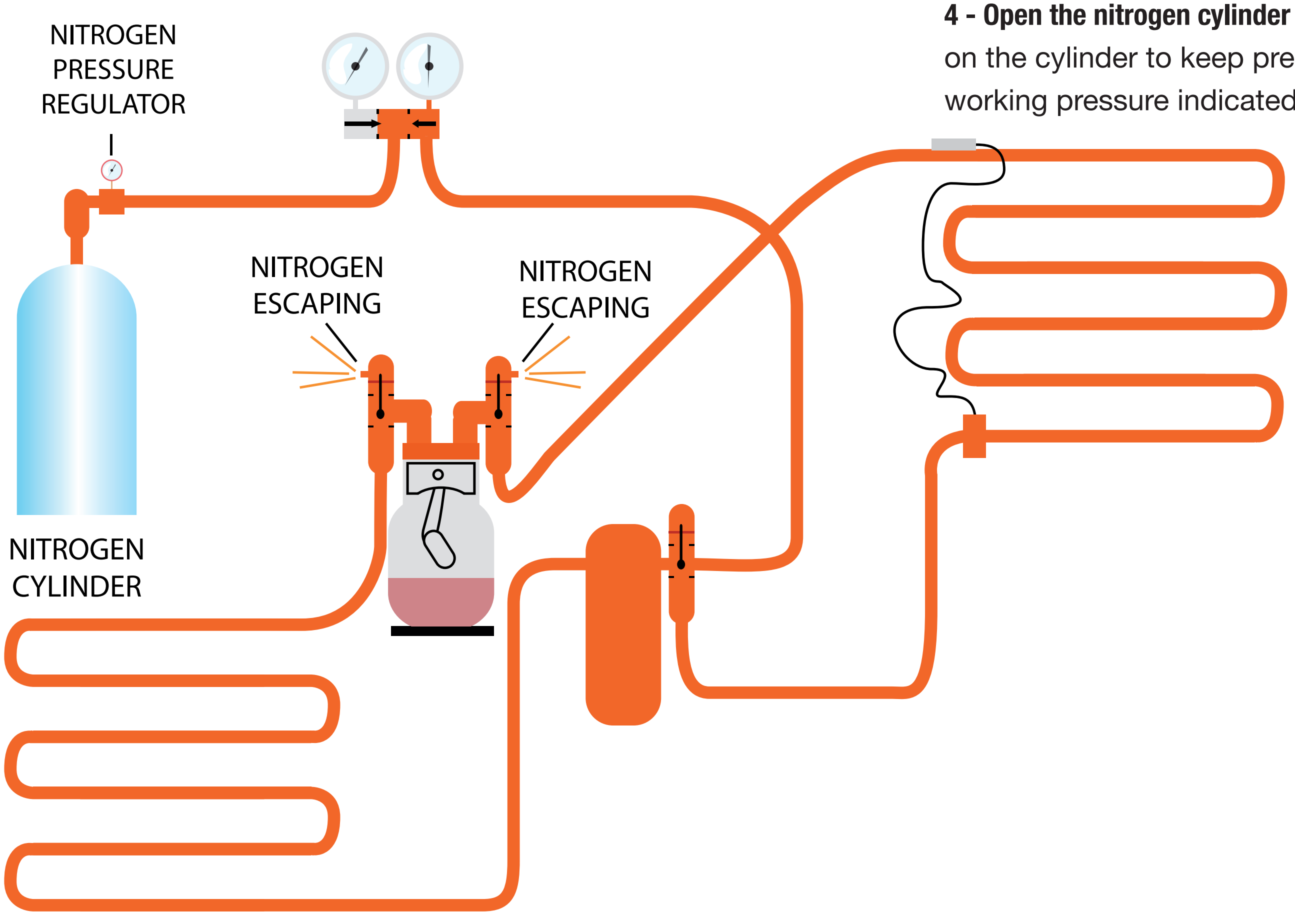
- Oxygen free dry nitrogen cylinder equipped with pressure regulator
- Nitrogen cylinder equipped with pressure regulator
- Manifold gauges with hoses
- Vacuum pump
- Two servicing valves (or the system is equipped with servicing valves).



Purging procedure

The following steps should be followed when performing system cleaning (purging):

1 - Set the connections as shown here:



2 - As with the evacuation procedure, ensure that all stop valves, solenoid valves and other such devices have been fully opened so not to restrict the flow around any parts of the system.

3 - Open the low-pressure side and high-pressure side valves in the manifold gauges.

4 - Open the nitrogen cylinder main valve using the pressure regulator on the cylinder to keep pressure of OFDN at less than the maximum working pressure indicated on the equipment nameplate.

5 - Keep the OFDN flowing for several minutes or until dry clean gas is discharged, indicating that all the contaminants have been removed.

6 - Remove the residual nitrogen with a vacuum pump using the proper procedure.

Leak detection

RAC systems are designed to operate adequately with a fixed charge of refrigerant. If it has been determined that a system has insufficient refrigerant, the system must be checked for leaks, then repaired and recharged.

Refrigerant leaks are caused by material failure. The mechanism that creates the material failure is normally attributable to one or more of the following factors:

- **Vibration** – Vibration is a significant factor in material failure and is responsible for "work hardening" of copper, misalignment of seals, loosening of securing bolts to flanges, etc.
- **Pressure changes** – Refrigeration systems depend on the changes in pressure for their operation. The rate of change of pressure has different effects on the various components in the system, which results in material stress and differential expansion and contraction.
- **Temperature changes** – Refrigeration systems frequently consist of different materials of differing thickness. Rapid changes in temperature result in material stress and differential expansion and contraction.
- **Frictional wear** – There are many cases of frictional wear causing material failure, and they vary from poorly-fixed pipework to shaft seals.
- **Incorrect material selection** – In a number of cases, inappropriate materials are selected e.g., certain types of flexible hoses have a known leakage rate, and materials that are known to fail under conditions of vibration and transient pressure and temperature changes are used.
- **Poor quality control** – Unless the materials used in the refrigeration system are of a high and consistent standard, changes in vibration, pressure and temperature will cause failure.
- **Poor connections** – Poorly made connections, either brazed joints, screwed connections, or not replacing caps on valves, can allow refrigerant to escape.
- **Corrosion** – Exposure to a variety of chemicals or the weathering can result in a variety of different corrosion modes, which decays the construction material resulting in the eventual creation of holes.
- **Accidental damage** – Accidental mechanical impacts to refrigerant-containing parts can happen under many circumstances, and therefore it is appropriate to ensure that all parts of the system are protected against external impacts.

> Designers, installers and service and maintenance technicians should all be aware of these phenomena, and always check to see if any are occurring or leading to leakage whenever possible.

Detection methods

When a system is thought to have a leak, the whole system should be checked, with leaks found being marked for rectification. One should never assume a system has only one leak.

Leak detection is the manual procedure, carried out by a qualified technician, of checking refrigeration systems to identify possible leaks in tubes, joints and/or connections, etc.

Generally, the main methods for detecting leaks in the servicing field are:

- **Using soap solution** ▶
- **Using an electronic refrigerant detector** ▶
- **Using an ultra-violet lamp** ▶
- **Using a halide torch** ▶

Note: Fault-finding

There are a number of problems that may develop in RAC systems that would have the same symptoms as a refrigerant leak. For example: the fan, the compressor and various controls could be in operation, but the system is not cooling. It is sensible to always determine the other possible reasons for poor operation before recharging the refrigerant into a system. Also adding refrigerant to a system that does not necessarily need it can adversely affect its performance, including reducing its efficiency. It can also present significant safety hazards such as causing elevated pressures above what the system can tolerate.

Topping-up

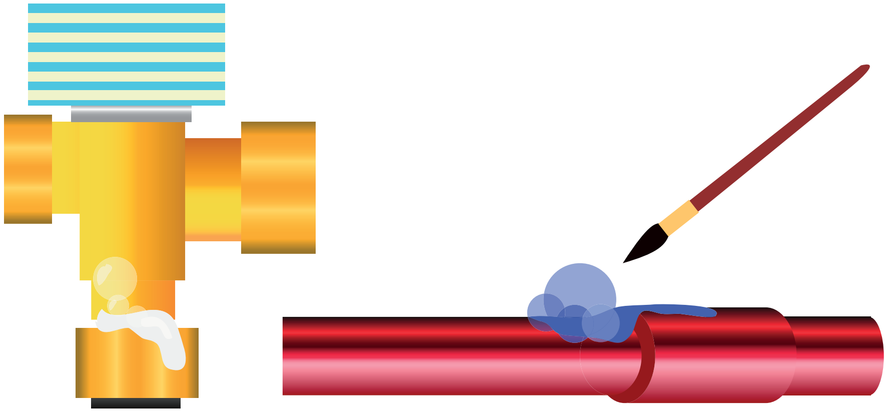
If a system has a deficit of refrigerant, it is highly likely that this is because of a refrigerant leak. Often, technicians take the approach of quickly “topping-up” a system to its original charge amount, since this a quick and easy way of getting the system to work properly again. However, this is only a temporary, costly, and environmentally unacceptable approach to take.

No refrigerant should be added to the system without first locating and repairing the leaks. Simply adding refrigerant will not permanently correct the problem, and in fact, it accelerates the degradation of the system in the longer term, thus reducing its operational lifetime. Instead, the technician should identify the leaks before recovering the refrigerant, to avoid contaminating the surrounding air with refrigerant from a newly open system, remembering that refrigerant should not be vented to the air.

Using soap-solution

A water-soap solution is the most popular, minimal cost, and one of the most effective methods used among servicing technicians.

Applying a soap solution to joints, connections and fittings while system is running or under a standing pressure of nitrogen helps to identify leak points when bubbles appear, as shown here:

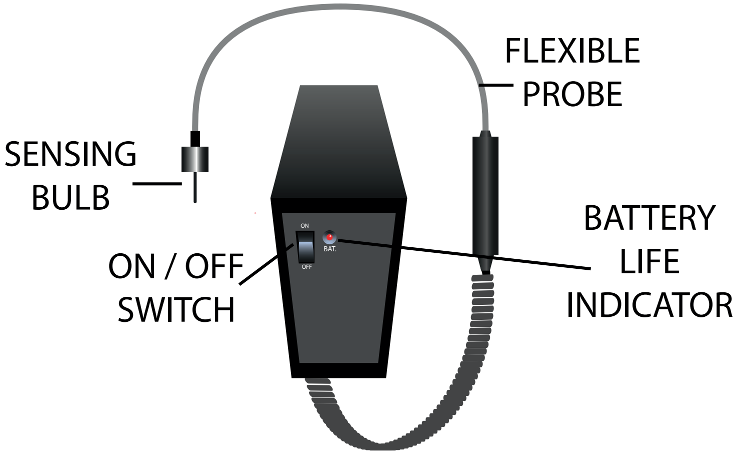


Use of soap-solution for leak detection

Using an electronic refrigerant detector

Electronic refrigerant detectors contain an element sensitive to a particular chemical component in a refrigerant. The device may be battery or AC-powered and often has a pump to suck in the gas and air mixture. Often, an audible “ticking” signal, and/or visible flashing indicating lamp increases in frequency and intensity as the sensor analyses higher concentrations of refrigerant, which suggests to the operator that the source of the leak is closer.

Many refrigerant detection devices also have varying sensitivity ranges that can be adjusted, as shown here:



Electronic refrigerant detector

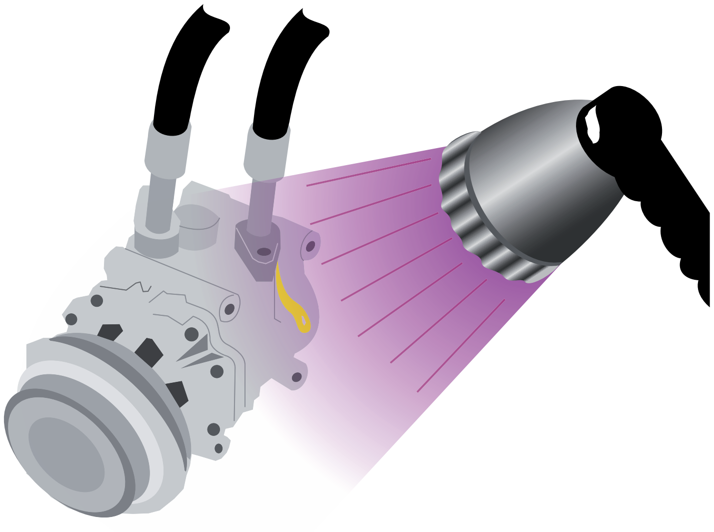
Many modern refrigerant detectors have selector switches for switching between refrigerant types, e.g. chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), HFCs or HCs. HCFCs have less chlorine than CFCs and the sensitivity has to be changed by the selector switch. When using electronic refrigerant detectors in a workshop, always ensure good ventilation since sometimes it gives false signals due to other refrigerants being present in the surrounding area.

Electronic refrigerant detectors may be used to detect hydrocarbons (HCs), but the sensitivity may not be adequate, or may need re-calibration. The detection equipment should be calibrated in a refrigerant-free area. Ensure that the detector is not a potential source of ignition and is suitable for hydrocarbon refrigerants.

Using an ultra-violet lamp

Ultra-violet lamp is a method commonly used in large systems where accessing all joints and connections by soap solution or electronic detectors is difficult.

By adding an additive dye to the refrigerant, the leak will glow yellow green-colours when pointed by the ultra-violet lamp, as shown here:

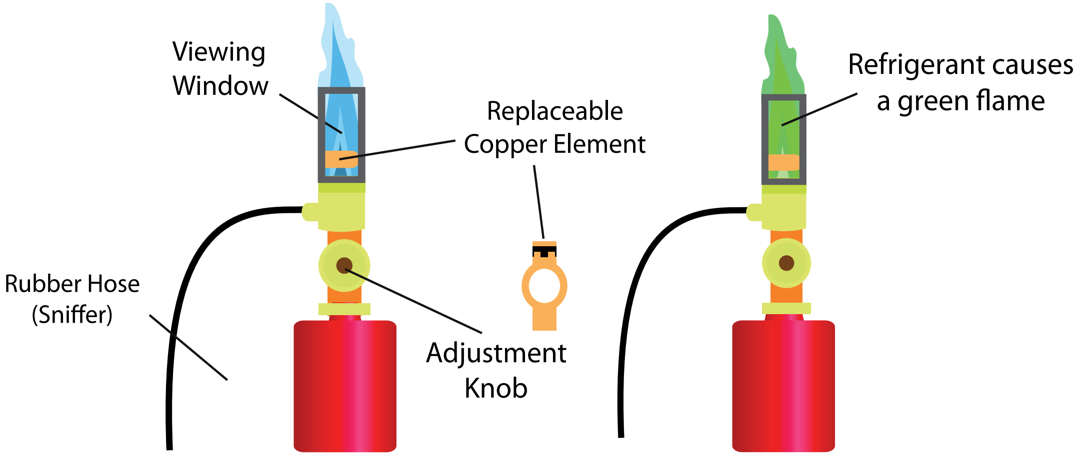


Using additives and ultra-violet lamp

Using a halide torch

The halide torch used to be the traditional means of leak detection with CFCs and HCFCs. A blue flame draws air (and refrigerant) from the hose and across a copper catalyst.

When refrigerant burns in the presence of this catalyst, the chlorine components of the refrigerant reacts to cause the flame to change colour from blue (normal) to green as shown here:



Halide torch

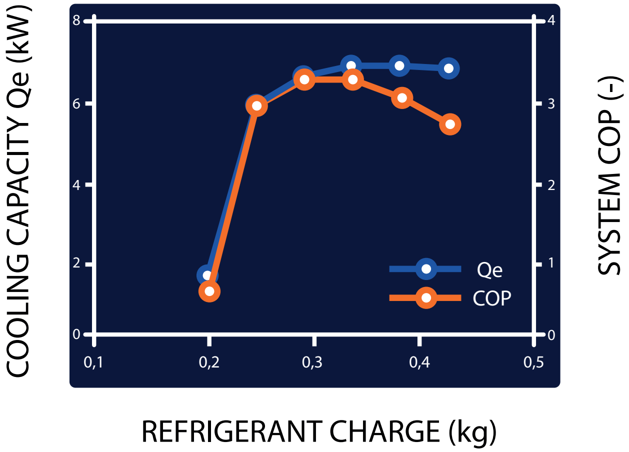
Since HFCs do not contain chlorine, halide torches will not work when searching for leaks from HFC system. The same applies to carbon dioxide (R744), ammonia (R717) and hydrocarbons (R290, R600a, etc). Obviously, from a safety point-of-view, the halide torch should not be used to detect hydrocarbons or any other flammable refrigerants, anyway, or in the presence of other flammable gases.

Charging

System charging is adding the proper quantity of refrigerant to refrigeration system so that it operates as intended. For a given set of conditions (design conditions) systems have an “optimum” charge – this is the mass of refrigerant that the highest efficiency and design cooling capacity (or heating capacity, in the case of a heat pump) will be achieved. At off-design conditions, for example, at a higher or lower ambient temperatures, the optimum charge will be different. However, it is best to add the specified charge since this is what the system has been designed to handle.

Some systems can handle a wider variation of charge size, in particular, those with liquid receivers. Direct expansion systems with small condensers and capillary tube expansion devices tend to be very sensitive to refrigerant mass and are said to be “critically charged”.

This figure illustrates the sensitivity of a critically charged system, where a small variation in charge size can greatly reduce the equipment efficiency:



Example of how refrigerant charge affects performance

In all cases, the system data-plate should contain useful information such as the design refrigerant charge size.

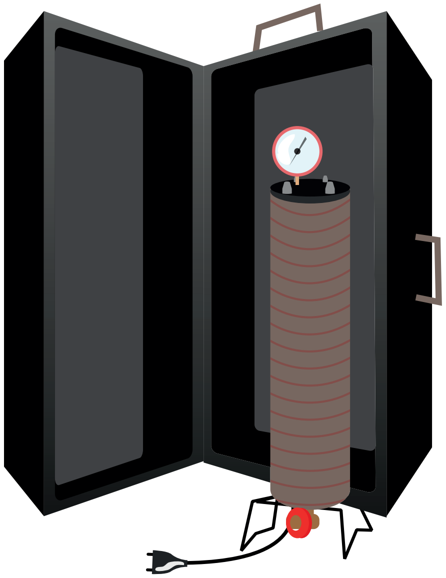
> There are several ways to charge systems, and the most appropriate depends upon the local conditions, the quantity and other factors such as the type of system.

These methods include:

- **Volumetric charging by graduated cylinder** ▶
- **Mass charging by balance** ▶
- **Charging to sight glass** ▶
- **Charging according to system performance** ▶
- **Electronic charging machines** ▶
- **Vapour Refrigerant Charging** ▶
- **Liquid refrigerant charging** ▶

Volumetric charging by graduated cylinder

Using graduated charging cylinder is one of the most popular charging methods, an example is shown here:



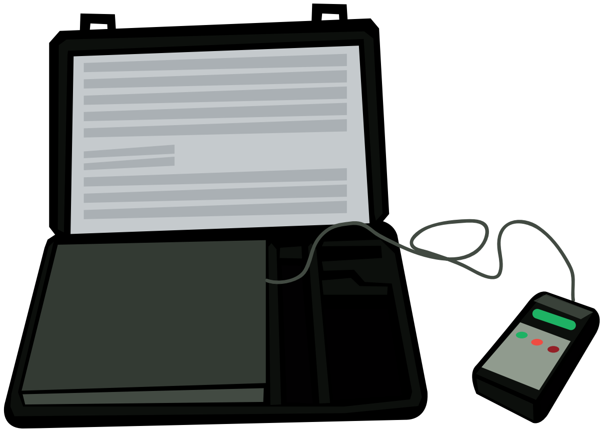
Graduated charging cylinder

It uses a glass tube liquid level indicator, which allows a technician to transfer refrigerant into a system and measure the amount on a scale. Some cylinders are electrically heated to speed up the evaporation and maintain pressure in the cylinder. This process of electrically heating cylinder is usually done with an electrical insert. In some cases, the compressor itself is heated, using a heat gun so the refrigerant and oil will circulate and be purged more easily.

In both cases, it is extremely important that a pressure control relief valve and thermostat be used to provide the required temperature and pressure safety controls. The system has a pressure gauge and hand valve on the bottom for filling the charging cylinder liquid refrigerant into a system. It also has valve at the top of the cylinder. This valve is used for charging refrigerant vapour into the system.

Mass charging by balance

Using an electronic weight balance, such as the one shown here:

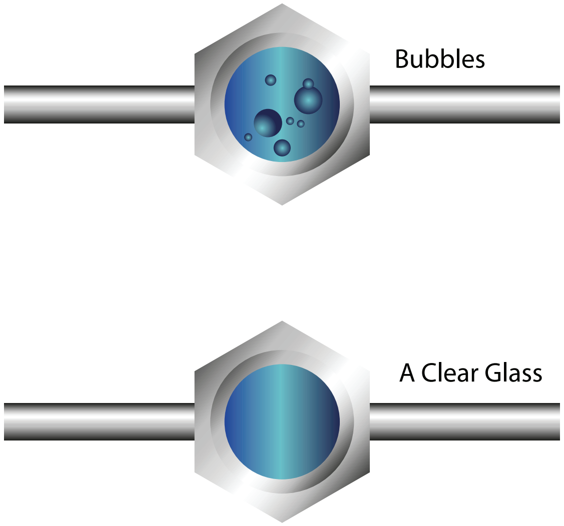


Electronic weight balance is typically one of the most accurate ways to charge refrigerant. System charging could be performed in vapour or liquid phase. This is generally done in smaller systems, which are more sensitive to charge size. Therefore it is important to be aware of the additional refrigerant within the refrigerant hoses, and the artificial weight of the hoses themselves on the balance reading, so that the actual mass added to the system is not erroneous.

Charging to sight glass

This method normally applies to larger systems that have a liquid receiver. Refrigerant is charged into the system, and as it is metered in, the technician observes the sight glass in the liquid line.

Eventually, once no more bubbles can be seen in the sight glass, the charge size has approximately been achieved, as shown here:



Charging by sight glass

However, as there is always a delay between adding the refrigerant and the effect on the sight glass, the technician should take extra time to ensure that the correct charge has been added. It should also be borne in mind that longer delays between adding refrigerant and the response of the sight glass occur with larger systems. As with all other systems, it is important to consider the ambient temperature and the possibility of adding a little more refrigerant so that no bubbles appear during warmer/cooler ambient conditions.

In addition, the refrigerant cylinder(s) should be weighed before and after, and the charged amount checked against the intended charge or compared against the size of the liquid receiver to ensure that it will not hydraulically fill during pump-down.

Charging according to system performance

It is possible to charge a system according to the system's performance characteristics. This is done by monitoring the suction pressure, discharge pressure, evaporator superheat and liquid subcooling out of the condenser.

First, the design performance characteristics are noted: the ambient temperature, the application temperature (to be cooled to), the intended superheat and subcooling. From the ambient temperature and the application temperature, a typical condenser and evaporator temperature difference is assumed for the equipment under consideration (say, for example, 8 K), from which the saturated condensing and evaporating temperatures, and finally suction and discharge pressures are estimated.

Thermometers are tightly attached to the liquid line and suction line (using a heat transfer paste and insulated). Refrigerant is then gradually added into the system and the pressures and temperatures monitored. As the estimated suction and discharge pressures are approached, and the design subcooling and superheat values are achieved, a suitable charge is achieved.

Again, as with the sight glass, there is a delay between adding refrigerant and the resulting performance characteristics being achieved, so these performance characteristics should be observed for some time to ensure that the reading are more or less constant.

Electronic charging machines

During larger-scale manufacturing, equipment tends to be charged using electronically controlled charging machines. These generally measure refrigerant into a system using precise mass flow meters, and are generally accurate to ±0.5g or better.

Vapour refrigerant charging

Vapour refrigerant charging is the process of moving vapour out of the vapour space of the refrigerant cylinder to the low-pressure side of the system. Charging while the system is running is acceptable as long as the suction pressure is closely checked during the charging process. Due to pressure difference consideration, the cylinder pressure could become lower than system suction pressure during charging. Using a hot water or servicing charging heaters could solve this problem. Never use a brazing torch to heat cylinders.

In general, follow the same connection scheme as in evacuation process and replace the connection with vacuum pump with the refrigerant charging cylinder as shown here:

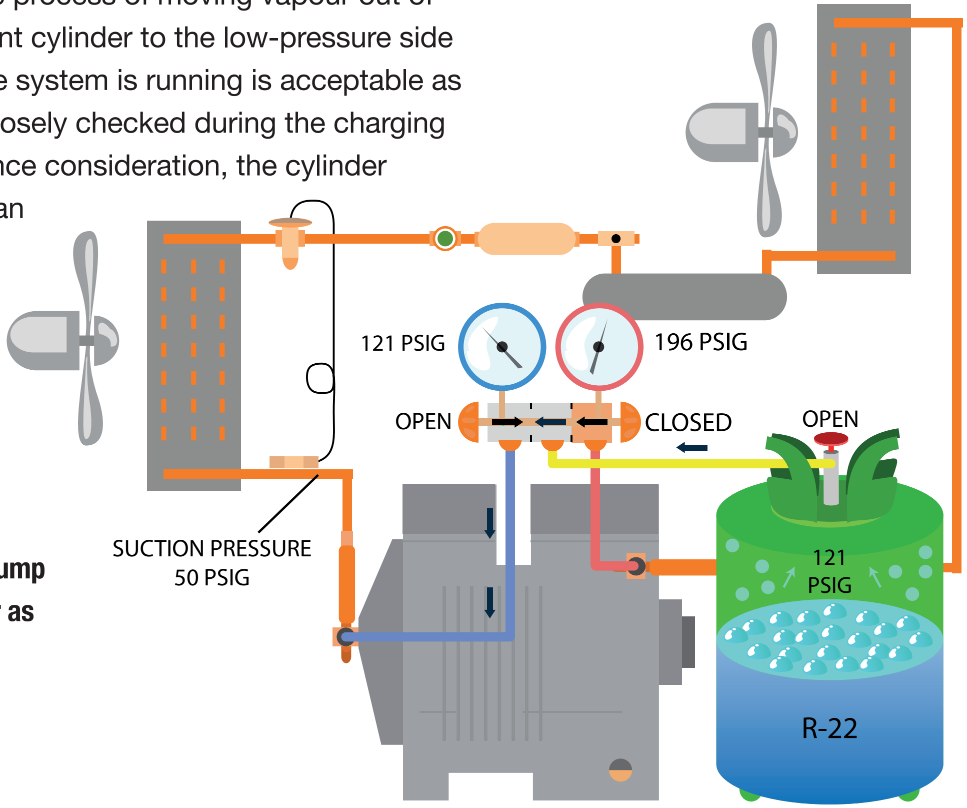
Then:

1 - Open the low-pressure side valve then open refrigerant graduated charging cylinder valve keeping eye on system pressure and refrigerant weight scale.

2 - When the pressure has equalised between system and charging cylinder, close the charging cylinder valve and operate the system for 1-2 minutes until the low-pressure side reading indicates lower reading than the charging cylinder.

3 - Continue adding refrigerant by opening the charging cylinder valve until the proper charge is obtained.

Before connecting any refrigerant hose to a service or tap valve, the hose should be briefly purged (vented) with refrigerant from the cylinder to ensure that air and moisture does not enter the system.

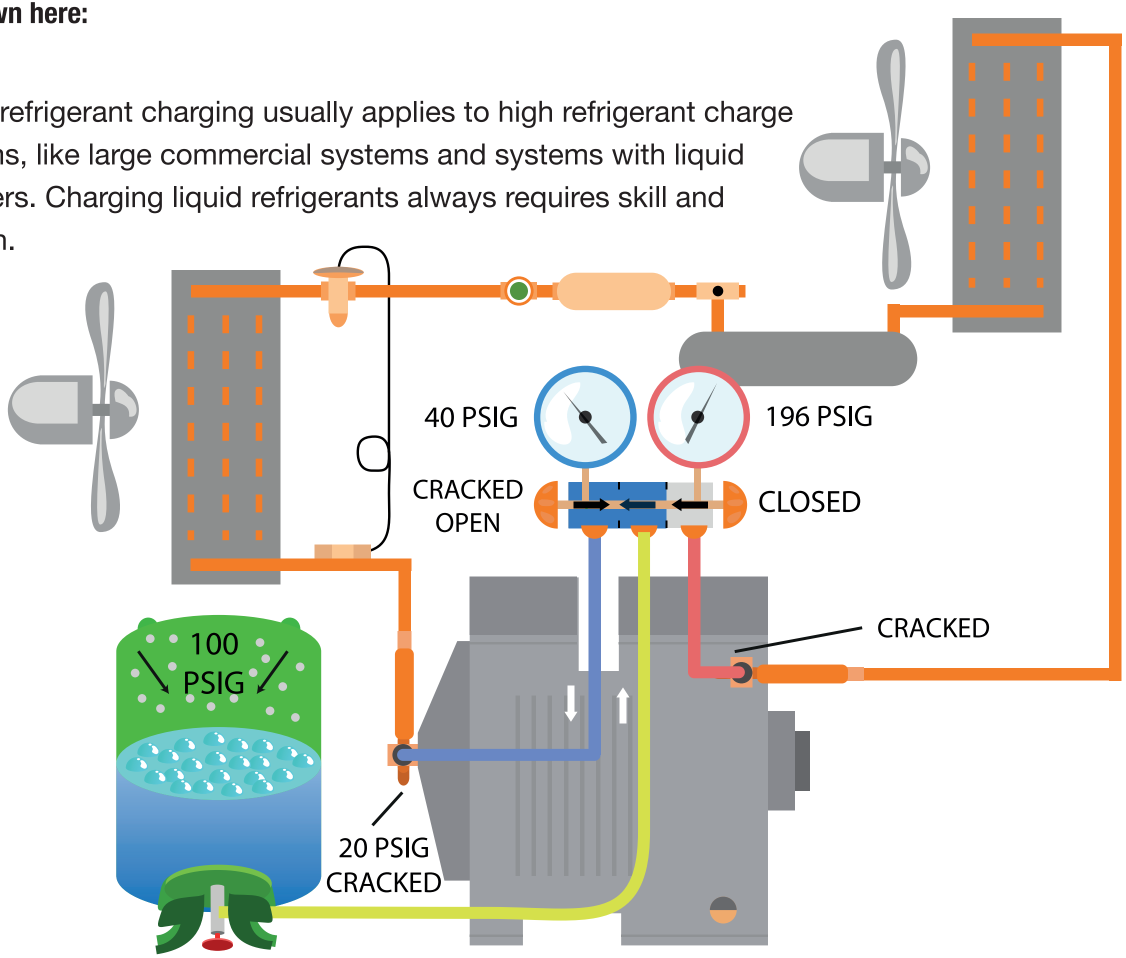


Vapour refrigerant charging

Liquid refrigerant charging

Liquid refrigerant charging is the process of moving liquid refrigerant from the liquid space of the refrigerant cylinder to the liquid side of the system, as shown here:

Liquid refrigerant charging usually applies to high refrigerant charge systems, like large commercial systems and systems with liquid receivers. Charging liquid refrigerants always requires skill and caution.



Liquid refrigerant charging

The suction hand-valve is to be used carefully to monitor the liquid gauge pressure to not exceed 140 kPa (approximately 20 psig) above suction pressure; when the blue hose (suction line) frost is observed close to the hand-valve, check the suction pressure. Repeat until the desired charge is obtained.

Remember always to make sure that:

- If the refrigerant cylinder does not have a dip-tube, it should be placed in an upside down position to guarantee liquid flow.
- Bypassing the low-pressure side control to avoid shutting off during charging.

Why charge refrigerant blends as liquids?

Refrigerant blends are simply a mixture of different refrigerant components. If the blend is a zeotropic mixture (i.e. R4xx) and it is charged as vapour, the refrigerant with the highest vapour pressure will be charged at a higher proportion than the other component(s). Charging as a liquid is the only way to guarantee that the blend is charged within its intended composition.

Fractionation of a refrigerant blend (separation of the individual components) can occur by removing the refrigerant from the cylinder as a vapour instead of a liquid. This can potentially lead to both safety and performance issues. As such, it is recommended charging all blends in liquid phase only. From a safety standpoint, a blend with an A1 safety classification – that has been composed of non-flammable and flammable substances – will remain non-flammable, even after fractionation has occurred.

Performance may be significantly affected, depending on the extent of fractionation. If only a small amount of the refrigerant placed into the system was charged as vapour, the blend may perform adequately. The performance of systems containing larger percentages of a blend charged as vapour is more likely to be affected by fractionation. Typically, more of the high-pressure components will be found in the system, and less in the cylinder.

Additionally, the refrigerant remaining in the cylinder may also be compromised. In these cases, it is recommended contact technical support of the refrigerant supplier.

It is also important to note that if the entire contents of a refrigerant blend container (full cylinder) are charged into a system as vapour, it will produce the same effect as charging the entire cylinder as liquid. Also, certain refrigerant blends are more susceptible to fractionation than others, and their stated temperature glide provides an indication of this. For example, fractionation is a greater concern when working with R409A (high temperature glide, ~ 8 K) than when working with R410A (a small glide, < 1 K).

Further reading

UK Air Conditioning and Refrigeration Industry Board - *Guidelines for the Use of Hydrocarbon Refrigerants in Static Refrigeration and Air Conditioning Systems, 2001*

▸ **www.acrib.org.uk/web_images/documents/technical_updates/Use%20of%20Hydrocarbon%20Refrigerants%20Guidelines.pdf**

UNEP DTIE OzonAction – *Guidebook for Implementation of Codes of Good Practice Refrigeration Sector, UNEP, 1998*

▸ **www.unep.fr/ozonaction/information/mmcfiles/2174-e.pdf**

UK Institute of Refrigeration Service Engineers' Section – *Bulletin 24 on Refrigerant Handling and Registration Schemes, 2006*

▸ **www.ior.org.uk/ior_/images/pdf/se/bulletin%2024%20refrigerant%20handling%20schemes.pdf**

UK Institute of Refrigeration Service Engineers' Section - *Bulletin 28 on Leak checking and Record Keeping under the F Gas Regulations, 2007*

▸ **www.ior.org.uk/ior_/images/pdf/se/bulletin%2028%20f%20gas%20leak%20checking.pdf**

UK Institute of Refrigeration Service Engineers' Section – *Technical Information on F Gas Refrigerant Handling Training, 2009*

▸ **www.ior.org.uk/ior_/images/pdf/se/SMfgastraining12revised09.pdf**

UNEP DTIE OzonAction – Fact Sheet No. 13 on Retrofit of CFCs based Refrigeration & Air Conditioning Equipment, UNEP

▸ **www.unep.fr/ozonaction/information/mmcfiles/4766-e-13retrofits.pdf**

UNEP DTIE OzonAction - *Study on the Potential for Hydrocarbon Replacements in Existing Domestic and Small Commercial Refrigeration Appliances, UNEP, 1997*

US Environmental Protection Agency – *web section on GreenChill Advanced Refrigeration Partnership which is an EPA cooperative alliance with the supermarket industry and other stakeholders to promote advanced technologies, strategies, and practices that reduce refrigerant charges and emissions of ozone-depleting substances and greenhouse gases*

▸ **www.epa.gov/greenchill**

5

Retrofitting

Content

5 Retrofitting

Summary

This section addresses the approach and working procedures for changing refrigerants within an existing system. It provides guidelines for the use of drop-in refrigerants as well as for retrofitting of both stationary and mobile systems. It includes a range of procedures specific to certain types of common systems.

Upon completion, the technician should be able to:

- **Introduce the proper use of drop-in refrigerants**
- **Identify the procedures for retrofitting chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) based systems**
- **Introduce the procedures for mobile vehicle air conditioning (MVAC) systems**
- **Discuss the main aspects involved in retrofitting domestic refrigerators and MVACs**

5.1. General retrofitting guidelines

Getting started

In general, the retrofit of an equipment or installation means to substitute older parts for new or modernised ones in order to improve the performance. In RAC recently, retrofit has come to mean the procedure of replacing ozone depleting substances (ODS), or hydrofluorocarbon (HFC) refrigerants in existing plants with zero ozone depleting potential (ODP) or zero GWP refrigerants. Retrofitting usually requires modifications such as a change of lubricant, replacement of expansion device or compressor. If the conversion does not require such major modifications, the alternate refrigerant is called a drop-in replacement, or retro-fill process.

Retrofitting from an ODS-using system to an ozone-friendly refrigerant requires a thorough investigation and study of the system.

Some factors must be taken into account:

- Retrofit the system if it is more cost-effective than replacement. If a major repair (e.g. compressor change, etc.) or modification of an ODS using system is necessary it shall be evaluated if retrofit can be done at acceptable cost.
- Properly working and leak-free systems are not recommended for retrofit, at least until there is a need to open the refrigeration system for repair. Properly operating systems can continue operating for many years without causing harm to the ozone layer. For older systems that are prone to faults, failures and leaks, it may be more cost-effective to replace the system rather than retrofit. In addition, new equipment will be more energy efficient.

- Upon evaluation of a system that requires major repair and is close to the end of its technical/economical life, consider replacement if it is more cost effective than retrofitting.
- The safety and environmental properties of alternative refrigerant to be used, such as flammability, toxicity, ODP and global warming potential shall be considered.
- Include in the assessment the compatibility of components and materials in the system, such as elastomers and oil. Also components like sight glasses and oil separators must be checked for suitability.
- Assess and examine the operating conditions of the system and determine the service and its operational history.

If necessary, consult the equipment manufacturer for the recommended alternative refrigerant and lubricant for the system.

Use of drop-in refrigerants

The phasing-out of ODS refrigerants, and in particular, CFCs in the RAC sector, has led to the development of new refrigerants that are often claimed to be direct replacements for the original ODS refrigerants. These refrigerants vary in compositions; some are synthetic fluorocarbons, others are natural refrigerants such as hydrocarbons (HCs), some are single substances, others are blends. However, it is important to thoroughly investigate any particular refrigerant that is being considered for use, to ensure that it is a suitable replacement for the situation under consideration, and that those working with the refrigerant are fully aware of its implications.

The following should be carried out:

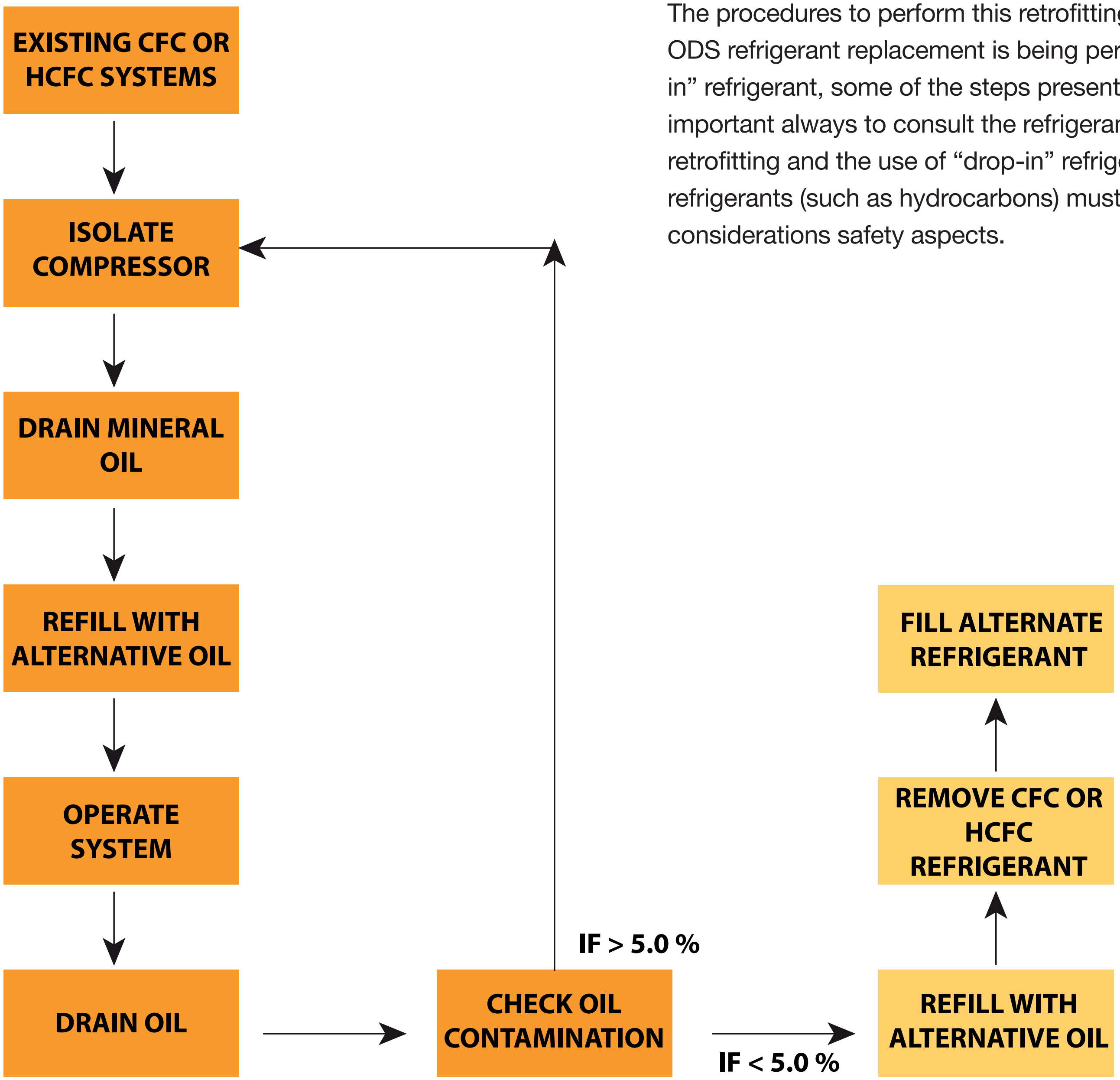
- Check the Material Safety Data Sheets (MSDS) to understand its safety characteristics
- Request relevant information related to the substance from the manufacturer of the substance
- Find out whether or not the existing mineral oil needs to be replaced or not
- Technicians should also look for training on the proper handling of these new refrigerants.

Hydrocarbons are known to be flammable, although there are certain concentrations that must be reached prior to explosion if ignition occurs. That is why education and information dissemination is very important. Several developing countries are implementing, with the support of UNEP and other implementing agencies, training programmes in good practices, and the use of drop-in refrigerants among other topics are covered in such courses.

General retrofitting procedures

A generalised procedure should be followed when retrofitting any refrigeration system with an alternative refrigerant. However, there may well be specific variations according to the particular characteristics of the system under consideration and the refrigerants involved. See the interactive diagram to see how this flow works for a retrofitting of CFC refrigeration equipment.

The procedures to perform this retrofitting are explained below. If the ODS refrigerant replacement is being performed with the use of a “drop-in” refrigerant, some of the steps presented may not be necessary. It is important always to consult the refrigerant manufacturer’s guidelines for retrofitting and the use of “drop-in” refrigerants. The retrofit to flammable refrigerants (such as hydrocarbons) must be executed taking into considerations safety aspects.



General retrofitting process flows

The specific procedures are:

- **Retrofitting stationary RAC systems** ▶
- **MVAC retrofitting procedure** ▶

Retrofitting stationary RAC systems

Here are the sequential steps involved in a retrofit of a CFC or HCFC based system.

1 - Record the system performance data prior to retrofit in order to establish the normal operating conditions for the equipment. Data should include temperatures and pressure measurements throughout the system, including the evaporator, compressor suction and discharge, condenser and expansion device. These measurements will be useful when adjusting the system during the retrofit.

2 - Pump down the system and recover the refrigerant before opening the refrigeration system.

3 - Recovered refrigerant must be stored only in a specified refillable container or cylinder and properly labelled.

4 - Recovery of refrigerant shall be done using a recovery machine or a recovery and recycling machine, operated only by a qualified technician.

5 - Knowing the recommended CFC or HCFC charge size for the system is helpful. If it is not known, weigh the entire amount of refrigerant removed. This amount can be used as a guide for the initial quantity of replacement refrigerant to be charged into the system.

6 - The technician should exert all efforts to ensure the prevention of refrigerant emissions during the recovery operation.

7 - If the refrigerant to be added to the system is incompatible with the existing oil (typically a mineral oil) then it must be removed (otherwise, this stage can be ignored). Drain and recover the existing mineral oil charge, measure the quantity and compare with the recommended oil charge to determine the quantity of oil left in the system. A major problem with retrofits is removing the residual mineral oil. This is important because enough mineral oil is not removed, it can deposit on the evaporator heat exchanger surfaces, severely degrading performance. Since many small hermetic compressors do not have oil drains, removal of the compressor from the system may be necessary for draining the lubricant. The best point in the system to drain the lubricant is the suction line of the compressor. Small hand-operated pumps are available which permit insertion of a tube into the compressor access port for removal of the mineral oil without removing the compressor from the system. Remember that most of the mineral oil must be removed from the system before adding the replacement lubricant.

8 - Replace all equipment components and accessories that will be affected by the new alternative refrigerant and the refrigerant oil suitable for the new alternative refrigerant e.g. expansion valve, gaskets, filter drier, etc., as recommended by the manufacturer. Most CFC or HCFC systems with expansion valves will operate satisfactorily, however, it may be necessary to adjust the superheat. If the system uses a capillary tube, it will need to be replaced with one of greater or lesser restriction in order to achieve satisfactory performance over the complete range of design conditions. It is recommended that the technician consults with the equipment manufacturer before replacing the capillary tube.

9 - Charge the system with new and correct amount of alternative refrigerant oil as recommended by compressor/system manufacturer.

10 - Reinstall the compressor following the standard service practices recommended by the manufacturer. If an oil pump was used to remove the oil, reseal the access port.

11 - Run the system while performing the oil change procedure as many times as necessary until the mineral oil in the system does not exceed the recommended 5% acceptable level. Test kits are available from several lubricant suppliers that check for residual mineral oil content. Generally, it will require about three charges to get the mineral oil content down to the acceptable level.

12 - Leak test the system with oxygen-free dry nitrogen and observe a 24-hour standing pressure. Make corrections if deemed necessary.

13 - Evacuate system to at least 1000 microns (1 mbar, 29.87 in Hg) using an appropriate vacuum pump and an electronic vacuum gauge. Use normal service practices to reconnect and evacuate the system, to remove air and other non-condensable contaminants.

14 - Charge the system with the appropriate amount of alternative refrigerant. This can normally be approximated by using the ratio of liquid densities at the condensing temperature. When charging the system with alternative refrigerant, use the same charging procedures that you would use for CFC or HCFC to ensure optimal system performance. In general, systems will require a smaller charge size than those using CFC or HCFC. If the original capillary tube is used, it will generally be necessary to undercharge the system to prevent liquid flood back to the compressor. Special care should be taken when charging with refrigerant blends, as presented in section 4.

15 - Run the system and charge additional refrigerant if needed until full-charged. The use of an expansion device not optimised for the system, such as the original capillary tube, will make the system more sensitive to charge and/or operating conditions. As a result, system performance will change more quickly if the system is overcharged (or undercharged). To avoid overcharging, it is best to charge the system by first measuring the operating conditions (including discharge and suction pressures, suction line temperature, compressor amps, superheat) before using the liquid level sight glass as a guide.

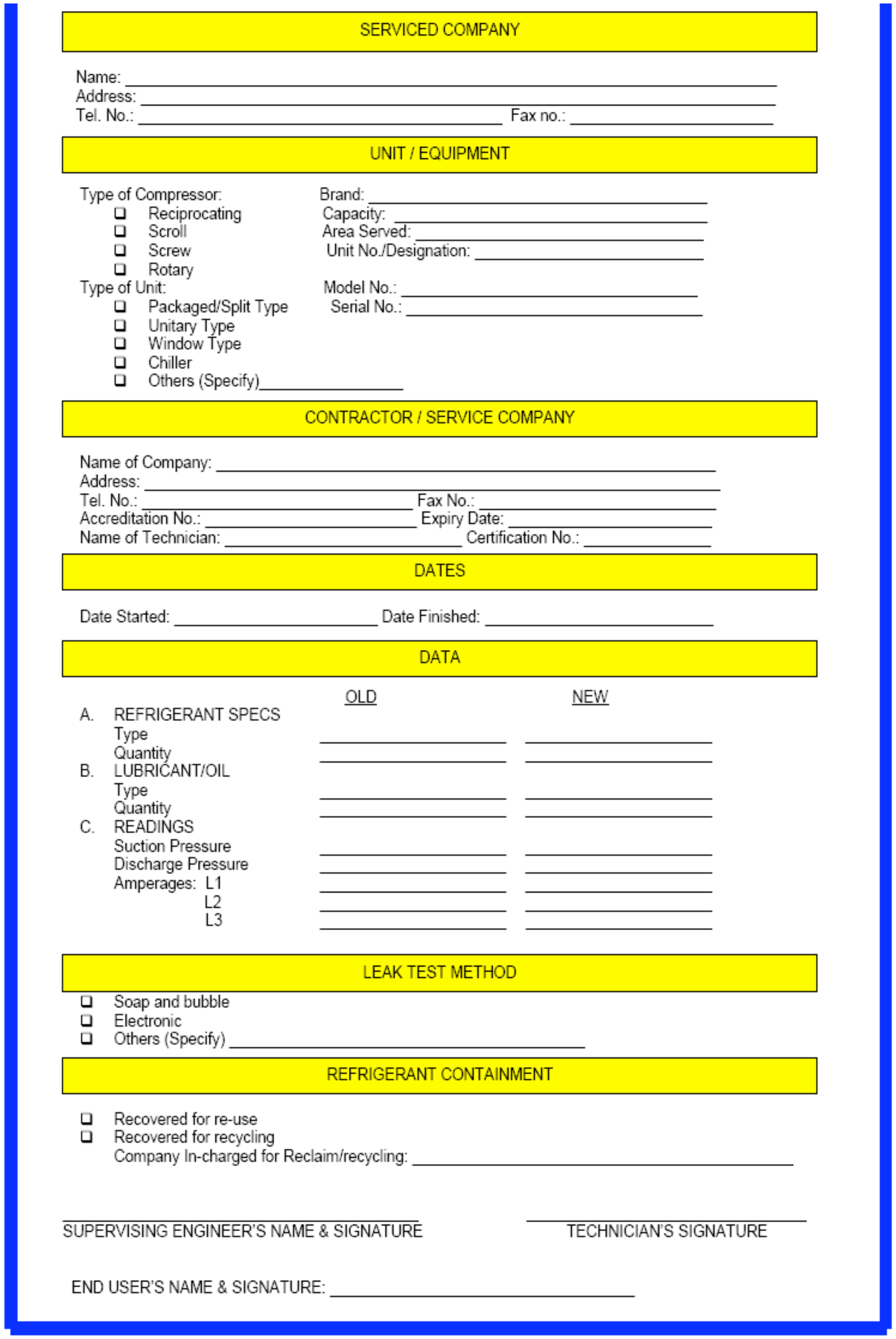
16 - Monitor the system operation and performance for at least 48 hours or longer and make necessary adjustment.

17 - Check remaining content of mineral oil with a refractometer or oil test kit.

18 - Follow the system and/or compressor manufacturer recommendations as tolerance are dependent on the system and its operating conditions.

19 - Label the system (as shown in the downloadable data sheet). After retrofitting the system, label the system components to identify the refrigerant and specify type of lubricant (by brand name) in the system. This will help ensure that the proper refrigerant and lubricant will be used to service the equipment in the future.

Retrofitting data sheet



SERVICED COMPANY

Name: ______________________________
Address: ______________________________
Tel. No.: ____________________ Fax no.: ____________

UNIT / EQUIPMENT

Type of Compressor:
- ☐ Reciprocating
- ☐ Scroll
- ☐ Screw
- ☐ Rotary

Type of Unit:
- ☐ Packaged/Split Type
- ☐ Unitary Type
- ☐ Window Type
- ☐ Chiller
- ☐ Others (Specify)____________

Brand: ____________________
Capacity: ____________________
Area Served: ____________________
Unit No./Designation: ____________________
Model No.: ____________________
Serial No.: ____________________

CONTRACTOR / SERVICE COMPANY

Name of Company: ______________________________
Address: ______________________________
Tel. No.: ____________________ Fax No.: ____________
Accreditation No.: ____________ Expiry Date: ____________
Name of Technician: ____________ Certification No.: ____________

DATES

Date Started: ____________ Date Finished: ____________

DATA

		OLD	NEW
A.	REFRIGERANT SPECS		
	Type	____________	____________
	Quantity	____________	____________
B.	LUBRICANT/OIL		
	Type	____________	____________
	Quantity	____________	____________
C.	READINGS		
	Suction Pressure	____________	____________
	Discharge Pressure	____________	____________
	Amperages: L1	____________	____________
	L2	____________	____________
	L3	____________	____________

LEAK TEST METHOD

- ☐ Soap and bubble
- ☐ Electronic
- ☐ Others (Specify) ______________________

REFRIGERANT CONTAINMENT

- ☐ Recovered for re-use
- ☐ Recovered for recycling

Company In-charged for Reclaim/recycling: ______________________

____
SUPERVISING ENGINEER'S NAME & SIGNATURE

____
TECHNICIAN'S SIGNATURE

END USER'S NAME & SIGNATURE: ______________________

MVAC retrofitting procedure

Refer to the manufacturer's retrofit procedures whenever available.

The following are recommended procedures, specifically for retrofitting R12 MVAC systems to a R134a system:

1 - Check for leaks using a hand-held leak detector (refer also to SAE J1628: 2003) and set to detect R12 and/or use the soap bubble test. Make repairs if necessary.

2 - Run the vehicle to obtain suction and discharge pressures, which should be noted, and check again for leaks.

3 - Recover the entire refrigerant from the system following the standard procedure for CFC refrigerant recovery and store in a specified refillable container which is properly labelled.

4 - Remove the compressor from its mounting bracket and drain its lubricating oil.

5 - Rinse the internal parts by pouring alternative oil for new refrigerant into the compressor and manually rotating the compressor shaft. The amount of oil for rinsing is about 50% of the recommended factory oil charge.

6 - Repeat the oil rinsing procedure as necessary.

7 - Pour the proper amount of alternative refrigerant oil into the compressor as per the original equipment manufacturer (OEM) recommendations, and cap the suction and discharge lines until the system is ready for re-assembly.

8 - Flush the entire system with oxygen-free dry nitrogen and any cleaning agent not containing an ODS.

9 - Carry out tightness tests for each component for leaks. Repair or replace if necessary.

10 - Replace the expansion device and the filter drier with ones that are compatible with the alternative refrigerant.

11 - Change all flare type to O-ring type fittings.

12 - Replace all O-ring seals on pipes and hoses with those approved for R134a and PAG oils.

13 - Re-install and assemble system components.

14 - Modify the access valves/fittings to accept only the new alternative refrigerant fittings.

15 - Evacuate system to at least 1000 microns using the appropriate vacuum pump and an electronic vacuum gauge. Make corrections if necessary.

16 - Charge the system with the alternative refrigerant (SAE J1657: 2003) as recommended by the manufacturer whenever possible. Notice that the optimum charge will change when systems are retrofitted.

17 - Run the vehicle to observe the system operation and check again for leaks.

18 - Compare the new set of performance data to that obtained when the system was still using CFC.

19 - Label the system clearly.

Practical cases of retrofitting – discussion and procedures

There are a series of specific examples for you to choose from:

Domestic refrigerator retrofit

CFC-based domestic refrigerators and small capacity commercial refrigeration appliances can be retrofitted with a hydrocarbon blend (a mixture of propane and isobutane), other commercially available drop-in blends and R134a. For the hydrocarbon blend retrofitting, there are typically no changes that need to be done to the refrigeration system.

However, it is essential that the electrical components associated with the appliance are checked to determine whether or not they are potential sources of ignition; if they are they must be replaced with non-sparking equivalent components, sealed or positioned in an air-tight enclosure. Such electrical components include relays, thermostat, door switches and possibly bulb-holders.

Safety is the most important consideration while retrofitting with HC blends. For retrofitting with R134a, major components like the compressor, capillary, and filter dryer might need to be changed. These will make the cost of retrofit very high and uneconomical. Thus retrofitting with R134a is normally not recommended. Retrofitting with HC blend or other drop-in blend could achieve a similar reliability and energy performance as the original equipment.

Retrofitting MVAC systems

MVAC can be retrofitted with R134a, the only accepted refrigerant by car manufacturers worldwide. However, due to compatibility issues, the lubricant oil, O-rings, filter dryers and dual pressure switches may also need to be replaced. The essential point is to get the system flushed and cleaned and to be made fully leak-tight. This may be termed as simple or economic retrofit. In this case there will be slight loss in cooling capacity.

Recently, a more simplified retrofit approach has been adopted: just adding lubricant (PAG) and charging the system with R134a (80% of R12 charge) is believed to be compatible for MVAC retrofitting by some experts in the MVAC sector.
Most car manufacturers have also developed specific retrofitting kits and procedures for their various models. The OEM retrofit procedure will provide the greatest assurance of comparable performance of retrofitted to the original MVAC. But in most cases, the cost may be relatively high.

For the retrofitted MVAC with R134a, the cooling capacity and energy efficiency would be slightly reduced depending on the various factors, but nevertheless, such energy penalty is acceptable. There is no reported increased failure rate of the retrofitted R134a MVAC compared with the original produced one. However, due to the higher R134a operating pressure, a reduction of cooling performance may occur during city traffic operation.

MVACs are also retrofitted (drop-in mode) with HC blend in some states of Australia, USA and Canada.
Although, in general, car manufacturers do not condone this option

Although, in general, car manufacturers do not condone this option on safety grounds, there have been many hundreds of thousands of retrofits for ten or more years without any incidents. However, if such a retrofit is to be carried out, it must be acknowledged and accepted by the vehicle owner.

The possibility of cross contamination of refrigerants and improper system evacuation is generally noticed in MVAC servicing in many developing countries which leads to poor performance of the system. In some cases, such bad practices are attributed as a result of improper retrofitting processes.

Retrofitting of R22 supermarket refrigeration system

The following steps should be followed when retrofitting a supermarket refrigeration system from R502 or R22 to an HFC refrigerant that is not a drop-in blend:

1 - Pump-down the R502 or R22 refrigerant charge to the liquid receiver.

2 - Drain as much of the old lubricant from the system as possible, including from the compressor sump, oil reservoir, and oil separator. If large amounts of mineral oil remain, it may clog the system and cause the efficiency of the heat exchangers to decline.

3 - Replace oil filters and filter driers when performing oil changes.

4 - Measure the amount of oil removed, add back an identical quantity of new oil. Ensure that the new oil chosen is approved by the compressor manufacturer.

5 - Run the system with the existing refrigerant for at least 24 hours. Systems running for an extended period may require fewer oil changes.

6 - Check the system for leaks.

7 - Repeat steps 1 through 4 until the residual oil is less than 5%, testing using lab analysis or a refractometer.

8 - Evaluate expansion devices using the process described.

9 - Recover the R502 or R22 from the system.

10 - Evacuate the system.

11 - Evaluate the pressure controls, including high pressure cut-outs, fan cycling controls, and pressure relief devices.

12 - Recharge the system with the new HFC refrigerant.

13 - Check the system for leaks.

Valve rebuilds (for systems built before 1995)

Systems built before 1995 will most likely require new gaskets and O-rings (elastomers):

1 - Rebuild all Evaporator Pressure Regulators (EPRs).

2 - Rebuild all solenoid valves.

3 - Rebuild hold back valves.

4 - Rebuild heat reclaim valves.

5 - Evaluate thermostatic expansion valves (TXVs) and new refrigerant for proper capacity and superheat. Replace the whole valve or power head if necessary. Existing R22 valves may be under-sized for higher mass flow refrigerants R507A, R404A and R422A.

6 - Replace O-rings on the receiver float, and receiver optic switch.

7 - Replace nylon gasket on Roto Lock fittings. Complete steps 6 and 7 prior to pulling a vacuum.

System "Rack"

Replace Schraeder caps and Schraeder cores on the high side. All Schraeder caps should be brass.

1 - Replace liquid line filters on the conversion date.

2 - Replace suction felts or cores on the conversion date.

3 - Use brass sealing caps on ball valves and compressor service valves.

4 - Set holdback valves on the condenser drain leg.

5 - Set evaporator pressure regulating valves to the manufacturer's parameters before setting any superheats.

6 - Set mechanical sub-coolers to the rack manufacturers' parameters. Verify the stable operation of the system before setting any superheats.

7 - Set thermostatic expansion valve superheats to 8–10 K for medium temperature applications and 5-7 K for low temperature applications. With blended refrigerants use dew-point temperatures for superheat measurements.

Retrofitting of R22 chillers

In recent years, R22 water chillers have been converted for use with a hydrocarbon refrigerant (R290) in some installations in Asian countries. Procedures used for conversion are similar to the general procedures.

It must be stressed that it is of utmost importance to ensure that the correct procedures are followed, that the technicians are trained correctly and the right safety devices are in place.

Provided these requirements are carried out, a HC charged chiller will offer a lifetime of service with reduced power consumption and more efficient cooling.

Certain situations are such that HCs cannot be used for retrofitting chillers, such as:

- Basement units with no option to ventilate
- Poorly maintained units with existing major problems
- Units adjacent to ignition sources that cannot be isolated
- Large units where the public have access.

Further reading

UNEP DTIE OzonAction – *Guidebook for Implementation of Codes of Good Practice Refrigeration Sector, UNEP, 1998*

- **www.unep.fr/ozonaction/information/mmcfiles/2174-e.pdf**

UNEP DTIE OzonAction – *Fact Sheet No. 13 on Retrofit of CFCs based Refrigeration & Air Conditioning Equipment, UNEP*

- **www.unep.fr/ozonaction/information/mmcfiles/4766-e-13retrofits.pdf**

UNEP DTIE OzonAction - *Information Paper on Retrofitting with Non-CFC Substitutes, UNEP, 1994*

- **www.unep.fr/ozonaction/information/mmcfiles/3143-e.pdf**

Ozone Unit of The Former Yugoslav Republic of Macedonia - *Manual for Refrigeration Service Technicians, 2006*

- **www.ozoneunit.gov.mk/eng/doc/Training_manual_for_service_technicians.pdf**

UNEP DTIE OzonAction - *Training Manual on Good Practices in Refrigeration – Training Manual, 1994*

UNEP DTIE OzonAction - *Training Manual on Chillers and Refrigerant Management, UNEP 1994*

6

Safety Guidelines

Content

6

Safe Refrigerant Handling

Summary

This section covers the relevant safety issues necessary for working with refrigerants. There is a general description of the safety implications of refrigerants, including toxicity, oxygen displacement, flammability, degradation products, and high pressure to highlight the major hazards. It includes a summary of the important safety procedures, such as personal protection, ensuring a safe working area, working on a system safety, and how to handle refrigerant cylinders appropriately.

Primarily aimed at the use of hydrocarbon (HC) refrigerants, there is also a section detailing the special requirements for working with flammable refrigerants, and further guidelines specific to the use of ammonia (NH_3, R717).

Upon completion, the technician should be able to identify safety procedures for handling refrigerants and servicing installations.

6.1. Overview of refrigerant safety

The use, storage and handling of all refrigerants present safety hazards. These hazards may be related to a number of aspects, in that they may:

- be stored at high pressure
- displace oxygen when released in air
- have toxicological effects
- be flammable
- have dangerous decomposition products.

At least one of these characteristics applies to any refrigerant, and for that reason, a variety of precautions must be followed to ensure against injury to persons and damage to property. Thus, safety begins with observing basic precautions and following simple procedures.

Before using or handling any refrigerant, personnel should be familiar with the characteristics of the specific substance, reading all relevant information, which is always available from the supplier and manufacturer.

It is also important to understand that safety hazards equally apply to other materials used with refrigerating systems. These include refrigeration oils, nitrogen, cleaning agents and oxy-acetylene for brazing.

Whenever handling hazardous substances, a risk assessment should be carried out, in order to determine what the potential risks are, what the consequences could be, and most significantly, to identify the safeguards and precautions to put in place to ensure that an undesirable event does not occur.

These are considered in the following order:

- **High pressure fluids** ▶
- **Oxygen displacement** ▶
- **Toxicological effects** ▶
- **Flammability and degradation products** ▶

High pressure fluids

Most refrigerants are stored under pressure, since they would be a gas at atmospheric pressure. This presents a number of hazards that those using refrigerants should be aware of. A fluid being stored at a pressure several times higher than atmospheric pressure has the potential to produce a rapid expansion, which is explosive in nature and can produce shock waves that can injure people and property. Therefore it is important to ensure that whenever a high pressure fluid is handled, transferred or released, it is done so under strict safety procedures.

When a pressurised liquid is exposed to atmospheric pressure, it will rapidly boil off, thus drawing heat from its surroundings. In the event that a liquid spill occurs on the skin, this can result in freezing, thereby causing cell damage and pain. Thus, whenever handling refrigerants, one must always wear safety glasses and gloves. If contact with skin should occur, flush the exposed area with lukewarm (not hot) water. If there is evidence of frostbite, bathe in lukewarm water, or use other means to warm the skin slowly. Should eye contact occur, immediately flush with large amounts of lukewarm water for at least 15 minutes, lifting eyelids occasionally to facilitate irrigation. Seek medical attention as soon as possible.

Oxygen displacement

All refrigerants will displace air if released, and when oxygen levels are depleted, asphyxiation of people (and animals) occurs. Often, this is manifest by a loss of consciousness without the individual being aware that it is happening. Furthermore, most refrigerants are denser than air, which means that rooms below ground, seated areas, and enclosed spaces are more susceptible. Since most refrigerants are odourless, occupants may not be aware that oxygen is being displaced, and may become asphyxiated before they become aware of this problem.

If a large release of refrigerant occurs, the area should be evacuated immediately. Good ventilation must be provided in areas where high concentrations of the vapour could accumulate. Once the area is evacuated, it must be ventilated using blowers or fans to circulate the air at floor-level: the lowest point possible. Before performing maintenance in areas where refrigerants could have accumulated, a thorough assessment must be carried out in order to determine whether respiratory protection is required.

It is worth noting that within the field of RAC, there have been more fatalities associated with oxygen displacement than with any other aspect. It is essential to use appropriate breathing apparatus to retrieve someone who has lost consciousness.

Toxicological effects

All refrigerants have some toxicological effects, primarily when inhaled, but also if they are ingested or come into contact with skin or other body parts. Normally, the various toxicological effects are considered according to the potentially dangerous concentrations, and for each substance, maximum concentrations are issued.

Many countries tend to have their own criteria, definitions and allowable concentrations. However, across most countries, there are two values, which are based on exposure in the workplace:

- A long-term exposure limit, based on an 8-hour time weighted average reference period, and
- A short-term exposure limit, based on a 15-minute time weighted average reference period

The long-term exposure limit represents the allowable concentration that workers can be constantly exposed to during their working hours, without any adverse effects. The short-term exposure limit applies to the maximum concentrations that can be tolerated by most people in the event of a catastrophic release, where they need to make an emergency escape. Concentrations are normally specified in parts per million (ppm) or milligramme (mg) per m3.

These exposure limits have different names in different countries. For example, in the UK they are termed the Workplace Exposure Limits (WEL), in Japan, France and Germany they are Occupational Exposure Limits (OEL), in the USA they are Permissible Exposure

Limits (PEL), and the European Union employs two different values: Indicative Occupational Exposure Limit Values (IOELV) and Binding Occupational Exposure Limit Values (BOELV), depending upon the circumstances.

In general, it is important to check whether the products one intends to work with can be safely used in all of their considered applications and handled in accordance with manufacturer information. Whilst the toxicity of most refrigerants is low, the possibility of injury or death exists in unusual situations or if they are deliberately misused.

Exposure to refrigerant concentrations above the recommended exposure levels can result in loss of concentration, drowsiness, cardiac arrhythmia, and other symptoms, that can all lead to fatality. The allowable exposure levels for some of the alternative refrigerants are lower than those of the chlorofluorocarbons (CFCs). As mentioned before, skin should be protected; many fluorinated refrigerants and ammonia can irritate the skin and eyes.

Inhalation of concentrated refrigerant vapour is dangerous and can be fatal. If inhaled, the victim should be moved to an area with fresh air. If they are not breathing, they should be given artificial respiration, and if breathing is difficult, give oxygen. It is important to avoid stimulants, and do not give them adrenaline (epinephrine) because this can complicate possible effects on the heart. Medical help must be sought urgently.

Flammability and degradation products

A number of refrigerants are flammable under atmospheric conditions. Flammability means that if ignited with a flame or spark, they can sustain combustion. All hydrocarbon refrigerants are flammable, as are some hydrofluorocarbon (HFC) refrigerants. The refrigerants table in section 2 identifies those refrigerants which are flammable. The refrigerant supplier will also provide information relating to a refrigerants’ flammability.

Refrigerants table in Chapter 2 ▶

Depending upon the characteristics of a particular substance, the consequences of ignition can be severe, and therefore it is essential to take the appropriate precautions whenever designing, constructing or working on a system that uses flammable refrigerants.

Whilst many CFC, hydrochlorofluorocarbons (HCFCs) and HFC refrigerants are not flammable under normal conditions, they can become flammable when under pressure and mixed with air and/or oil. Because of this potential, the refrigerants should never be mixed with air in tanks or supply lines, or allowed to accumulate in storage tanks, and sources of ignition should also be avoided.

Even if the conditions are such that CFC, HCFC and HFC refrigerants are non-flammable, these substances will decompose at high temperatures such as those associated with gas flames or electric heaters.

The compounds that result under these circumstances always include hydrofluoric acid. If the compound contains chlorine, hydrochloric acid will also be formed, and if a source of water, (or oxygen), is present, a smaller amount of phosgene will be formed. Halogen acids have a very sharp, stinging effect on the nose and if they are detected, the area should be evacuated until the air has been cleared of decomposition products.

Important safety procedures

Before working with a refrigerant, information and appropriate rules of conduct should be sought:

- Personnel who handle refrigerants should be properly trained in their safe use and handling.
- Personnel should have reviewed the material safety data sheet (MSDS) for the refrigerant used.
- Personnel must not smoke, braze, or weld when refrigerant vapour is present. Refrigerants can either ignite, or decompose to produce harmful, corrosive and toxic substances when exposed to an open flame or hot surface.

There are a number of aspects that technicians should always be aware of whilst handling refrigerants.

Personal protection ▶
Ensuring a safe work area ▶
Safe working with a system ▶
Handling refrigerant cylinders ▶

Personal protection

Prior to working on a system, or handling refrigerant, technicians should be adequately equipped with the appropriate safety equipment:

- Check the MSDS for the refrigerant, lubricant and other substances in order to determine the proper level of protection required.
- Wear safety goggles and gloves at all times when handling refrigerants or servicing a refrigeration system.

> Wear the proper respiratory protection while working with refrigerants. Inhalation of refrigerants can cause intoxication, induce anaesthetic effects, cause stumbling, shortness of breath, tremors, convulsions, and the heart to cease functioning properly and may be fatal.

Ensuring a safe work area

Before working with a refrigerant, the local area must be prepared accordingly in case of an accidental release:

- Proper ventilation or respiratory protection is required for any work on equipment in an enclosed area where a leak is suspected.
- Always ventilate or test the atmosphere of an enclosed area before beginning work. Many refrigerants which may be undetectable by human senses are heavier than air and will replace the oxygen in an enclosed area causing loss of consciousness.
- Evacuate the area if a large spill occurs. Return only after the area has been properly ventilated.
- Always ventilate the work area before using open flames.

Safe working with a system

When working on a system, several basic considerations should be borne in mind:

- Always check for the correct operating pressure of the refrigerant used. Use gauges to monitor the system pressure.
- Charge the refrigerant into the low side of the system to avoid damaging the compressor, or causing the system to rupture.
- Refrigerant oil in a hermetic compressor is often very acidic causing severe burns. Avoid skin contact with this oil.

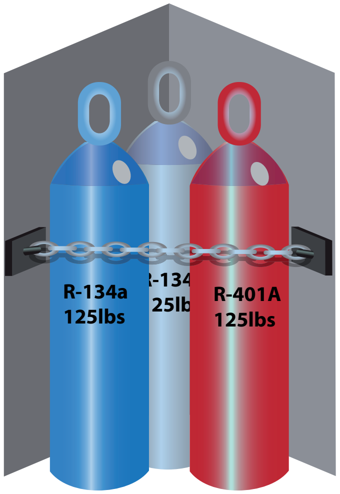
- Never cut or drill into any refrigeration system, without first removing the refrigerant. The high pressure refrigerant will be released rapidly and have serious consequences.
- Ensure that all refrigerant is removed from the system and the pressure has been brought up to atmospheric pressure with oxygen-free dry nitrogen before disassembling a system.
- When soldering, brazing, or welding on refrigeration lines, the lines should be continuously purged with low pressure oxygen-free dry nitrogen. Cylinders, transfer lines and other equipment used with refrigerants should not be exposed to high temperature sources, such as welding, brazing and open flames.
- Following work, the system parts should only be pressure tested with nitrogen.
- Never pressurise systems or vessels containing refrigerants with air for leak testing or any other purpose.
- Before transferring refrigerant, verify that the hoses are properly connected to the system and cylinders.
- Open cylinder valves, hose valves and manifold valves slowly and steadily.
- Verify that the system has been completely evacuated with a vacuum pump before cutting any lines.
- Before welding or brazing, evacuate the equipment and then break the vacuum with oxygen free dry nitrogen. Do not perform any repair on pressurised equipment.
- Whenever using nitrogen cylinders, ensure that the correctly rated regulator is used, and the setting does not exceed the maximum working pressure of the system being worked on.

Handling refrigerant cylinders

Refrigerant cylinders tend to be transported widely and subjected to a variety of conditions. For these reasons it is important to ensure that they are handled carefully to avoid severe consequences:

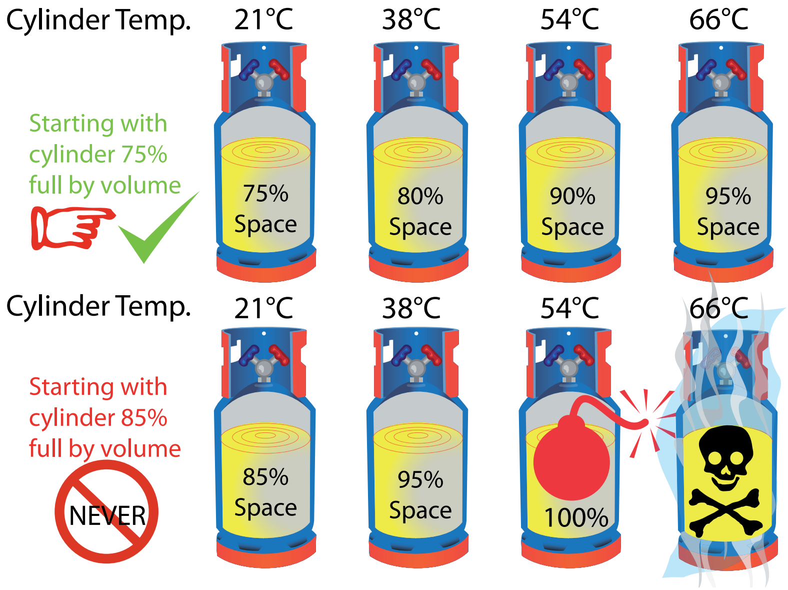
- Always store and transport refrigerant cylinders in upright position to keep the pressure relief valve in contact with the vapour space.
- Do not throw or drop refrigerant cylinders during transportation, and never permit them to strike each other violently.
- Do not apply direct heat to refrigerant cylinder while charging a system to maintain inside pressure; a warm water bath should be used for that purpose.
- Keep the cylinder cap on the cylinder at all times unless the cylinder is in use.
- When refrigerant is discharged from a cylinder, immediately weigh the cylinder, and record the weight of the refrigerant remaining in the cylinder.
- Ensure only regulators and pressure gauges designed for the particular refrigerant in the cylinder are used, and do not use different refrigerants in the same regulator or gauges. Never attempt to repair cylinders or valves.
- Never use a lifting magnet or a sling. A crane may be used when a safe cradle is provided to hold the cylinders.
- Never use cylinders for any other purpose than to carry refrigerants.
- Never tamper with cylinder valves or pressure relief devices, or other safety devices.

- Never force connections that do not fit. Ensure the cylinder valve outlet threads are the same as what is being connected to it.
- **Cylinders should always be stored upright, and larger cylinders should be chained in place to avoid falling as shown here:**



- It is preferable to store cylinders within a secured cage.
- Cylinders stored in the open must be protected from extremes of weather and direct sunlight.
- Never expose cylinders to continuous dampness, salt water, or spray. They should be kept in a cool, dry and properly ventilated storage area, away from heat, flames, corrosive chemicals, fumes and explosives, and be otherwise protected from damage.
- Cylinders should never be exposed to temperature above 52°C.
- Store full and empty cylinders apart to avoid confusion. They must be clearly marked.
- Store cylinders secured and upright in an area where they will not be knocked over or damaged, and never store cylinders near elevators or gangways, or near highly flammable substances.
- **Refrigerant cylinders should never be filled over 80% of their capacity because the liquid expansion may cause the cylinder to burst – as shown in this illustration:**

- Always check the refrigerant number before charging to avoid mixing refrigerants.
- Check the cylinder stamp to ensure the cylinder is safe. Inspect refrigerant cylinders regularly. Do not use the cylinders if they show signs of rust, distortion, denting, or corrosion.
- Never refill disposable cylinders with anything. Do not use disposable refrigerant cylinders as compressed air tanks.
- Any evidence of a leak, visual or by a leak detector must be corrected immediately, by either stopping the leak or transferring all products from the leaking container into a secure container to allow for repairs.



Effect of temperature on liquid volume inside a cylinder

Safe handling of flammable refrigerants

Whilst hydrocarbons are very good refrigerants, their flammability means that their use need to be considered carefully. Safety and legislative issues need to be fully understood. The use of hydrocarbons has been widespread in the European domestic refrigeration market since the mid-nineties.

The following steps will help:

- **Manuals and instructions** ▶
- **General Approach to hydrocarbon refrigerant handling** ▶
- **Safety check of the working area** ▶
- **Safety check of the refrigeration equipment** ▶
- **Safety checks to electrical devices** ▶
- **Detection of hydrocarbon refrigerants** ▶
- **Breaking into a system and removal of refrigerant** ▶
- **Charging of refrigerant** ▶
- **Cylinder handling** ▶
- **Storage of cylinders** ▶

Manuals and instructions

Before handling hydrocarbon refrigerants be aware of detailed information to be provided in manuals for the installation, service and operation (be they separate or combined manuals). The manuals will include all the relevant information about the equipment, such as the maximum refrigerant charge, the minimum rated airflow if required, the minimum floor area of the room or any other special requirements, as well as all the corresponding warnings. Importantly, they must all provide the necessary information and instructions for the correct handling of flammable refrigerants and associated equipment, refrigerant detection, charging, equipment decommissioning, removal, recovery and storage of the refrigerant, and aspects related to ensuring the integrity of the protection for electrical components.

Only competent professionals trained in the use of flammable refrigerants are permitted to open equipment housing or to break into the refrigerant circuit, and the maintenance and repair requiring the assistance of another skilled person should be carried out under the supervision of the competent individual.

General Approach to hydrocarbon refrigerant handling

Any equipment used in the process of repair must be suitable for use with flammable refrigerants.

All tools and equipment (including measuring equipment) are to be checked for suitability for working on the equipment, particular attention is to be paid to the selection of:

- Refrigerant recovery units
- Refrigerant leak testing units
- Electrical test meters
- Refrigerant recovery cylinders
- Portable lighting.

If the installation permits, it is recommended that the equipment be removed from its existing position to a controlled workshop environment suitable for the type of repair where work can be conducted safely.

Safety check of the working area

Prior to beginning work on systems containing hydrocarbon refrigerants, safety checks are necessary to ensure that the risk of ignition is minimised.

For repair to the refrigerating system prior to conducting work on the system, the following precautions shall be complied with:

- Work shall be undertaken under a controlled procedure so as to minimise the risk of a flammable gas or vapour being present while the work is being performed.
- All maintenance staff and others working in the local area should be instructed as to the nature of work being carried out.
- Work in confined spaces must be avoided. The area around the workspace is to be sectioned off.
- Ensure that the conditions within the area have been made safe by the control of flammable material.
- The area shall be checked with an appropriate refrigerant detector prior to and during work to ensure that the technician is aware of potentially flammable atmospheres. Ensure that the

leak detection equipment being used is suitable for use with flammable refrigerants, i.e. non-sparking, adequately sealed or intrinsically safe.

- If any hot work is to be conducted on the refrigeration equipment or any associated parts, appropriate fire extinguishing equipment shall be available to hand. Have a dry powder or carbon dioxide fire extinguisher adjacent to the charging area.
- No person carrying out work in relation to a refrigeration system which involves exposing any pipe work which contains or has contained flammable refrigerant shall use any sources of ignition in such a manner that it may lead to the risk of fire or explosion.
- All possible ignition sources, including cigarette smoking, should be sufficiently far away from the site of installation, repairing, removing and disposal during which flammable refrigerant can possibly be released to surrounding space. Prior to work taking place, the area around the equipment is to be surveyed to establish any flammable hazards or ignition risks. Display “No Smoking” signs.
- Ensure that the area is in the open or that it is adequately ventilated before breaking into the system or conducting any hot work. A degree of ventilation should continue during the period that the work is carried out. The ventilation should safely disperse any released refrigerant and preferably expel it externally to the atmosphere.

Safety check of the refrigeration equipment

Where electrical components are being changed, they are to be “fit for purpose”, and to the correct specification. At all times the manufacturer’s maintenance and service guidelines are to be followed. If in doubt consult the manufacturer’s technical department for assistance.

The following checks should be applied to installations using flammable refrigerants:

- That the charge size is in accordance with the room size within which the refrigerant containing parts are installed. Hydrocarbon charge sizes are typically 40% to 50% of CFC, HCFC and HFC charge sizes.
- That ventilation machinery and outlets are operating adequately and not obstructed.
- Confirm the operation of equipment such as refrigerant leak detectors and mechanical ventilation systems.
- If an indirect refrigerating circuit is being used, the secondary circuit should be checked for the presence of refrigerant.
- Ensure that marking to the equipment continues to be visible and legible. Marking and signs that are worn should be corrected.
- Check that refrigeration pipe or components are not installed in a position where they are likely to be exposed to any substance which may corrode refrigerant-containing components, unless the components are constructed of materials which are inherently resistant to being corroded or are suitably protected against corrosion.

Safety checks to electrical devices

Repair and maintenance to electrical components shall include initial safety checks and component inspection procedures. If a fault exists that could compromise safety, then no electrical supply should be connected to the circuit until it is satisfactorily dealt with. If the fault cannot be corrected immediately but it is necessary to continue operation, an adequate temporary solution shall be used, but this must be reported to the owner of the equipment so all parties are aware.

Initial safety checks should be as follows:

- Ensure that capacitors are discharged. This should be done in a safe manner to avoid the possibility of sparking.
- Do not work on “live” electrical components and wiring whilst charging, recovering or purging the system.
- Continuity of earth bonding.

During repairs to sealed components, all electrical supplies must be disconnected from the equipment being worked upon prior to any removal of sealed covers, etc. If it is absolutely necessary to have an electrical supply to equipment during servicing, then a permanently operating form of leak detection shall be located at the most critical point to forewarn the individual of a potentially hazardous situation.

For repairs to sealed components, particular attention should be paid to the following:

- Ensure that by working on electrical components, the casing is not altered in such a way that the level of protection is affected. This should include damage to cables, too many connections, terminals not made to the original specification, damage to seals, incorrect fitting of glands, etc. This includes the secure mounting of the apparatus.
- Ensure that seals or sealing materials have not degraded such that it is no longer serving the purpose of preventing the ingress of flammable atmospheres.
- Replace only with parts specified by the manufacturer. Other parts may result in the ignition of refrigerant in the atmosphere from a leak.

Check that cabling will not be subject to wear corrosion, excessive pressure, sharp edges or any other adverse environmental effects. This should also take into account the effects of ageing or continual vibration from sources such as the compressor or fans.

Detection of hydrocarbon refrigerants

Under no circumstances should potential sources of ignition be used in the searching or detection of refrigerant leaks. A halide torch (or any other detector using a naked flame) must not be used.

The following leak detection methods can be used on systems containing hydrocarbons:

- Electronic leak detectors may be used to detect hydrocarbons, but the sensitivity may not be adequate, or may need calibration (detection equipment should be calibrated in a refrigerant-free area). Ensure that the detector is not a potential source of ignition and is suitable for hydrocarbon refrigerants.

- Leak detection equipment should be set at a percentage of the LFL of the refrigerant and should be calibrated to the refrigerant employed and the appropriate percentage of gas (25% maximum) is confirmed.
- Leak detection fluids are suitable for use with hydrocarbon refrigerants but the use of detergents containing chlorine should be avoided as the chlorine may react with the refrigerant and corrode the copper pipework.
- Oil additives such as those used in fluorescent leak detection systems will operate with hydrocarbons.
- If a leak is suspected from a hydrocarbon refrigerant system all naked flames should be removed or extinguished.

If a leakage of refrigerant is found which requires brazing, all of the refrigerant shall be recovered from the system, or isolated (by means of shut off valves) in a part of the system remote from the leak. Oxygen Free Nitrogen (OFN) should then be purged through the system both before and during the brazing process.

Breaking into a system and removal of refrigerant

When breaking into the refrigerant circuit to make repairs - or for any other purpose – conventional procedures are used. However, it is important that best practice is followed since flammability is now a consideration.

The following procedure shall be adhered to:

- remove the refrigerant
- purge the circuit with inert gas
- evacuate
- purge again with inert gas
- open the circuit by cutting or brazing.

The refrigerant charge should be recovered into the correct recovery cylinders. The system is then to be “flushed” with OFN to render the unit safe; this process may need to be repeated several times. Do not use compressed air or oxygen for this task.

Flushing is achieved by breaking the vacuum in the system with OFN and continuing to fill until the working pressure is achieved, then venting to the atmosphere, and finally pulling down to a vacuum. This process is repeated until the technician is satisfied that no hydrocarbons are within the system.

When the final OFN charge is used, the system can be vented down to atmospheric pressure to enable work to take place. This operation is absolutely vital if brazing operations on the pipe work are to take place. Ensure that the outlet for the vacuum pump is not close to any ignition sources and ventilation is available.

Charging of refrigerant

The charging of refrigeration systems with hydrocarbon refrigerants is similar to those using halocarbon refrigerants. As with all blend refrigerants, hydrocarbon refrigerant blends should also be charged in the liquid phase in order to maintain the correct composition of the blend.

The following additional requirements should be adhered to:

- Ensure that contamination of different refrigerants does not occur when using charging equipment. Hoses or lines are to be as short as possible to minimise the amount of refrigerant contained in them.
- Cylinders must be kept upright.
- Charge the refrigerant in the liquid phase.
- Ensure that the refrigeration system is earthed prior to charging the system with refrigerant.
- Label the system when charging is complete. The label should state that hydrocarbon refrigerants have been charged into the system and that it is flammable. Position the label in a prominent position on the equipment.
- Extreme care shall be taken not to overfill the refrigeration system. Hydrocarbon charge sizes are typically 40% to 50% of CFC, HCFC and HFC charge sizes.
- The system must be leak tested on completion of charging.

Cylinder handling

Safe cylinder handling differs little from other refrigerant cylinders which are as follows:

- Do not remove or obscure the official labelling on a cylinder.
- Always refit the valve cap when the cylinder is not in use.
- Use and store cylinders in an upright position.
- Check the condition of the thread and ensure that it is clean and not damaged.
- Store and use cylinders in dry, well-ventilated areas remote from fire risk.
- Do not expose cylinders to direct sources of heat such as steam or electric radiators.
- Do not repair or modify cylinders or cylinder valves.
- Always use a proper trolley for moving cylinders even for a short distance – never roll cylinders long the ground.
- Take precautions to avoid oil, water and foreign matter entering the cylinder.
- If it is necessary to warm the cylinder, use only warm water or air, not naked flames or radiant heaters. The temperature of the water or air must not exceed 40°C.
- Always weigh the cylinder to check if it is empty – its pressure is not an accurate indication of the amount of refrigerant that remains in the cylinder.
- Use only dedicated recovery cylinders for the recovery of hydrocarbon refrigerants.

Storage of cylinders

Refrigerant cylinders should be stored taking into account the following precautions:

- Cylinders should be preferably stored outside and never stored in residential premises.
- Cylinders may be stored in commercial and industrial premises according to the following guidelines for storage.
- Quantities stored are to be restricted to no more than 70 kg and stored in specific dedicated areas or cages.
- Access to storage areas restricted to ‘authorised persons only’, and such places shall be marked with notices prohibiting smoking and the use of naked flames.
- Cylinders containing hydrocarbon refrigerants should be stored at ground level, never in cellars or basements. Cylinders should be readily accessible, and stored upright.

Safe handling of ammonia (NH3, R717)

The safety classification of R717 is lower flammability and higher toxicity. In general, it is fairly difficult to ignite, and even then, it does not easily sustain a flame. Nevertheless, due to its flammable nature, it should be treated as such.

Safe handling of flammable refrigerants ▶

R717 is also a higher toxicity refrigerant, and for this reason, extra caution should be taken. Because of its affinity for water, R717 will attack any moist body parts such as armpits, eyes, throat and groin at relatively low concentrations. Its strong odour is detectable by most people at 2 to 5 ppm. Low temperatures increase the sensitivity to the presence of ammonia. High humidity reduces the level at which ammonia is perceived.

You can review:

Recommendations for exposure ▶
Safety procedure guidelines ▶

Physiological effects of different R717 concentrations (IOR, 2005)

Concentration	Effect on unprotected human body	Exposure Limits
20 ppm	Smell readily detected by most people	Unlimited
25 ppm	HSE long term exposure limit	8hrs per day 5 days per week
35 ppm	HSE short term exposure limit	15mins per day not more than 1 hour per week
50 ppm	Smell is distinctive and may be irritating	Do not stay longer than necessary
70 ppm	No dangerous effects on healthy people	Leave the area
400 – 700 ppm	Immediate irritation to eyes, nose, throat and respiratory system.	Under normal circumstances no serious injury in 1 hour
1700 ppm	Severe coughing, cramp, serious irritation to nose, eyes, throat and respiratory system	30 mins exposure can lead to serious injury
2000 – 5000 ppm	Severe coughing, cramp, serious irritation to nose, eyes, throat and respiratory system	30 mins exposure can lead to death
5000 ppm	Respiratory spasm, rapid asphyxia	Lethal within a few minutes

Recommendations for exposure

If you do come into physical contact with ammonia, you should administer the following first aid, and seek immediate medical attention:

Skin contact: Remove contaminated clothing. Drench with large quantities of water and continue to wash affected skin areas for at least 20 – 30 minutes, and use safety shower if available. In the case of freeze burns, clothing may adhere to the skin, in which case, immerse the affected area in comfortably warm water to defrost.

Eye contact: Flood eyes with clean tap water for at least 20 – 30 minutes followed by immediate medical attention.

Ingestion: Rinse mouth with water and give plenty to drink. Do not induce vomiting but seek medical attention immediately.

Inhalation: Remove the patient to fresh air immediately. Remove contaminated clothing and keep the patient warm and rested. Seek medical assistance immediately. The patient must be kept under observation for at least 48 hours after exposure as delayed pulmonary oedema may develop.

Safety procedure guidelines

In order to be able to respond to a release of R717, the following should be adhered to:

- Escape routes should be known and must be free from obstacles.
- Suitable personal protective equipment including gloves and goggles must be worn at all times.
- Ensure that breathing apparatus and/or respirator masks are available and close to hand. It is good practice for engineers to wear their respirator mask loose around the neck when carrying out any works other than visual inspections.
- Fire-fighting equipment should be accessible within the machinery room.
- Work should only commence on equipment after carrying out a full and approved risk assessment plus a method statement so that “everyone” is aware of what works are being undertaken and by whom.
- Only qualified or experienced engineers should work on ammonia systems.
- If carrying out works other than routine checks then engineers should work in pairs.

Due to the widespread use of ammonia throughout industry, many countries have specific laws relating to its use and handling.

It is important to check national regulations with respect to the following:

- General health and safety legislation
- National and international refrigeration safety standards
- Codes of practice issues by trade bodies and institutes
- Rules for storage and handling of hazardous materials.

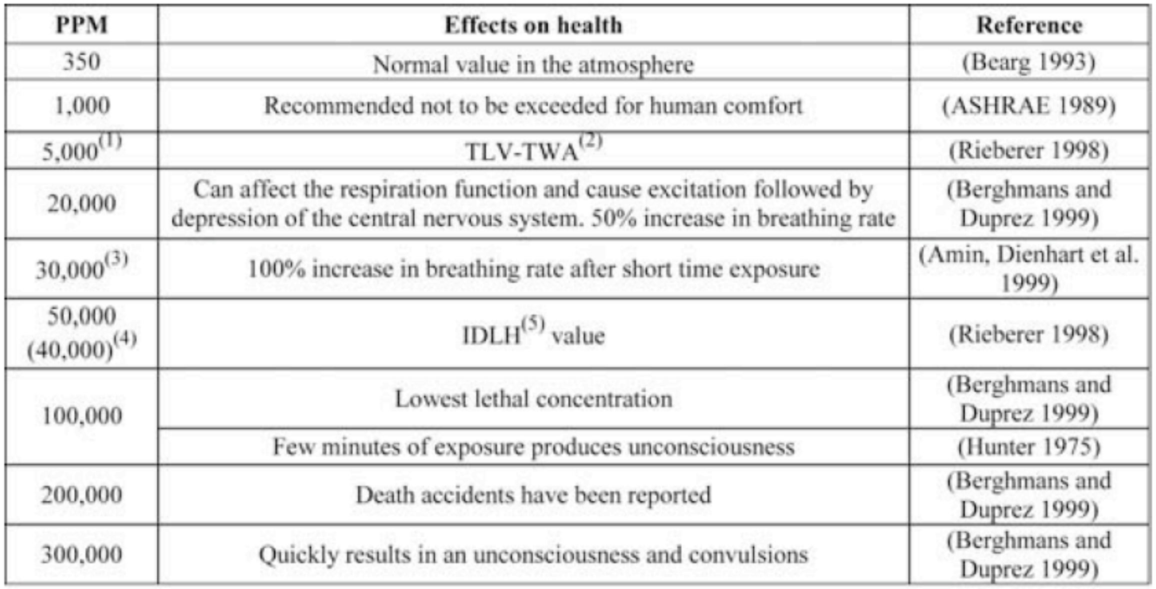
Safe handling of carbon dioxide (CO2, R744)

CO2 is a relatively safe refrigerant compared to natural and artificial working fluids. It is classified in group A1, which are the refrigerants with low toxicity and non-flammable, according to ASHRAE Handbook-Fundamentals and ISO 817: 2005, which is the international standard for refrigerant safety classification. A1 is the group that contains the refrigerants that are least hazardous and without an identified toxicity at concentrations below 400 ppm. Naturally, CO2 exists in the atmosphere at concentrations around 350 ppm and for concentrations between 300 and 600 PPM people do not usually notice the difference.

According to ASHRAE, a CO2 concentration of 1000 ppm is the recommended limit to satisfy comfort for the occupants, where in a CO2 controlled ventilation system fresh air should be supplied so that the CO2 concentration level will not exceed this value. This is the case of an application when a small CO2 generation rate is expected due to different human activities.

However, in the case of high leakage rate that might occur in supermarket space or in the machine room, the consequences of serious health hazards, such as suffocation, must be taken into account.

Different concentrations of CO2 and the expected health consequences (GTZ2008)



PPM	Effects on health	Reference
350	Normal value in the atmosphere	(Bearg 1993)
1,000	Recommended not to be exceeded for human comfort	(ASHRAE 1989)
5,000(1)	TLV-TWA(2)	(Rieberer 1998)
20,000	Can affect the respiration function and cause excitation followed by depression of the central nervous system. 50% increase in breathing rate	(Berghmans and Duprez 1999)
30,000(3)	100% increase in breathing rate after short time exposure	(Amin, Dienhart et al. 1999)
50,000 (40,000)(4)	IDLH(5) value	(Rieberer 1998)
100,000	Lowest lethal concentration	(Berghmans and Duprez 1999)
	Few minutes of exposure produces unconsciousness	(Hunter 1975)
200,000	Death accidents have been reported	(Berghmans and Duprez 1999)
300,000	Quickly results in an unconsciousness and convulsions	(Berghmans and Duprez 1999)

1 - The Occupational Safety and Health Administration (OSHA) revised Permissible Exposure Limit (PEL): Time-Weighted Average (TWA) concentration that must not be exceeded during any 8 hour per day 40 hour per week.

2 - Threshold Limit Value (TLV): TWA concentration to which one may be repeatedly exposed for 8 hours per day 40 hours per week without adverse effect.

3 - Short Term Exposure Limit (STEL): a 15-minute TWA exposure that should not be exceeded at any time during a workday.

4 - National Institute for Occupational Safety and Health (NIOSH) revised Immediately Dangerous to Life or Health (IDLH) value.

5 - IDLH: maximum level for which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects.

CO2 has a main drawback of not being self-alarming by lacking a distinctive odour or colour. This implies that facilities where CO2 may leak must be equipped with sensors that trigger alarm when the concentration level exceeds 5000 ppm, above which CO2 concentration may have effect on health. CO2 is heavier than air and therefore will collect close to the floor when it leaks; thus, the sensors and the ventilators in the space where CO2 might leak should be located close to the floor.

In case of component rupture, the fact that CO2 has relatively high operating pressure compared to other refrigerants raises questions concerning the hazards of blast effects, shocks and flying fragments. The sudden depressurization leads to explosive vaporization and a transient overpressure peak that may burst the vessel. The explosive energy per kg for CO2 is high compared to R22. However, when the comparison is made for ductless residential air conditioning system with equal cooling or heating capacities and similar efficiencies then owing to the smaller volume and refrigerant charge of the CO2 system, the actual explosive energies are in the same range. In the supermarket system the expected explosive energy may be higher than the cases with conventional systems. This is due to the presence of the accumulation tank in most of the CO2 system solutions which increases the system's charge and volume.

However, the explosive energy is more of a concern with systems where the occupants are close to the system's components; such as mobile air conditioning (MAC) and residential air conditioning. In supermarket systems the high pressure components are in the machine room and the distribution lines are usually kept in a distance from the consumers.

Further reading

UK Institute of Refrigeration Service Engineers' Section - *Datasheet 16 "Ammonia Safety", 2005*

UK Institute of Refrigeration Service Engineers' Section – *Assessment for Save Handling of Refrigerants, 2006*

- **www.ior.org.uk/ior_/images/pdf/serv%20matters%209-%20ref%20assessments.pdf**

European Fluorocarbon Technical Committee – *an association of fluorocarbon producers in Western Europe under the umbrella of CETIC, References on Refrigeration Fluids and Safety*

- **www.fluorocarbons.org/en/debate/safety_aspects/references_on_refrigeration_fluids_and_safety.html**

UK Air Conditioning and Refrigeration Industry Board - *Guidelines for the Use of Hydrocarbon Refrigerants in Static RAC Systems*

- **http://www.acrib.org.uk/web_images/documents/technical_updates/Use%20of%20Hydrocarbon%20Refrigerants%20Guidelines.pdf**

Air Conditioning and Refrigeration Guide

- **http://www.air-conditioning-and-refrigeration-guide.com/**

UK Institute of Refrigeration Service Engineers' Section - *Safety Code of Practice for Ammonia Refrigeration Systems, 2009*

- **http://www.ior.org.uk/**

Glossary

Absolute pressure
The actual pressure, where a true vacuum is the zero value, and so atmospheric pressure is approximately 1.013 bar.

Accumulator
A vessel capable of holding liquid refrigerant and permanently connected between the exit of the evaporator and suction of the compressor.

Air-conditioning
It is the process of controlling temperature, humidity, composition, and distribution of air for the purpose of human comfort or for special technical need of a industrial process (pharmaceutical, textile, etc.) or other application.

Article 2 countries
Parties to the Montreal Protocol that do not operate under Article 5. “Article 2 countries” refer to developed countries.

Article 5 countries
Developing country Parties to the Montreal Protocol whose annual per capita consumption and production of ozone depleting substances (ODS) is less than 0.3 kg to comply with the control measures of the Protocol, are referred to as Article 5 countries. Currently, 147 of the 196 Parties to the Montreal Protocol meet these criteria. Article 5 countries are eligible to receive technical and financial assistance from the Multilateral Fund Secretariat, as per Article 10 of the Protocol.

Atmospheric lifetime
A measure of the average time that a molecule remains intact once released into the atmosphere.

Atmospheric pressure
Also known as barometric pressure. It is the pressure exerted by the atmosphere above the surface of the Earth. Standard sea level pressure is a unit of pressure and, by definition, equals 1 atmosphere (atm) or 101.35 kPa.

Azeotrope
A blend consisting of one or more refrigerants of different volatilities that does not appreciably change in composition or temperature as it evaporates (boils) or condenses (liquefies) under constant pressure. Refrigerant blends assigned an R5xx series number designation by ISO 817 are azeotropes.

Banks
The total amount of substances contained in existing equipment, chemical stockpiles, foams and other products not yet released to the atmosphere.

Blends (mixtures)
A mixture of two or more pure fluids. Blends are used to achieve properties that fit many refrigeration purposes. For example, a mixture of a high pressure and a low pressure substance mixed in order to match the pressure of another substance. Blends can be divided into two categories: azeotropic, and zeotropic blends.

Boiling point
The temperature of a liquid at the point it starts to vaporize (see NBP).

Brazed joint
A joint obtained by the joining of metal parts with alloys which melt at temperatures in general higher than 450°C but less than the melting temperatures of the joined parts

Bubble point
Liquid saturation temperature of a refrigerant at the specified pressure; the temperature at which a liquid refrigerant first begins to boil.

Cascade system
Two or more independent refrigeration circuits where the condenser of one system rejects heat directly to the evaporator of another.

Chlorofluorocarbons (CFCs)
Halocarbons containing only chlorine, fluorine and carbon atoms. CFCs are both ozone depleting substances and greenhouse gases.

Climate change
Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or

external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that Article 1 of the Framework Convention on Climate Change (UNFCCC) defines ‘climate change’ as ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability, observed over comparable time periods’. The UNFCCC thus makes a distinction between ‘climate change’ attributable to human activities altering the atmospheric composition, and ‘climate variability’ attributable to natural causes.

Coefficient of Performance (COP)
A measure of the energy efficiency of a refrigerating system. The ratio of useful effect (heat) to the work supplied. The useful effect is the cooling rate in the case of RAC systems, and it is the heating rate in the case of heat pumps. The COP is primarily dependant on the working cycle and the temperature levels (evaporating/ condensing temperature) as well as on the properties of the refrigerant, system design and size.

Coil
A part of the refrigerating system constructed from bent or straight pipes or tubes suitably connected and serving as a heat exchanger (evaporator or condenser).

Competence
The ability to perform satisfactorily the activities within an occupation.

Compressor
A device for mechanically increasing the pressure of a refrigerant vapour.

Condenser
A heat exchanger in which vaporised refrigerant is liquefied by removal of heat

Condensing unit
A combination of one or more compressors, condensers, liquid receivers (when required) and the regularly furnished accessories.

Containment
The application of service techniques or special equipment designed to preclude or reduce loss of refrigerant from equipment during installation, operation, service or disposal of refrigeration and air-conditioning equipment.

Controlled substance
Under the Montreal Protocol, any ozone depleting substance that is subject to control measures, such as a phase-out requirement.

Destruction
Destruction of ozone depleting substances or their mixtures by approved destruction plants.

Dew point
Vapour saturation temperature of a refrigerant at the specified pressure; the temperature at which a vapour refrigerant first begins to condense.

Disposal
Conveying a product to another party, usually for destruction.

Drop-in replacement
The procedure for replacing CFC refrigerants with non-CFC refrigerants in existing refrigerating, air-conditioning and heat pump plants without doing any plant modifications. However, drop-in procedures are normally referred to as retrofitting because plants need minor modifications, such as the change of lubricant, and the replacement of the expansion device and the desiccant material.

Emissions
The release of gases or aerosols into the atmosphere over a specified area and period of time.

Evaporator
A heat exchanger in which liquid refrigerant is vaporized by absorbing heat from the substance to be cooled.

Expansion device
A device, such as an expansion valve, expansion orifice, turbine or capillary tube, that is used to control the mass flow of a refrigerant from the high-pressure side to the low-pressure side of a refrigeration system.

Fluorocarbons
Halocarbons containing fluorine atoms, including chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons and perfluorocarbons.

Fossil fuels
Carbon-based fuels derived from geological (fossil) carbon deposits. Examples include coal, oil and natural gas.

Fractionation
The change in composition of a refrigerant mixture by e.g. evaporation of the more volatile component(s) or condensation of the less volatile component(s).

Gauge pressure
The pressure for which the value is equal to the difference between the absolute pressure and atmospheric pressure.

Global warming potential (GWP)
An index comparing the climate impact of an emission of a greenhouse gas relative to that of emitting the same amount of carbon dioxide. GWP is determined as the ratio of the time integrated radiative forcing arising from a pulse emission of 1 kg of a substance relative to that of 1 kg of carbon dioxide, over a fixed time horizon.

Greenhouse effect
Greenhouse gases in the atmosphere effectively absorb the thermal infrared radiation that is emitted by the Earth's surface, by the atmosphere itself, and by clouds. The atmosphere emits radiation in all directions, including downward to the Earth's surface. Greenhouse gases trap heat within the surface troposphere system and raise the temperature of the Earth's surface. This is called the natural greenhouse effect. An increase in the concentration of greenhouse gases leads to increased absorption of infrared radiation and causes a radiative forcing, or energy imbalance, that is compensated for by an increase in the temperature of the surface-troposphere system. This is the enhanced greenhouse effect.

Greenhouse gases (GHGs)
The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation within the spectrum of the thermal infrared radiation that is emitted by the Earth's surface, by the atmosphere and by clouds. This property causes the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide, nitrous oxide, methane and ozone. Moreover, there are a number of entirely anthropogenic greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances that are covered by the Montreal Protocol. Some other trace gases, such as sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons , are also greenhouse gases.

Halocarbons
Chemical compounds containing carbon atoms, and one or more atoms of the halogens chlorine, fluorine, bromine or iodine. Fully halogenated halocarbons contain only carbon and halogen atoms, whereas partially halogenated halocarbons also contain hydrogen atoms. Halocarbons that release chlorine, bromine or iodine into the stratosphere cause ozone depletion. Halocarbons are also greenhouse gases. Halocarbons include chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, perfluorocarbons and halons.

Halogens
A family of chemical elements with similar chemical properties that includes fluorine, chlorine, bromine and iodine.

Heat
It is a form of energy that transferred from one place to another owing to a temperature difference between them. Heat could be transferred from one form of energy to another.

Heat exchanger
A part of the refrigerating system used for transferring heat across a boundary, including the condenser, evaporator, and intercoolers.

Hermetic
An airtight sealed system.

Hermetic compressor
A combination of a compressor and electrical motor, both of which are enclosed in the same housing, with no external shaft or shaft seals, the electrical motor operating in a mixture of oil and refrigerant vapour.

High pressure side
The part of a refrigerating system operating at approximately the condenser or gas cooler pressure.

Hydrocarbons (HCs)
Chemical compounds consisting of one or more carbon atoms surrounded only by hydrogen atoms.

Hydrochlorofluorocarbons (HCFCs)
Halocarbons containing only hydrogen, chlorine, fluorine and carbon atoms. Because HCFCs contain chlorine, they contribute to ozone depletion. They are also greenhouse gases.

Hydrofluorocarbons (HFCs)
Halocarbons containing only carbon, hydrogen and fluorine atoms. Because HFCs contain no chlorine, bromine or iodine, they do not deplete the ozone layer. Like other halocarbons they are potent greenhouse gases.

Isolating valve
A valve which prevent flow in either direction when closed.

Joint
A connection made between two parts.

Kyoto Protocol
The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Third Session of the Conference of the Parties (COP) to the UNFCCC in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol agreed to reduce their anthropogenic greenhouse-gas emissions (specifically carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by at least 5% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol entered into force on 16 February 2005.

Latent heat
It is the amount of heat needed to change the phase of a pure substance where temperature remains constant.

Liquid receiver
A vessel permanently connected to a system by inlet and outlet pipes for accumulation of liquid refrigerant.

Low pressure side
The part of a refrigerating system operating at approximately the evaporator pressure.

Machinery room
A completely enclosed room or space, vented by mechanical ventilation and only accessible to authorized persons, which is intended for the installation of components of the refrigerating system or of the complete refrigerating system. Other equipment may also be installed provided it is compatible with the safety requirements for the refrigerating system.

Maintenance
All kinds of work that may be performed by a maintenance technician, primarily related to ensuring the continued good operation and working of refrigeration systems, as well as record-keeping.

Materials safety data sheet (MSDS)
A safety advisory bulletin prepared by chemical producers for a specific refrigerant or compound.

Maximum allowable pressure
The maximum pressure for which the equipment is designed, as specified by the manufacturer.

Maximum working pressure
The maximum pressure for which the equipment is designed, as specified by the manufacturer.

Mobile system
A refrigerating system which is normally in transit during operation.

Montreal Protocol
The Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in September 1987. Following the discovery of the Antarctic ozone

hole in late 1985, governments recognized the need for firm measures to reduce the production and consumption of a number of CFCs (CFC-11, -12, -113, -114, and -115) and several Halons (1211, 1301, 2402). The Protocol was designed so that the phase-out schedules could be revised on the basis of periodic scientific and technological assessments. Following such assessments, the Protocol was adjusted to accelerate the phase-out schedules in 1990 (London), 1992 (Copenhagen), 1995 (Vienna), 1997 (Montreal), 1999 (Beijing) and again in 2007 in Montreal.

Multilateral Fund
Part of the financial mechanism under the Montreal Protocol. The Multilateral Fund was established by a decision of the Second Meeting of the Parties to the Montreal Protocol (London, June 1990) and began its operation in 1991. The main objective of the Multilateral Fund is to assist Article 5 parties to the Montreal Protocol whose annual per capita consumption and production of ODS is less than 0.3 kg to comply with the control measures of the Protocol.

Non-condensable gases
Gases with very low temperature boiling points, which are not easily condensed. Nitrogen and oxygen are the most common ones.

Normal boiling point (NBP)
The boiling point of a compound at atmospheric pressure (1.013 bar).

Occupied space
A completely enclosed space which is occupied for a significant period by people. The occupied space may be accessible to the public (for example supermarket) or only to trained persons (for example cutting up of meat). In an occupied space, both parts of a refrigerating system or the complete refrigerating system may be located/installed.

Open compressor
A compressor having a drive shaft penetrating the refrigerant-tight housing.

Ozone depletion
Accelerated chemical destruction of the stratospheric ozone layer by the presence of substances produced by human activities.

Ozone depleting potential (ODP)
A relative index indicating the extent to which a chemical product may cause ozone depletion compared with the depletion caused by R11. Specifically, the ODP of an ozone depleting substance is defined as the integrated change in total ozone per unit mass emission of that substance relative to the integrated change in total ozone per unit mass emission of R11.

Ozone layer
The layer in the stratosphere where the concentration of ozone is greatest. The layer extends from about 12 to 40 km. This layer is being depleted by anthropogenic emissions of chlorine and bromine compounds. Every year, during the Southern Hemisphere spring, a very strong depletion of the ozone layer takes place over the Antarctic region. This depletion is caused by anthropogenic chlorine and bromine compounds in combination with the specific meteorological conditions of that region. This phenomenon is called the Antarctic ozone hole.

Ozone
The triatomic form of oxygen (O3), which is a gaseous atmospheric constituent. In the troposphere it is created by photochemical reactions involving gases occurring naturally and resulting from anthropogenic activities (‘smog’). Tropospheric ozone acts as a greenhouse gas. In the stratosphere ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O2). Stratospheric ozone plays a major role in the stratospheric radiative balance. Its concentration is highest in the ozone layer.

Ozone depleting substances (ODS)
Substances known to deplete the stratospheric ozone layer. ODS controlled under the Montreal Protocol and its Amendments are chlorofluorocarbons, hydrochlorofluorocarbons, halons, methyl bromide, carbon tetrachloride, methyl chloroform, hydrobromofluorocarbons and bromochloromethane.

Perfluorocarbons (PFCs)
Synthetically produced halocarbons containing only carbon and fluorine atoms. They are characterized by extreme stability, non-flammability, low toxicity, zero ozone depleting potential and high global warming potential.

Phase-out
The ending of all production and consumption of a chemical controlled under the Montreal Protocol.

Piping
All pipes or tubes (including hoses, bellows, fittings, or flexible pipes) for interconnecting the various parts of a refrigerating system.

Power
It's the time rate of which work is done or energy is transferred.

Pressure relief device
A pressure relief valve or bursting disc device designed to relieve excessive pressure automatically.

Pressure relief valve
A pressure actuated valve held shut by a spring or other means and designed to relieve excessive pressure automatically by starting to open at a set pressure and re-closing after the pressure has fallen below the set pressure.

Push-pull method
A method for recovering and recycling refrigerant from a system using a negative pressure (suction) on one side to pull the old refrigerant out and pumping recycled refrigerant vapour to the other side to push the old refrigerant through the system.

Reclaim
Processing used refrigerants to new product specifications. Chemical analysis of the refrigerant determines that appropriate specifications are met. The identification of contaminants and required chemical analysis both are specified in national and international standards for new product specifications.

Reclamation
Reprocessing and upgrading of a recovered controlled substance through mechanisms such as filtering, drying, distillation and chemical treatment in order to restore the substance to a specified standard of performance. Chemical analysis is required to determine that appropriate product specifications are met. It often involves processing off-site at a central facility.

Recovery
The collection and storage in an external container, of controlled substances from machinery, equipment, containment vessels, etc., during servicing or prior to disposal without necessarily testing or processing it in any way.

Recycling
Reducing contaminants in used refrigerants by separating oil, removing non-condensables and using devices such as filters, driers or filter-driers to reduce moisture, acidity and particulate matter. The aim of recycling is to reuse the recovered refrigerant and normally involves recharge back into equipment and it often occurs on-site.

Refrigerant
A fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure and rejects heat at a higher temperature and a higher pressure usually involving changes of the state of the fluid.

Refrigerant detector
A sensing device which responds to a pre-set concentration of refrigerant gas in the environment.

Refrigerating system
A combination of interconnected refrigerant-containing parts constituting one closed refrigerant circuit in which the refrigerant is circulated for the purpose of extracting and rejecting heat (i.e. cooling, heating).

Refrigeration
It is the process of lowering the temperature of substance or a space to a desired temperature based on type of application.

Retrofit
The upgrading or adjustment of equipment so that it can be used under altered conditions; for example, of refrigeration equipment to be able to use an alternative refrigerant in place of a CFC, HCFC or HFC.

Saturated vapour pressure
The maximum vapour pressure of a substance at a given temperature when accumulated over its liquid state in a confined space.

Sealed system
A refrigerating system in which all refrigerant containing parts are made tight by welding, brazing or a similar permanent connection; it contains no non-permanent connections.

Secondary (or indirect) cooling system
A system employing a fluid which transfers heat from the product or spaces to be cooled or heated or from another cooling or heating system to the refrigerating system without compression and expansion of the fluid.

Semi-hermetic compressor
A combination consisting of a compressor and electrical motor, both of which are enclosed in the same housing, having removable covers for access, but having no external shaft or shaft seals, the electrical motor operating in a mixture of oil and refrigerant vapour.

Sensible heat
It is the amount of heat that causes a change in the temperature of substance without changing its phase. It can be evaluated by means of temperature reading device.

Servicing
All kinds of work that may be performed by a service technician, from installation, operations, inspection, repair, retrofitting, redesign and decommissioning of refrigeration systems to handling, storage, recovery and recycling of refrigerants, as well as record-keeping.

Shut-off device
A device to shut off the flow of the fluid, e.g. refrigerant, brine.

Soft soldered joint
A joint obtained by joining of metal parts with metallic mixtures or alloys which melt below 200 °C.

Soldered joint
A joint obtained by the joining of metal parts with metallic mixtures or alloys which melt at temperatures in general less than 450 °C

Specific heat
The quantity of heat needed to raise a unit mass of substance by 1°C. It is measured in joules per Kelvin per kilogram.

Strength test pressure
The pressure that is applied to test the strength of a refrigerating system or any part of it.

Tightness test
The pressurisation of a refrigeration system, or any part of it, in order to test for its tightness against leaks.

Ton refrigeration (TR)
It's the common used unit for refrigeration or air-conditioning system capacity. It is defined as the rate of energy required to melt a ton of ice at 0 oC in 24 hours. 1 ton of refrigeration (TR) = 3.517 kW = 12,000 Btu/h.

Total equivalent warming impact (TEWI)
A measure of the overall global-warming impact of equipment based on the total related emissions of greenhouse gases during the lifetime of the equipment, including its manufacture and the disposal of the operating fluids and hardware at the end-of-life. TEWI takes into account both direct emissions, and energy related emissions produced through the energy consumed in operating the equipment. TEWI is measured in units of mass of CO2 equivalent.

Transcritical cycle
A refrigerating cycle whose compressor discharges refrigerant at a pressure above the critical point.

Transitional substance
Under the Montreal Protocol, a chemical whose use is permitted as a replacement for ozone depleting substances, but only temporarily because the substance's ozone depleting potential is non-zero.

Ultraviolet radiation (UV)
Radiation from the Sun with wavelengths between visible light and X-rays.

UV-B (280–320 nm), one of three bands of UV radiation, is harmful to life on the Earth's surface and is mostly absorbed by the ozone layer.

United Nations Environment Programme (UNEP)
Established in 1972, UNEP is the specialised agency of the United Nations for environmental protection.

Venting
A service practice where the refrigerant is allowed to escape into the atmosphere, and is usually done as a short-cut instead of recovery.

Vapour compression refrigeration cycle - vapour compression technology
The most widely used refrigeration cycle. In this cycle refrigerant is vaporized and condensed alternately and is compressed in the vapour phase. Basic components are: compressor, condenser, expansion device, and evaporator.

Welded joint
A joint obtained by the joining of metal parts in the plastic or molten state.

Zeotrope
A refrigerant blend consisting of two or more substances of different volatilities that appreciably changes in composition or temperature as it evaporates (boils) or condenses (liquefies) at a given pressure. A zeotropic refrigerant blend assigned an R4xx series number designation in ISO 817.

Acknowledgements

ISBN: 978-92-807-2911-5
UNEP Job Number: DTI/1040/PA

This publication was produced by the United Nations Environment Programme Division of Technology, Industry and Economics (UNEP DTIE), OzonAction Branch, as part of UNEP's work programme as an Implementing Agency of the Multilateral Fund for the Implementation of the Montreal Protocol.

The project was managed by the following team in the OzonAction Branch

- **Mr. Rajendra Shende** *Head*
- **Ms. Anne Fenner** *Information Manager*
- **Mr. Halvart Koeppen** *Regional Network Coordinator, Europe and Central Asia*
- **Ms. Barbara Huber** *Programme Assistant*
- **Ms. Ursulet Mugure Kibe** *Documentation Assistant*

This publication was written by

- **Dr. Roberto de Aguiar Peixoto** *Centro Universitario, Instituto Mauá de Tecnologia (MAUA), Brazil*

Peer review was provided by

- **Dr. Daniel Colbourne** *Re-phridge, United Kingdom*

Additional review and input was provided by

- **Prof. Radhey Agarwal** *Indian Institute of Technology, India*
- **Mr. Yerzhan Aisabayev** *Programme Officer, OzonAction Compliance Assistance Programme (CAP), UNEP ROLAC, Panama*
- **Dr. Ezra Clark** *Programme Officer, OzonAction Branch, UNEP DTIE, France*
- **Mr. James S. Curlin** *Interim Network and Policy Manager, OzonAction Branch, UNEP DTIE, France*
- **Mr. Ayman El Talouny** *Programme Officer, OzonAction CAP, UNEP ROWA, Bahrain*
- **Mr. Etienne Gonin** *Project Coordinating Consultant, EC JumpStart Project, OzonAction Branch, UNEP DTIE, France*
- **Mr Yamar Guisse** *Programme Officer, OzonAction CAP, UNEP ROA, Kenya*
- **Mr Shaofeng Hu** *Programme Officer, OzonAction CAP, UNEP ROAP, Thailand*
- **Mr. Marco Pinzon** *Programme Officer, OzonAction CAP, UNEP ROLAC, Panama City*
- **Mr. Saiful Ridwan** *Information Technology Specialist, OzonAction CAP, UNEP DTIE, France*

Editing

- **Mr. Wayne Talbot** *consultant, United Kingdom*

Design and e-book platform

- **Steve Button, Brigitte Bousquet** *DesignAnnexe*
- **Marcella Cucco** *Illustrations*

UNEP DTIE wishes to thank all of above contributors for helping to make this manual possible.

About the UNEP DTIE

About the UNEP Division of Technology, Industry and Economics

The UNEP Division of Technology, Industry and Economics (DTIE) helps governments, local authorities and decision-makers in business and industry to develop and implement policies and practices focusing on sustainable development.

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 as a contribution to human development through global markets.*
- **Chemicals** *(Geneva), which catalyzes global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.*
- **Energy** *(Paris and Nairobi), 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.*

UNEP DTIE activities focus on raising awareness, improving the transfer of knowledge and information, fostering technological cooperation and partnerships, and implementing international conventions and agreements.

For more information see ▸ www.unep.fr

Copyright © United Nations Environment Programme 2010

This publication may be reproduced in whole or in part and in any form for educational or non-profit purposes without special permission from the copyright holder, provided acknowledgement of the source is made. The United Nations Environment Programme would appreciate receiving a copy of any publication that uses this publication as a source.

No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from United Nations Environment Programme.

Disclaimer

While reasonable efforts have been made to ensure that the contents of this publication are factually correct and properly referenced, United Nations Environment Programme does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the United Nations Environment Programme concerning the legal status of any country, territory, city or area or of its authorities, or concerning delimitation of its frontiers or boundaries. Moreover, the views expressed do not necessarily represent the decision or the stated policy of the United Nations Environment Programme, nor does citing of trade names or commercial processes constitute endorsement.