Technologies for Protecting the Ozone Layer

Catalogue

Refrigeration, Air Conditioning and Heat Pumps

SOURCE BOOK

Technologies for Protecting the Ozone Layer

Catalogue Refrigeration, Air-Conditioning, and Heat Pumps

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Foreword

Mounting scientific research has implicated chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs) and methyl bromide in the depletion of the stratospheric ozone layer, that segment of the earth's atmosphere which protects animal and plant life from the damaging effects of ultraviolet radiation. In September 1987, nations concerned about this crisis signed the Montreal Protocol, a landmark agreement that identified the major ozone-depleting substances (ODSs) and established a timetable for the reduction and eventual elimination of their use. Under the Protocol and its amendments, ODS production and consumption of the controlled substances are to be reduced and eliminated through the development of chemical substitutes and alternative manufacturing processes. Information exchange is crucial in order to realize this global phaseout.

As an Implementing Agency of the Multilateral Fund for the Implementation of the Montreal Protocol (MF), one role of the United Nations Environment Programme (UNEP) is to provide Article 5 (i.e., developing) countries with the latest technical information to assist their expeditious phaseout of controlled ODS. Through various regular feedback mechanisms with the concerned countries, UNEP's Industry and Environment office (UNEP IE) has perceived the broad information needs of Article 5 countries to be:

- *what are the technical options that currently exist to eliminate ODS;*
- *who are the suppliers of the technologies, equipment and products required for each technical option; and*
- *how can a company assess and implement an alternative technology.*

In response to each of these demonstrated needs, UNEP's OzonAction programme under the Multilateral Fund is producing a series of technical reference publications and guidelines that will assist industry in developing countries to make the transition from ODS to non-ODS alternatives, including the development of ODS phase-out projects. As part of the series of sector-specific *Catalogues of Technologies for Protecting the Ozone Layer,* this publication is intended to assist industry and governments in Article 5 countries with:

- identifying alternative technologies in the refrigeration, air conditioning and heat pump sector.
- initiating related ODS phase-out projects.

Assistance Available to Article 5 Countries from UNEP IE

Technical Options
To address the need to understand the available technical options, UNEP IE has produced a series of easy-to-read brochures that provide an overview of the options available to companies and organizations seeking to eliminate their ODS use. The *Protecting the Ozone Layer* technical brochure series is based on the UNEP Technical Options Committee reports, which are also available to developing countries through UNEP IE.

The brochures are designed for decision-makers in government and industry, and make an excellent introduction to the alternatives in the aerosols, foams, halons, solvents, and refrigeration sectors.

Technology Suppliers
Once the technical options are understood, the next step a developing country must face is to select an appropriate option and then identify the worldwide suppliers of the alternative technologies and equipment. In response to this need, UNEP IE is producing a series of *Catalogues of Technologies for Protecting the Ozone Layer* for the major ODS use sectors (aerosols, foams, solvents, and refrigeration). These technical references provide descriptions of the current ODS uses in the sector, an overview of what ODS alternatives currently exist, and contacts for the suppliers of the alternative technologies. These catalogues are being developed with the cooperation of the UNEP Technical Option Committees, and one has been co-produced with USEPA and industry associations such as ICOLP.

These sector-specific catalogues are targeted at plant engineers and managers responsible for identifying, evaluating, and implementing these alternatives. It is also expected that the government ODS officers in the national ozone units in developing countries will use them as they work with their industry, Implementing Agencies, and others to develop ODS phase-out projects.

Assessment and Implementation
The next step a company or government must take after the technology is selected and the suppliers are identified is to successfully implement the chosen technology. UNEP IE is assisting this process through two publications:

- *Practical Guide to Policy Guidelines for Industry on Management of Phase-out of ODS.* The guide is a practical document whose objective is to help industry in developing countries, specifically small and medium-sized enterprises (SMEs), to better manage and accelerate their phase-out of ozone depleting substances controlled under the Montreal Protocol. It is intended to be a "management guideline" document for business managers.
- *Elements for Establishing Policies, Strategies and Institutional Framework for Ozone Layer Protection.* This manual will provide governments in developing countries with guidelines for establishing an ODS phase-out policy and strategy, including the supporting actions, in particular the establishment of an "ozone office" in developing countries.

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Getting Started

The following is a step-by-step guide to using this document. Taking these steps will ensure that the reader makes the best possible use of the catalogue.

Step 1: Read the "Introduction" section

Read the Introduction section at the beginning of the catalogue. It provides a summary of the problem of ozone-depletion and the content of the catalogue.

Step 2: Read the relevant application chapters (5 - 13)

The sections of the Catalogue which apply to the relevant use of ozone-depleting substances -- domestic, commercial, cold storage and food processing, industrial, air conditioning and heat pumps (air cooled systems), air conditioning (water chillers), transport refrigeration and air conditioning, vehicle air conditioning, heat pumps (heating only) -- should be read next.

Step 3: Read the description of CFC- and non-CFC technologies and guidelines for how to retrofit

For more technical information, read Chapter 3 and 4, which describes the CFC and Non-CFC Refrigerants and technologies, gives a complete set of criteria that should be considered in the evaluation of alternative technologies, and provides detailed technical information about conversion procedures, system modifications etc.

Step 4: Read the "Disclaimer"

The disclaimer provides important information about the nature of the information presented in the catalogue.

Step 5: Gather additional information on potential alternatives

Readers may wish to use the list of suppliers provided in chapter 14 to gather additional information on alternatives of interest. Trade publications, industry experts, conferences, and in-house staff may also be good sources of information. Additional information may also be available from UNEP IE's OzonAction database.

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1 INTRODUCTION

1.1 Introduction

1.1.1 The Montreal Protocol and the Multilateral Fund

In 1974, Sherwood Rowland and Mario Molina of the University of California claimed that the man-made chemicals known as chlorofluorocarbons (CFCs) were damaging the stratospheric ozone layer. Subsequent research supported the theory, and it is now established that the stratospheric ozone layer -- which protects the earth from dangerously high levels of ultraviolet radiation from the sun -- is being destroyed by human activity. Ozone depleting substances (ODSs) including CFCs and carbon tetrachloride are used in the manufacture and operation of thousands of products, including aerosol products, sterilants, solvent applications, and miscellaneous uses.

The Montreal Protocol on Substances that Deplete the Ozone Layer was drawn up under the guidance of the United Nations Environment Programme (UNEP) in September 1987. The Protocol identified the main ODSs, and set specific limits on their production and consumption levels in the future. 134 countries have ratified the agreement as of May 1994. Universal ratification is quite probable in the near future.

1.1.2 London Amendments to the Montreal Protocol

It is intended that the Protocol be continually updated as necessary to reflect the changing scientific evidence and technological developments. In June 1990, the Parties to the Protocol met in London to consider the implications of new scientific evidence that showed that the ozone layer was being depleted even faster than originally thought. The London meeting agreed to phase out the consumption and production of CFCs and halons by the year 2000, and to control other chemicals, namely carbon tetrachloride and 1,1,1-trichloroethane.

The London Amendments acknowledged the financial and technical assistance that developing countries would need, and to meet this need the Parties established the Multilateral Fund (MF) as part of a financial mechanism. The MF serves all countries that operate under paragraph 1 of Article 5 of the Protocol (known as "Article 5 countries"). United Nations Development Program (UNEP), the United Nations Development Programme (UNDP), and the World Bank were chosen to be the Fund's original implementing agencies, with the United Nations Industrial Development Organization (UNIDO) being added later. UNEP's responsibility as an implementing agency is to conduct research, gather data, and to provide a clearinghouse function.

1.1.3 Copenhagen Amendments to the Montreal Protocol

At their fourth meeting in Copenhagen, Denmark (November 1992), the Parties took decisions that advanced the phaseout schedules in non-Article 5 (i.e., developed) countries for several ODSs, included methyl bromide and HCFCs as new controlled substances, and continued the financial mechanism to assist Article 5 countries.

The London and Copenhagen Amendments were ratified by the required number of parties, and both amendments have entered into force.

1.1.4 Bangkok Meeting of the Parties

At their fifth meeting in Bangkok, Thailand (November 1993), the Parties approved a budget of US$ 510 million for the MF for the 1994-96 period. In light of the availability of banked halons and the efficiency of technical alternatives to halons, the Parties decided that in 1994 no exemptions for production of halon for essential uses were necessary for developed countries. The Parties also agreed, inter alia, that information on HCFC and methyl bromide alternatives and substitutes be updated annually.

Signatories to the Protocol have agreed to reduce and eliminate the use of the controlled ODSs even though substitutes and alternatives technologies were not yet fully developed. Industries and manufacturers are starting to replace the controlled ODSs with less damaging substances, but a major obstacle in the conversion process is a lack of up-to-date, accurate information on issues relating to ODS substitutes and ODS-free technologies. UNEP is meeting this challenge through its OzonAction programme (see Annex A).

1.1.5 Refrigeration, Air Conditioning and Heat Pumps

For refrigeration, air conditioning and heat pump systems, a total phase out of CFCs is required to meet the restrictions for environmental protection.

CFCs will not be produced after 1995 in developed countries, except for very small quantities agreed by the Parties for essential uses. Presently there are no essential uses agreed for the Refrigeration, Air Conditioning and Heat pumps sector. Efforts must be made to develop and implement effective, safe, and appropriate replacements. Acceptable alternatives already exist, although some are more temporary ("transitional") than others. There is a growing interest in natural refrigerants, ammonia, hydrocarbons, CO_2, etc. in the developed countries. No undesirable influence on the global environment, combined with low refrigerant cost and good performance, make these fluids future alternatives in various applications.

In order to avoid a lack of refrigerants for the end users until acceptable, long-term alternatives are available, systems and equipment for recovery, recycling and reclamation of CFCs and transitional substances must be introduced. UNEP IE has compiled a worldwide directory of such equipment available (please see section 14.7).

Table 1.1 shows refrigerants controlled by the Montreal Protocol, and their phase-out dates according to the Copenhagen and London adjustments and amendments.

Table 1.1 *Refrigerants covered by the Montreal Protocol, and summary of the Copenhagen and London adjustments and amendments /UNEP, 1991 a, Kuijpers, 1993/.*

	Name of Substance	Phase-out schedule (non-Article-5 Countries)	
Annex A, Group I:		**Annex A, Group I:**	
		Reference year 1986	
CFC-11	Trichlorofluoromethane	Freeze by:	1 July 1989
CFC-12	Dichlorodifluoromethane	75% reduction by:	1 Jan 1994
CFC-113	1,1,2-Trichloro-1,2,2-trifluoroethane	100% reduction by:	1 Jan 1996
CFC-114	1,2-Dichlorotetrafluoroethane		
CFC-115	Chloropentafluoroethane		
Annex B, Group I:		**Annex B, Group I:**	
CFC-13	Chlorotrifluoromethane	Reference year 1989	
		20% reduction by:	1 Jan 1993
		75% reduction by:	1 Jan 1994
		100%reduction by:	1 Jan 1996
Annex C:		**Annex C:**	
HCFC-22	Chlorodifluoromethane	Referenced (ODP) cap consumption equals 100% of HCFC consumption + 3,1% of CFC consumption. Reference year 1989.	
HCFC-123	Dichlorotrifluoroethane		
HCFC-124	Dichlorotetrafluoroethane		
HCFC-141b	Dichlorofluoroethane	Freeze by:	1 Jan 1996
HCFC-142b	Chlorodifluoroethane	35% reduction by:	1 Jan 2004
		65% reduction by:	1 Jan 2010
		90% reduction by:	1 Jan 2015
		99,5% reduction by:	1 Jan 2020
		100% reduction by:	1 Jan 2030

Note: Some Halons (Annex A, Group II) are also used as refrigerants. Their production in non-Article 5 countries is already phased out.

1.2 Purpose of the Catalogue

This catalogue describes ODS-free and ODS-reducing technologies for refrigeration, air-conditioning and heat pump systems. The intention is *to provide information on available technologies for Article 5 (developing) countries*, without recommending any refrigerants or refrigeration equipment. It is up to the reader to determine which technology or product is most appropriate to his/her own needs.

The catalogue is divided into two parts:

- A *catalogue* describing different methods of converting refrigeration, air conditioning and heat pumps with CFC-refrigerants to non-CFC (ODS-free) alternatives. The catalogue concentrates on the currently available refrigerants and technologies.

- A *supplier's list* with names and addresses of supplier's of products, equipment and plants using non-CFC refrigerants, or minimizing the CFC-refrigerant charge in new plants, reclamation of refrigerants, etc.

1.3 Target Groups

To provide reliable and focussed information to the users of the catalogue, the following target groups are defined:

- Users/Owners of refrigeration units and equipment
- Consultants/Contractors/Manufacturers
- Politicians/Decision Makers

1.3.1 Users/Owners

The first step to consider changing to an acceptable refrigerant must be made by the owner of the refrigeration system. The decision might be a result of time for natural change of components or systems, decreased availability of CFCs, local restrictions about using CFCs (valid for countries having signed the Montreal Protocol), etc. It is important for the user to be aware of the situation about the ongoing phase-out of CFCs worldwide and the consequences it might have for his plant. Throughout the catalogue, the different aspects of each common replacement refrigerant is discussed.

1.3.2 Consultants/Contractors/Manufacturers

The technical considerations of converting to non-CFC refrigerants and equipment must be performed by the consultant and the contractor/manufacturer. Therefore, most of the catalogue and the supplier's list is concentrated on the needs of this target group. Most of the necessary information for choosing the best suitable system and check lists for conversion are schematically worked out.

1.3.3 Governmental Decision-Makers

The information provided for this group is meant to give an overview of the necessity for phasing-out CFCs. The technical aspects are not the most important, rather, the reasons for doing so.

1.4 How to Use the Catalogue and the Supplier's List

The *catalogue* will give the background for the phase out of CFCs, and the guidelines for conversion in each application. The *supplier's list* provides information about where to find available technologies and equipment.

In addition to conference proceedings and other publications, about 500 companies in 47 different countries has been consulted in order to gather the information for this catalogue. For details about the data collection method and the survey used to develop the supplier's list, see Annex E.

The catalogue is divided into 15 chapters, some to be read by all target groups, some specifically written for government and industry decision-makers and some written from a technical point of view. The references in the text make it possible for the reader to go directly to the appropriate sections.

The chapters related to each target group are shown in Table 1.2.

Table 1.2 Chapters for the target groups

Target group	Chapter
Users/Owners	1, 5 to 13, 14
Consultants/Contractors/Manufacturers	1, 3, 4, 5 to 13, 14
Politicians/Decision-makers	1, 2

For the *User/Owner*, the application areas defined in the Montreal Protocol are described, with references to the necessary converting procedures for his specific plant or system.

For the *Consultants/Contractors/Manufacturers*, the most vital characteristics and properties about the CFCs and non-CFCs are presented. Conversion procedures are described, in addition to special concerns for each application area.

For the *Governmental Decision-makers*, political aspects are covered, to describe the consequences of a CFC phase-out in the Article 5 countries.

The purpose of the supplier's list, is to give names and addresses of manufacturers of non-CFC and CFC-reducing products and technologies. The supplier's list is presented in *chapter 14*.

Example of how to use the catalogue:

A user wants to find available information on refrigerators:

- Go to chapter 5, *Domestic Refrigeration*. This chapter gives an introduction about the equipment used earlier, and about the alternatives for retrofits and for new equipment for refrigerators and freezers. There are also a few examples of refrigerators and freezers with new refrigerants at the end of the chapter.

- Go to chapter 14.2, *Supplier's List for Refrigeration, Air Conditioning and Heat Pumps: Technologies and Products, Units*. In the list of manufacturers, the supplier's of refrigerators are marked with *Domestic refrigerators/freezers*.

A user wants to find available information on retrofitting of centrifugal water chillers with CFC-12:

- Go to chapter 10, *Air Conditioning (Water chillers)*..This chapter gives an introduction about the equipment used earlier, and about the alternatives for retrofits and for new equipment. There are also a few examples of retrofits at the end of the chapter.

- Go to chapter 4, *How to Convert to Non-CFC Refrigerants and Technologies*, to find more detailed information on the chosen retrofit procedure.

- Chapter 14.8, *Supplier's List for Refrigeration, Air Conditioning and Heat Pumps: Technologies and Products, Consultants, research and development, organizations* gives names and addresses for retrofits consultants. **The supplier of the equipment that are being retrofitted should always be consulted.**

- In some cases retrofits can not be done. Go to chapter 14.2, *Supplier's List for Refrigeration, Air Conditioning and Heat Pumps: Technologies and Products, Units*. In the list of manufacturers, the supplier's of centrifugal water chillers are market with *Absorption chillers/water chillers/chillers.*

IMPORTANT NOTE

It is up to each person responsible for the conversion or replacement to evaluate which technology or product is most appropriate for his/her own needs. Please consider the technical merits, environmental effects, and worker safety issues related to each technology or product.

UNEP IE is in no way endorsing any of the companies, technologies or products listed in this catalogue. UNEP IE recommends anyone considering a new technology or retrofitting to consult original equipment manufacturers or technical experts, their local refrigeration, air conditioning, and heat pump association to obtain appropriate advice.

1.5 Request for Information

This catalogue is a "living" document that will be updated on a regular basis to reflect technological advancement, new products, and changing control measures. Information is welcome both on alternatives to uses covered in the catalogue as well as on alternatives not discussed. UNEP request that companies or individuals with such information use the form in Annex F to supply this information to:

UNEP IE OzonAction Programme
Ref.: Refrig Catalogue Update
Tour Mirabeau
39-43, Quai André Citroën
75739 Paris Cedex 15
France
Tel: (33) 1 44 37 14 50
Fax: (33) 1 44 37 14 74

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2. ENVIRONMENTAL ASPECTS

2.1 Global and Local Environment

The catalogue concentrates on the most common refrigerants and well-known alternatives. We recommend *"1991 Report of the UNEP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee"*, for a more detailed study of chlorofluorocarbon refrigerants and alternatives /UNEP, 1991 a/. Please be aware that a new assessment report will be issued at the end of 1994, which will provide revised and new information on alternatives.

A refrigerant must meet a set of requirements, apart from having the proper thermodynamic characteristics. It should have none or a minimal effect on the global and local environment, and meet the highest fire and explosion safety standards. The availability and the price are also important matters. The most common alternative refrigerants, with their most important properties are presented in Table 2.1 on page 2-3. The thermodynamic properties of the refrigerants are discussed in chapter 3, *"CFC and non-CFC Refrigerants and Technologies"* .

Ozone Depletion Potential-ODP
Substances containing chlorine react with ozone in the atmosphere, thus leading to a destruction of the ozone layer which protects human beings against ultraviolet radiation from the sun. The *ozone depletion potential (ODP)*, is a measure of the effect on the ozone layer from the specific refrigerant, with CFC-11 as a reference. The ODP is strongly related to the lifetime of the substance, since chlorine is only a catalyst and thus not used in the depletion reaction.

Global Warming Potential - GWP
New CFC-free technology might have other environmental impacts that should be taken into consideration as well. *The global warming potential (GWP)*, describes the direct contribution to the global warming effect when the refrigerants are released into the atmosphere. CO_2 is used as a reference, with a GWP value of 1. As with the ODP effect on the ozone layer, global warming potential is also related to the lifetime of the substance. The GWP is given with 20, 100 and 500 year integration time horizon. In political discussions, it is common to use the figures with 100 years integration time horizon.

Total Equivalent Warming Impact - TEWI
The indirect global warming effect from produced carbon dioxide when generating power driving the system, in many cases gives a more important contribution than the direct emission of the refrigerant. The energy efficiency for a given system is therefore very important. *The total equivalent warming impact (TEWI)*, combines the global warming effect associated with energy consumption (indirect GWP) and the effect from refrigerants emission (direct GWP). TEWI is therefore useful as an indicator for the relative contributions to future global warming. An improvement of the energy efficiency for a system of a few per cent has a great influence on the TEWI, compared to the new refrigerants with limited direct GWP and less leakage. Leakages can be decreased by better operation,

service and maintenance. TEWI depends on the system, how the power is generated, the lifetime of the system, leakages etc, and it is not possible to list the TEWI for each refrigerant /Oak Ridge, 1991/. The indirect GWP has a great impact for units with a long lifetime, but is less important for units with short lifetime and higher leakage, such as mobile air-conditioning and retail refrigeration systems.

The TEWI figure is quite dependent on the integration time used in calculation of the GWP. In general, longer integration time reduces the significance of the direct effect. It should also be taken into account the considerable uncertainties in GWP figures and the fundamentally different mechanisms of CO_2 and fluorocarbons in the atmosphere.

Toxicity - TLV

Exposure limit is represented by the *TLV (Threshold Limit Value)* /ACGIH, 1990/. TLV represent "conditions under which it is believed that nearly all workers can be repeatedly exposed day after day without adverse health effects". TLVs are expressed as parts per million volume concentrations in air.

Flammability - LFL

ASHRAE[1] Standard 34 /ASHRAE, 1989/ subdivides the *flammable refrigerants* into two degrees of flammability, based on the *LFL (Lower Flammable Limit)*, and heat of combustion, Δh_{comb}. LFL is by ASTM[2] Standard E 681-85 /ASTM, 1985/ defined as "the minimum concentration of a combustible substance that is capable of propagating a flame through a homogeneous mixture of the combustible and a gaseous oxidizer under the specified conditions of test" /ASTM, 1985/. The conditions of test for refrigerants are in air at ambient temperature and pressure. Heat of combustion, Δh_{comb}, is calculated assuming CO_2, HF, Cl_2 and H_2O as products. Negative and small positive values indicate that reaction with oxygen is not energetically favorable.

Availability

In Table 2.1, the *availability* of production quantities of the possible alternatives is estimated.
Availability of production quantities of refrigerants can be divided into:

- I - immediate
- S - short term, 1995 or before
- M - medium term, 1995 - 1997

[1] *American Society of Heating, Refrigerating and Air Conditioning Engineers. See Annex D for contact information.*

[2] *American Society for Testing and Materials. See Annex D for ontact information.*

Table 2.1 Environmental properties for CFC and non-CFC refrigerants /UNEP, 1991 a, IPCC, 1992/.

Refrigerant	Lifetime (year)	ODP	GWP 20 y	GWP 100 y	GWP 500 y	TLV (ppm)	LFL (%)	Δh_{comb} (MJ/kg)	Availability
CFC-11	*55*	*1.0*	*4500*	*3400*	*1400*	*1000*	*none*	*0.9*	*I*
CFC-12	*116*	*1.0*	*7100*	*7100*	*4100*	*1000*	*none*	*-0.8*	*I*
CFC-13	*400*	*1.0*	*11000*	*13000*	*15000*	*1000*	*none*	*-3.0*	*I*
CFC-114	*220*	*1.0*	*6100*	*7000*	*5800*	*1000*	*none*	*-3.1*	*I*
R-500						*1000*	*none*		*I*
R-502						*1000*	*none*		*I*
HCFC-22	15.8	0.055	4200	1600	540	1000	none	2.2	I
HCFC-123	1.71	0.02	330	90	30	10-100[3]	none	2.1	I
HCFC-141b	10.8	0.11	1800	580	200	500[3]	7.4	8.6	I
HFC-134a	15.6	0	3100	1200	400	1000[3]	none	4.2	I
HFC-152a	1.8	0	530	150	49	1000[3]	3.7	16.9	I
HFC-23		0			12000[4]	1000[3]	none	-12.5	I
HFC-125	40.5	0	5200	3400	1200	1000[3]	none	-1.5	I
HFC-143a	64.2	0	4700	3800	1600		7.1	10.3	I
Blends	-	-		-	-	-	-	-	I
Ammonia	<1	0				25	15.0	22.5	I
Propane	<1	0		3[5]	3[5]	s.a.[7]	2.1	50.3	I
Iso-butane	<1	0		3[5]	3[5]	1000[1]	1.8	49.4	I
n-butane	<1	0		3[5]	3[5]	800	1.5	49.5	I
Carbon dioxide	appr. 120	0		1[6]	1	5000	none		I

2.2 Natural and Synthetic Refrigerants

There has been much discussion during the last few years concerning whether it is best to continue using the standard vapor compression cycle, conventional circuits, and developing new chemicals as refrigerants, or to find a natural refrigerant with no effect on the environment; and then develop the cycle and the equipment to fit the refrigerant.

[3] *TLV not established by ACGIH (American Conference of Governmental Industrial Hygienists), estimate of comparable based on limited or incomplete toxicity testing*

[4] *Estimates based on limited data, GWP is steady-state value (McFarland, personal Communication)*

[5] *GWP of the hydrocarbons is due almost entirely to GWP of the CO_2 resulting from decomposition*

[6] *Although the GWP figure of 1 is given for CO_2 in the table (reference figure), the actual value will be 0 since CO_2 is recovered from waste gas.*

[7] *s.a. = simple asphyxiant*

Natural refrigerants are naturally existing substances which are harmless to nature and already circulating in quantity in the biosphere. *Synthetic refrigerants* are chemically manufactured substances. This group includes CFCs, HCFCs and HFCs. Since they are foreign to nature such as the CFCs, we do not yet fully know the consequences to the environment.

Many natural refrigerants have been applied in the past, such as ammonia, hydrocarbons, carbon dioxide, air and water. No undesirable influence on the global environment, combined with low refrigerant cost and good performance, make the natural fluids future alternatives in various applications. Some natural refrigerants are toxic or flammable, and will require safety precautions.

Ammonia is a well-known and is used to a large extent as a refrigerant in medium to large refrigeration plants. It has excellent thermodynamic properties and is widely available at a low price. Ammonia is toxic, but the strong, pungent odor at concentrations far below dangerous level makes it easy to detect leakages.

Especially in small refrigeration systems, the hydrocarbons seem to be acceptable alternatives. Several big manufacturers are now offering refrigerators with hydrocarbons as refrigerants. Propane is introduces as refrigerants in heat pumps, and it is also used in large refrigeration plants with turbo compressors, especially in petrochemical processing industry.

Carbon dioxide was a commonly used refrigerant before the CFCs entered the arena, being completely harmless, nontoxic and incombustible. It is cheap and available everywhere as a waste product from other activities. Other advantages are simple plant operation, with no recycling required. Carbon dioxide systems are operated at high pressure, but the small volumes limits the energy released in an explosion, and gives a compact system.

Water, in high temperature systems, and air will probably be used in industrial applications in the long-term time frame.

For all of these refrigerants, it is of vital importance to adjust the cycle and the equipment to the refrigerant to obtain optimal efficiency. For example, carbon dioxide is tested as refrigerant in automobile air-conditioning systems with a trans-critical process, with very competitive performance characteristics /Lorentzen, 1993 b/. Ammonia and hydrocarbons are taken into consideration in this manual, since they are already being used in some refrigeration applications.

2.3 National Laws and Regulations

Some countries have more stringent phase-out schedules than the Montreal Protocol. The reasons can be public awareness and campaigns, concern for a decrease in the ozone levels and uncertainties about future availability of CFCs. The national phase out schedules have to be taken into consideration when evaluating replacement with non-CFC refrigerants. For instance, Sweden might levy taxes on the use of HCFC-22, while Germany has started a discussion about the future use of HFC-134a.

Laws and regulations for refrigerants and refrigeration, air conditioning and heat pump plants are different for each country, especially for the natural refrigerants, of which some are toxic and flammable. There are also differences in the safety regulations. Excellent references for designing plants with toxic and flammable refrigerants are: *ASHRAE Handbooks* /ASHRAE, 1985, 1983 &1987/, *"American National Standard for Equipment, Design and Installation of Ammonia Mechanical Refrigeration Systems"* /IIAR, 1985/, *"ASHRAE Standard 34-1989, Number Designation and Safety Classification of Refrigerants"* /ASHRAE, 1989/, and *BS 4434 1989, Specifications for Safety Aspects in the Design, Construction and Installation of Refrigerating Appliances and Systems* /BSI, 1989/. UNEP IE's Information Papers *Standards and Codes of Practices* and *ODS Phase Out Legislations and Regulations*.

2.4 Implications of the Montreal Protocol

2.4.1 Reasons for Earlier Phase Out of CFCs

There are several reasons for a more rapid CFC phase out in developing countries than required by the Montreal Protocol:

- The availability of CFC refrigerants and refrigeration equipment and components will decrease due to a transfer to non-CFC technology in developed countries
- Technology must be up-to-date to achieve compatibility and marketability for export
- Increasing concerns about using ozone depleting substances in products among customers
- Some multinational companies require CFC-free imported products due to worldwide corporate policies of not using CFCs
- Financial and technical support through the Multilateral Fund will contribute to a smooth exchange of technology

To facilitate an early phase out, some major barriers should be removed. Barrier removal can be achieved by:

- Establishment or improvement of the local infrastructure, including steering committees comprising government and industry
- Adopting information of updated technology from local and international experts
- Differention of the phase out strategies according to the real needs of the country
- Funds that assure an effective development of local solutions according to specific needs

2.4.2 Usage and Availability of Refrigerants

In 1991, 260,000 metric tonnes of CFC chemicals were used in refrigeration, air conditioning and heat pumps worldwide /UNEP, 1991 a/. Phase out of CFCs will be made easier by recovery, recycling and reclamation of CFCs. If all the recovered CFCs were to be used in developed countries, the CFC production in these countries can be stopped in 1997 /UNEP, 1991 a/.

Even if the developing countries have a ten years grace period, they will still face problems in the availability of CFCs and CFC equipment. The availability of the most common refrigerants are listed in Table 2.2, page 2-5.

In developing countries, equipment is often used for a relatively long time. It is important for transitional substances not only to be available now, but also to remain available during the lifetime of the equipment that has been manufactured to use them. Otherwise, there might be a delayed CFC-phase out because of users awaiting more permanent and certain solutions.

Table 2.3, shows a forecast of use of CFC, HCFC and HFC refrigerants in different application areas, in the years 1995 and 2000. Extensive use of natural refrigerants will decrease the use of CFCs, HCFCs and HFCs.

Many manufacturers are still awaiting the situation until clearer signals of the definite choice about the alternative refrigerants are given. Therefore, it is difficult to predict the available quantities of the different alternatives.

HCFCs

There are many refrigeration applications where CFCs can be rapidly phased out by the means of HCFCs. HCFCs are in the Copenhagen Amendment to the Montreal Protocol, presented as transitional substances, with a 99.5 % reduction by the year 2020 and phase out by the year 2030 for developed countries.

Production of new transitional HCFCs depend on the following matters:

- Chemicals will only be produced if plant investment can be recovered or if the plant can be converted to produce other acceptable substances
- The costs to users for transition into and out of HCFC use must be acceptable
- The HCFC requirements for service during the useful life of the equipment

HCFC-22 is currently available, and can be made available in larger quantities at relatively short notice. Plants for production of CFC-11 and CFC-12 can be rapidly converted to HCFC-22 production.

HCFC-123 and HCFC-141b are already available in small quantities. Since they are also used in other sectors than refrigeration, they can be economically produced in large quantities.

HFCs

HFC-152a is currently available, mostly as a component in blends. The production costs are fairly low, due to rather simple manufacturing. HFC-134a is also available, a few production plants have been put in operation and several are under construction. The production costs are relatively high, which lead to a high price. HFC-23 is already available, since it has been used in some applications as a replacement for CFC-13. HFC-125 and HFC-142a are also commercialized.

Natural refrigerants

The natural refrigerants are available in required quantities, due to simple production and low production costs. CO_2 is a byproduct from other production processes, such as the petrochemical industry. The required purity quality of the hydrocarbons used as refrigerants are still being developed. Standard commercial hydrocarbons are produced by fractional distillation. It is difficult to obtain the same purity standards in this process as in production of HCFCs and HFCs, and it still remains to see whether the purity requirement for hydrocarbons require another production method.

Blends

Blends are likely to have an important place in retrofit applications, since they can be retrofit into systems with minor modifications. Many blends are yet commercially available, though the production is still limited.

Table 2.2 Forecast of use of CFC, HCFC and HFC refrigerants in different application areas, in the years 1995 and 2000, metric tonnes per year /UNEP, 1991 a/.

	Domestic	Commercial	Cold Storage	Industrial	AC[8] unitary	AC chillers	Transport refrigeration	MAC[9]	Heat Pumps	Total Consumption
1995:										
CFC demand Art 5[10]	3 330	2 300	2 700	550		500	175			9 555
CFC net demand	4 780	18 900	7 600	1 400		1 600	4 320		354	27 640
CFC mobile air-cond Art 5								9 300		9 300
CFC mobile air-c net demand								70 000		70 000
HCFC demand Art 5		5 150	1 200	600	26 000	1 600	900			35 450
HCFC net demand		37 850	2 2800	11 850	129 000	14 970	16 350		424	233 250
HCFC mob air-cond. Art 5										
HCFC mob air-c net demand										
HFC demand Art 5	1 000					110	20			1 130
HFC net demand	5 902	20 000	2 600	450	2 000	7 110	150		1 090	39 302
HFC mob air-cond Art 5								1 500		1 500
HFC mobile air-c net demand								37 500		37 500
2000:										
CFC demand Art 5	890	1 250	2 500	500		400	130			
CFC net demand	890		- 3 300	- 500		200	- 384		117	- 3 000
CFC mob air-cond Art 5								8 000		8 000
CFC mobile air-c net demand										
HCFC demand Art 5		5 250	1 400	700	25 000	3 450	900			36 700
HCFC net demand		35 00	14 100	7 300	112 000	25 490	13 425		249	207 600
HCFC mob air-cond Art 5								30 200		30 200
HCFC mob air-c net demand										
HFC demand Art 5	7 200	4 000	100	25	1 000	1 100	100			73 700
HFC net demand	19 400	23 000	4 400	825	7 500	14 630	1 900		2 080	
HFC mobile air-cond Art 5								7 000		
HFC mobile air-c net demand								105 300		

[8] *AC = Air Conditioning*

[9] *MAC = Mobile Air Conditioning*

[10] *ART 5 = Countries operating under article 5 paragraph 1 of Montreal Protocol*

2.4.3 Economic Aspects of CFC Phase Out

Lower CFC availability will yield increasing maintenance costs for existing equipment. Introduction of substitutes requires new capital investments, and will to some extent lead to higher manufacturing and operation costs. Costs for converting to acceptable refrigerants depend on the extent of retrofitting and the condition of the existing equipment. It is therefore difficult to determine the expenses associated with the changes. However, for conversion of household refrigerators from CFC-12 to HFC-134a, the industrial production cost will increase 10-15%. This is due to approximately 5 times higher price for the refrigerant and 15 times higher price for new lubricant, in addition to necessary compressor modifications resulting in 15% increased volume to assure the same capacity, and 10% higher insulation cost. Increased production volumes may lower the costs /UNEP, 1991/.

To give an overview of the cost level for some refrigerants, both controlled substances and acceptable alternatives, Table 2.3 summarizes the relative values. The cost might change over time attributing to several factors such as:

- Increased production volumes for new refrigerants
- Lower production cost for HFCs
- Reduced availability of CFCs

Table 2.3 Approximate relative price for refrigerants/Lorentzen, 1993 b/.

CFC-12	HCFC-22	HFC-134a	HFC-152a	Ammonia	Commercial Propane	CO_2
1	1.5	3-5	1	0.2	0.4	0.1

Application of some new refrigerants makes it necessary to use other lubricants, which generally are more expensive than the mineral oils used for the CFCs.

Flammable or toxic refrigerants require special safety precautions due to national legislation. The cost of safety-related equipment is not easy to estimate, because of:

- Plant size (lower specific costs for larger plants)
- Location of the refrigeration equipment (room location and surroundings)
- Refrigerant charge
- Construction materials

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UNEP : Information Paper *Standards and Codes of Practices* 1994.

UNEP : Information Paper *ODS Phase-out Legislations and Regulations* 1994.

CFC AND NON-CFC REFRIGERANTS AND TECHNOLOGIES

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3. CFC AND NON-CFC REFRIGERANTS AND TECHNOLOGIES

The first part of this chapter presents an overview of the present use of CFC and non-CFC refrigerants in refrigeration, air conditioning and heat pump systems. The most important non-CFC alternatives in existing and new plants are discussed in detail: HCFC-22 (R-22), HFC-134a (R-134a), HFC-152a (R-152a), ammonia (R-717) and hydrocarbons. Various tables show the most important characteristics and properties for the refrigerants, including physical and thermodynamic properties, relative refrigerating capacity, relative theoretical *coefficient of performance (COP)* at different operating conditions, relative price and availability.

The last part of the chapter provides a brief presentation of different alternative refrigeration cycles.

For an explanation of technical terms, see annex B, *Glossary of Significant Terms*.

3.1 CFC-Refrigerants

The following CFC refrigerants are discussed:

- CFC-11
- CFC-12
- CFC-13
- CFC-114
- R-500 (mixture of CFC-12 and HFC-152a)
- R-502 (mixture of CFC-115 and HCFC-22)

3.1.1 CFC-11 (R-11)

CFC-11 (CCl_3F) is a low-pressure refrigerant (0.40 bar at 0°C), which is mainly used in *centrifugal chillers for air conditioning* in the 350 kW to 10,000 kW range. Approximately 80% of all air conditioning water chillers use CFC-11 as refrigerant.

Some physical and thermodynamic data for CFC-11 are listed in Table 3.1 /UNEP,1991, Gosney, 1982/.

Table 3.1 Physical and thermodynamic data for CFC-11 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
137.37	23.8°C	198.0°C	44.1 bar	160.4°C

3.1.2 CFC-12 (R-12)

3.1.2.1 Current Applications

CFC-12 (CCl_2F_2) accounts for roughly *60%* of the total consumption of CFC and HCFC refrigerants today, in terms of mass, not considering the ODP factors. Current applications and sectors with CFC-12 as refrigerant are listed in Table 3.2 /UNEP,1991/. Estimated share of CFC-12 in each sector is given in percent of total.

Table 3.2 Current applications and sectors with CFC-12 as refrigerant /UNEP,1991/

AREA OF APPLICATION	% OF TOTAL	REMARKS
Domestic Refrigeration	≈ 100%	The vast majority of refrigerators and freezers in the domestic sector use CFC-12 as refrigerant
Commercial Refrigeration	79%	Used both for medium and high-temperature refrigeration (-15°C to 15°C)
Cold Storage and Food Processing	10%	Used both for medium and high-temperature refrigeration (-15°C to 15°C)
Industrial Refrigeration	18%	Commonly used from -30°C and upwards. Most centrifugal compressor systems operating below 0°C are with CFC-12. CFC-12 has a comparatively larger market share in developing than in developed countries.
Air Conditioning (Water Chillers)	25%	Rarely used in chillers with positive displacement compressors. Used in centrifugal chillers from approximately 350 kW to 4,500 kW cooling capacity.
Transport Refrigeration and Air Conditioning	50%	Used in 1) Marine air conditioning and provision rooms for refrigeration in ships, 2) Main refrigerant in refrigerated containers, 3) Main refrigerant in refrigeration units on railcars, 4) Road transport refrigeration and 5) Air conditioning in buses and coaches.
Automotive Air Conditioning	100%	
Heat Pumps (Heating only and Heat Recovery)	46%	Used for medium-temperature applications (up to approximately 80°C).

3.1.2.2 Physical and Thermodynamic Data and Characteristic Properties

Some physical and thermodynamic data for CFC-12 are listed in Table 3.3 /UNEP,1991, Gosney, 1982/.

Table 3.3 Physical and thermodynamic data for CFC-12 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
120.91	-29.8°C	111.8°C	41.1 bar	84.2°C

CFC-12 is characterized by the following properties:

- *Odorless, non-flammable and non-toxic.* However, when CFC-12 is exposed to open fire it will decompose into toxic and irritating gases.
- *Compatible* with most metals, alloys and sealing materials (at low moisture level).
- *Fully miscible in mineral oil* at all operating temperatures (high solubility).
- *Low compressor discharge temperature* compared to HCFC-22 and ammonia, which may positively affect the compressor reliability. At evaporating and condensing temperature -30°C/+40°C, one-stage compression and reasonable compressor efficiency, the discharge temperature is about 80°C for CFC-12, and 110°C for HCFC-22.
- *Volumetric refrigerating capacity* (kJ/m^3) is approximately 60% of HCFC-22 and ammonia, thereby demanding correspondingly larger compressors.
- *High molar mass* makes CFC-12 suitable for centrifugal compressors. The disadvantage is relatively high pressure drop in valves in reciprocating compressors.

3.1.3 CFC-13 (R-13)

CFC-13 ($CClF_3$) is a low-temperature refrigerant used in the temperature region -70°C to -45°C in a few *industrial refrigeration* plants. Some physical and thermodynamic data for CFC-13 are listed in Table 3.4 /UNEP,1991, Gosney, 1982/.

Table 3.4 Physical and thermodynamic data for CFC-13 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
104.46	-81.4°C	28.8°C	38.7 bar	130.8°C

3.1.4 CFC-114 (R-114)

CFC-114 ($CClF_2$-$CClF_2$) is a non-flammable and non-toxic high temperature refrigerant which is mainly used in *industrial heat pumps* in the temperature range from 80°C to 120°C. CFC-114 is also used in *ships for air conditioning* in some of the larger plants including naval vessels. The total use of CFC-114 is less than 1% of the total annual refrigerant consumption. Some physical and thermodynamic data for CFC-114 are listed in Table 3.5 /UNEP,1991, Gosney, 1982/.

Table 3.5 Physical and thermodynamic data for CFC-114 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
170.92	3.8°C	145.7°C	32.5 bar	130.8°C

3.1.5 R-500

R-500 is a *non-flammable* azeotropic mixture of 73.8% CFC-12 and 26.2% HFC-152a by weight. It is used to a small extent as an alternative to CFC-12, mainly due to slightly better COP and 10-15% higher volumetric refrigerant capacity. Some physical and thermodynamic data for R-500 are listed in Table 3.6 /UNEP,1991, Gosney, 1982/.

Table 3.6 Physical and thermodynamic data for R-500 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
99.30	-33.8°C	105.5°C	44.3 bar	75.5°C

3.1.6 R-502

3.1.6.1 Current Applications

R-502 is an azeotropic mixture of 48.8% HCFC-22 and 51.2% CFC-115 by weight. Current applications and sectors with R-502 as refrigerant are listed in Table 3.7 /UNEP,1991/. The estimated share of R-502 in each sector is given in percent of total:

Table 3.7 Current applications and sectors with R-502 as a refrigerant /UNEP,1991/.

AREA OF APPLICATION	% OF TOTAL	REMARKS
Commercial Refrigeration	19%	Used at evaporator temperatures down to -45°C and in some medium-temperature systems.
Cold Storage and Food Processing	5%	Used for low-temperature refrigeration down to -45°C.
Industrial Refrigeration	-	Used for low-temperature refrigeration down to -45°C.
Transport Refrigeration and Air Conditioning	50%	Very occasional use for low temperature refrigeration.
Heat Pumps (Heating only and Heat Recovery)	8%	

Some physical and thermodynamic data for R-502 are listed in Table 3.8 /UNEP,1991, Gosney, 1982/.

Table 3.8 Physical and thermodynamic data for R-502 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
111.65	-46.6°C	82.2°C	40.8 bar	58.1°C

3.1.6.2 Physical and Thermodynamic Data and Characteristic Properties

R-502 is characterized by the following properties (see also HCFC-22, page 3-7):

- *Colorless, almost odorless, non-flammable and non-toxic.*
- *Normal boiling point* is 5.8°C lower than HCFC-22. R-502 is therefore primarily used at low evaporating temperatures down to -45°C.
- *Large volumetric refrigerating capacity* (kJ/m^3) at low temperatures, about 1% to 7% higher than HCFC-22 in the temperature range -20°C to -40°C, with the result that a relatively moderate compressor capacity is needed.
- *5-15% lower COP* than HCFC-22 depending on the operating conditions.

- *Lower discharge temperature* than CFC-12 and HCFC-22, which may positively affect the compressor reliability. At evaporating/condensing temperatures -30°C/+40°C, one stage compression and a reasonable compressor efficiency, the discharge temperature is about 70°C with R-502, 80°C with CFC-12 and 110°C with HCFC-22 as refrigerant.

- *Solubility in mineral oil* is less than CFC-12 and HCFC-22 (low solubility).

3.2 Alternative Non-CFC Refrigerants

3.2.1 HCFC Refrigerants

Both HCFC and CFC refrigerants contain chlorine, but due to lower atmospheric chemical stability HCFCs have much lower ODP, typically 2-5% that of CFC-12. Moreover, the GWP factor is typically 20% of CFC-12. Due to the agreements at the Copenhagen Meeting in 1992, *the HCFCs are now controlled by the Montreal Protocol.* A 90% reduction of HCFCs is to be achieved before the year 2020, and a total phase out by the year 2030 (see chapter 1, *Introduction*, for details).

The following HCFC refrigerants are discussed:

- HCFC-22
- HCFC-123
- HCFC-141b

3.2.1.1 HCFC-22 (R-22)

a) Current Applications

HCFC-22 ($CHClF_2$), in terms of mass and not considering ODP factors, accounts for roughly 30% of the total consumption worldwide of CFCs and HCFCs today. Current applications and sectors using HCFC-22 as refrigerant are listed in Table 3.9 /UNEP,1991/. The estimated share of HCFC-22 in each sector is given in percent of total:

Table 3.9 Current applications and sectors with HCFC-22 as a refrigerant /UNEP,1991/.

AREA OF APPLICATION	% OF TOTAL	REMARKS
Commercial Refrigeration	13%	Used at evaporator temperatures down to -37°C
Cold Storage and Food Processing	10%	Temperature range as commercial refrigeration.
Industrial Refrigeration	40%	HCFC-22 together with ammonia is the most frequently used refrigerant above approximately -45°C. From -30°C and upwards HCFC-22 is commonly found in parallel to ammonia and CFC-12.
Air Conditioning & Heat Pumps (Air Cooled Systems)	≈100%	Nearly all units (cooling capacity from 2 kW to 420 kW) use HCFC-22 as a refrigerant.
Air Conditioning (Water Chillers)	30%	The most commonly used refrigerant in chillers with positive displacement compressors. HCFC-22 is also used in the largest centrifugal chillers from approximately 3,500 kW up to 35,000 kW cooling capacity.
Transport Refrigeration and Air Conditioning	47%	Used in 1) Marine air conditioning and provision room refrigeration in newer ships; most central cargo refrigeration plants; fish freezers and fishing boat refrigerated storage, 2) Main refrigerant in new refrigerated railcars, 3) In the smaller and newer trailer units within road transport refrigeration and 4) Bus and coach air conditioning.
Heat Pumps (Heating only and Heat Recovery)	41%	Normally used for low-temperature heat pump applications (up to 55°C). 40 bars plants can operate up to approximately 82°C.

b) Physical and Thermodynamic Data

Some physical and thermodynamic data for HCFC-22 are listed in Table 3.10 /UNEP,1991, Gosney, 1982/.

Table 3.10 Physical and thermodynamic data for HCFC-22 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
86.47	-40.8°C	96.2°C	49.9 bar	61.4°C

c) Retrofitting and New Plants with HCFC-22

Although HCFC-22 is controlled by the Montreal Protocol it is *regarded to be an important refrigerant in the phase out of CFCs*, both as a refrigerant in new plants and as a retrofitting refrigerant for CFCs (short and mid-term transition refrigerant).

HCFC-22 is characterized by the following properties:

- *Colorless, almost odorless, non-flammable*[1] *and non-toxic*. However, when HCFC-22 is exposed to open fire it will decompose into toxic and irritating gases.
- *Compatible* to most metals, alloys and sealing materials (as CFC-12). When retrofitting from CFCs it is necessary to change to recommended O-rings and other gasket materials, thus avoiding swelling and refrigerant leakage.
- *Not fully miscible in mineral lubricating oil* at all operating temperatures (medium solubility). For new plants and when retrofitting from CFCs it is important to use a proper oil return system including an efficient oil separator after the compressor. Choice of correct lubricant is also a crucial point. Generally alkylbenzenes are more miscible with HCFC-22 than naphtenic or paraffinic mineral oils.
- *Higher system pressure* than for example CFC-12. At 40°C condensing temperature HCFC-22 and CFC-12 has saturation pressures of 15.5 bar and 9.6 bar, respectively. This may in some cases disable retrofitting from CFCs to HCFC-22, due to limitations in design pressure.
- *Higher compressor discharge temperature* than those of CFC-12 and R-502. At evaporating/-condensing temperature -30°C/+40°C and reasonable compressor efficiency, the discharge temperature is about 110°C with HCFC-22, and 80°C with CFC-12. For low temperature purposes, two-stage compression may have to be used to a larger extent than with the CFCs. Energy efficiency will then be improved, typically 20-30%, and the initial costs may increase 10-20%.
- *Volumetric refrigerating capacity* (kJ/m^3) is approximately the same as with ammonia and 40% higher than that of CFC-12. Therefore, a moderate compressor capacity is needed. When retrofitting from CFCs to HCFC-22, it is necessary to adapt the compressor (refrigerating) capacity by changing compressor/motor or by reducing the motor drive speed.
- *Throttle valve* has to be changed when retrofitting from CFCs to HCFC-22.

[1] *Combustible in certain mixtures with air and elevated pressure*

- *Medium molar mass* makes HCFC-22 suitable for centrifugal compressors. There is however no possibility for substituting HCFC-22 into CFC-11 or CFC-12 centrifugal chillers (new compressor/motor, etc. is needed)

3.2.1.2 HCFC-123 (R-123) and HCFC-141b (R-141b)

HCFC-123 ($CHCl_2CF_3$) is regarded to be an important alternative in the *phase out of CFC-11 in centrifugal chillers* (short and mid-term transition refrigerant). Some physical and thermodynamic data for HCFC-123 are listed in Table 3.11 /UNEP,1991, Gosney, 1982/.

Table 3.11 Physical and thermodynamic data for HCFC-123 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
152.93	27.9°C	183.8°C	36.7 bar	-

HCFC-123 is *the only currently available candidate to replace CFC-11 in existing centrifugal chillers*. Retrofitting is regarded to be straight forward with open type compressors. HCFC-123 is a more aggressive solvent than CFC-11, and non-metallic materials (seals, gaskets etc.) will have to be replaced with materials which are more compatible with HCFC-123 in order to avoid swelling and refrigerant leakage. In semihermetic units, non-compatibility with motor winding insulation will require motor replacement and increase retrofit costs significantly.

Currently a number of *new* centrifugal chillers are being operated with HCFC-123.

HCFC-123 gives approximately *5% lower energy efficiency* than chillers with CFC-11 as refrigerant at the same operating conditions. Higher mass flow rates of HCFC-123 (0-20%) are required to generate the same cooling capacity as CFC-11, hence compressor size and motor and cost must be increased correspondingly.

Another issue with HCFC-123 is its *toxicity*. Exposure of personnel to HCFC-123 in an 8-hour workaday is limited to a 10 ppm (parts per million) time-weighted-average concentration. This means that machinery rooms for HCFC-123 chillers must be equipped with gas detectors, adequate ventilation systems, and means to alert operators in the event of significant leakage.

HCFC-141b (CCl_2FCH_3) has properties more or less equal to HCFC-123, and can be used as a replacement for CFC-11 in new centrifugal chillers as well as for HCFC-123. HCFC-141b has a very low toxicity, but it is *flammable*, with a *lower flammability limit (LFL)* at 7.4% by volume in dry ambient air.

Some physical and thermodynamic data for HCFC-141b are listed in Table 3.12 /UNEP,1991, Gosney, 1982/.

Table 3.12 Physical and thermodynamic data for HCFC-141b /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
116.95	32.0°C	204.7°C	-	-

3.2.2 HFC Refrigerants

All the HFC refrigerants are chlorine free and have an ODP of zero. However, some of them have a *relatively large GWP factor*, and they may for this reason be regulated at a later date (thus they are considered to be mid-term transitional refrigerants). For more specific GWP figures for each HFC refrigerant, see chapter 2, table 2.2.

The following HFC refrigerants are discussed:

- HFC-134a
- HFC-152a
- HFC-23
- HFC-32
- HFC-124
- HFC-143a

3.2.2.1 HFC-134a (R-134a)

a) General Aspects

HFC-134a (CF_3CH_2F) is quite similar to CFC-12 regarding thermodynamic and physical properties, and the phaseout of CFC-12 in applications operated at medium and high evaporating temperatures is strongly related to the availability of and experience with this refrigerant. These applications include *mobile air conditioning and refrigerating equipment, some stationary air conditioning equipment (air- and water-cooled), domestic appliances and heat pumps*. However, the application of HFC-134a is not a realistic option in low temperature applications, because of its relatively poor energy efficiency and low volumetric refrigerating capacity at low temperatures compared to CFC-12.

HFC-134a is not necessarily the best choice for developing countries for *price and availability reasons*. HFC-134a costs typically 3-5 times more than CFC-12/HCFC-22 and 25 times more than ammonia. In addition, the refrigerant is only produced by a limited group of large chemical companies due to patent protection (a monopoly situation).

HFC-134a has a *significant GWP factor* and in the future it may be regulated and classified as a transitional refrigerant, because of the increasing focus on the greenhouse effect.

b) Physical and Thermodynamic Data and Characteristic Properties

Some physical and thermodynamic data for HFC-134a are listed in Table 3.13 /UNEP,1991, Gosney, 1982/.

Table 3.13 Physical and thermodynamic data for HFC-134a /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
102.03	-26.1°C	101.1°C	40.6 bar	77.6°C

HFC-134a is characterized by the following properties:

- *Colorless, almost odorless, non-flammable*[2] *and extremely low toxicity.*
- *Compatible* to most metals, alloys and sealing materials (as CFC-12).
- *Lower compressor discharge temperature* than CFC-12. At evaporating/condensing temperature -20°C/+40°C and reasonable compressor efficiency, the discharge temperature is approximately 65°C with HFC-134a and 70°C with CFC-12.
- *High molar mass* makes HFC-134a suitable for centrifugal compressors.
- *At high and moderate evaporating temperatures and/or small pressure ratios, the compressor efficiency and COP of a refrigerating system will be almost the same as for CFC-12.* At low evaporating temperatures (below -10°C) HFC-134a will be less efficient than CFC-12. This is due to increased throttling losses and steeper saturation pressure curve which cause increased pressure ratio and lower compressor efficiency.

  To *improve the COP*, it is advisable to reduce the temperature difference over the throttling valve by installing a *suction gas heat exchanger* and an additional air or water cooled heat exchanger, to subcool the condensate from the condenser. In new plants, heat exchanger surfaces in evaporators and condensers should be designed for smaller temperature differences than for CFC-12 systems.

  For low temperature purposes, 2-stage compression will have to be used to a larger extent than with the CFCs. Energy efficiency will be improved, typically 20-30%, but the initial costs may increase 10-20%.

[2] *Combustible in certain mixtures with air and elevated pressure*

- *The volumetric refrigerating capacity* (kJ/m^3) of HFC-134a is typically 2-3% lower than for CFC-12 at +0°C evaporating temperature and 15-20% lower at -30°C, ie higher compressor capacity is needed, especially in the low temperature range. This is due to lower saturation pressure and vapor density at temperatures below +20°C. The difference in saturation pressure between HFC-134a and CFC-12 is rapidly increasing with decreasing temperatures. In addition, higher pressure ratio than CFC-12, especially at low temperatures, gives reduced volumetric compressor efficiency.

  The properties of HFC-134a makes it *more suitable for air conditioning, in medium- to high temperature cooling and heat pump purposes* than for low temperature (freezing) applications.

c) *Retrofitting and New Plants with HFC-134a: Lubricants*

One of the major problems with HFC-134a was to find suitable lubricants. HFC-134a has a very low solubility. Mineral oil does not mix well in HFC-134a, causing to the following problems:

- *poor oil return* to the compressor, resulting in possible compressor failure

- *fouling* of expansion valves and heat exchanger surfaces, leading to reduced system performance (lower COP)

Because of these problems new lubricants especially developed for use with HFC-134a are required. Several alternatives, such as the *polyol ester lubricants*, have been developed and tested, and the tests have shown them to the be most suitable. The polyol esters lubricants are now produced in a range of viscosities to suit most refrigeration applications with HFC-134a.

When *retrofitting* from CFC-12/R-500 to HFC-134a there are some very important factors to be considered.

Ester lubricants are significantly more hygroscopic than those based on mineral oil. The moisture content of the ester lubricant will rise when it is in contact with humid ambient air. Experiments show the beginning of a hydrolysis reaction of the ester by formation of *carbon acids*, if the moisture level exceeds 200 mg/kg. If the level of acid and moisture is too high, there is a risk of *copper plating* in the system and extra wear and tear in the compressor, especially at high temperatures.

To keep the system humidity as low as possible it is important to:

- Use *dry* nitrogen for purging and leakage testing.

- Avoid contact between ester lubricant and air over a long time. Before the ester lubricant is poured into the system it is advisable to heat the oil to about 50-60°C.

- *Ensure effective evacuation of the system* when retrofitting and servicing the system in order to remove air, moisture and non-condensable gases (recommended holding pressure: 1,5 mbar /Sintef, 1994/).

- Replace desiccant filters and moisture indicators.

It is also important to:

- Replace sealings, O-rings and shaft seal with compatible elastomers.
- Adjust or change throttle valve to one suitable for HFC-134a, to ensure optimum evaporator performance.
- Change impeller and gear/motor in larger systems with centrifugal compressors to maintain system performance (COP).

3.2.2.2 HFC-152a (R-152a)

a) General Aspects - Current Applications

HFC-152a (CHF_2CH_3) has been regarded one of the most promising of the pure halocarbons, but its main drawback is the flammability. The GWP factor is low (2% of CFC-12, using 100 years integration time horizon), and its thermodynamic and physical properties regarding pressures, volumetric refrigeration capacity, etc. are very similar to those of CFC-12 and HFC-134a.

HFC-152a has been produced for several years, primarily for the azeotropic mixture R-500 (see chapter 3.1.5). The refrigerant has also been successfully applied in some small heat pump systems and domestic refrigerators (China and USA), and in commercial refrigeration. HFC-152a is suggested as a component in binary and ternary blends. Because of its flammability it is most suitable for smaller systems with low refrigerant charge.

For some applications, especially for developing countries, HFC-152a and hydrocarbons favor over HFC-134a, which is much more difficult and expensive to produce (matter of availability and price). Examples are domestic refrigeration and heat pumps.

b) Physical and Thermodynamic Data and Characteristic Properties

Some physical and thermodynamic data for HFC-152a are listed in Table 3.14 /UNEP,1991, Gosney, 1982/.

Table 3.14 Physical and thermodynamic data for HFC-152a /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
66.05	-24.2°C	113.5°C	45.2 bar	82.8°C

HFC-152a is characterized by the following properties:

- *Flammable.* The *lower explosion limit (LEL)* is 4.8% by volume in dry ambient air and the ignition temperature is 477°C (propane has 2.1% and 470°C, respectively).
- *Colorless, almost odorless and non-toxic.*

- *Compatible* with most metals, alloys and sealing materials (as CFC-12).
- *Medium/low solubility in mineral oil* (as HCFC-22 and R-502).
- *Saturation pressure and pressure ratio* are approximately as for CFC-12.
- *Favorable theoretical performance*, for example 5% better *theoretical COP* than CFC-12 at evaporating and condensing temperature -30°C/40°C.
- *Volumetric refrigerating capacity* (kJ/m^3) is approximately 5% lower than of CFC-12 at operating conditions indicated above.

c) Retrofitting and New Plants with HFC-152a

Because of the flammability HFC-152a should only be retrofitted into *smaller systems with low refrigerant charge*. Domestic refrigerators and freezers have a typical refrigerant charge of 50-100 g per unit, and only exceptionally more than 300 g. For other appliances, refrigerant charges up to 3-5 kg per unit are considered acceptable by experts. *System design and refrigerant charge should always meet local laws and regulations.*

When retrofitting or designing new refrigeration, air conditioning and heat pump systems with flammable refrigerants, some *basic safety precautions* should be made to ensure the necessary safety precautions during operation and service. Examples of such precautions are given in chapter 3.2.3.2, "Hydrocarbons".

3.2.2.3 HFC-23 (R-23)

HFC-23 (CHF_3) is a non-flammable *low temperature refrigerant*. The normal boiling point is -82.1°C, and it is regarded as *an alternative to CFC-13 and BFC-13* in the low temperature part of cascade systems within industrial refrigeration. Lubricant considerations for HFC-23 are different and require thorough evaluation.

Some physical and thermodynamic data for HFC-23 are listed in Table 3.15 /UNEP,1991, Gosney, 1982/.

Table 3.15 Physical and thermodynamic data for HFC-23 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
70.01	-82.1°C	25.9°C	48.2 bar	-

HFC-23 has a very high GWP, almost three times higher than CFC-12, and has an extremely long atmospheric lifetime (310 years). The amount required for this particular application area will be quite limited, and it is not expected that regulations will jeopardize future availability.

3.2.2.4 HFC-32 (R-32)

HFC-32 (CH_2F_2) is a *moderately flammable* refrigerant with a GWP close to zero. The lower flammability limit (LFL) is 14.6% by volume in dry ambient air (propane has 2.1%). It is considered as a *suitable long-term replacement for HCFC-22* in air conditioning, heat pump and industrial refrigeration applications.

HFC-32 will primarily be applied as a component in non-flammable mixtures (ternary blends). However, HFC-32 is not expected to become of much importance until the second half of the decade.

Some physical and thermodynamic data for HFC-32 are listed in Table 3.16 /UNEP,1991, Gosney, 1982/.

Table 3.16 Physical and thermodynamic data for HFC-32 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
52.02	-51.8°C	78.4°C	58.3 bar	-

3.2.2.5 HFC-143a (R-143a) and HFC-125 (R-125)

HFC-143a (CF_3CH_3) and HFC-125 (CF_3CHF_2) are regarded as possible long term substitutes for R-502 and HCFC-22 in low temperature applications where the use of ammonia is considered less appropriate.

Some physical and thermodynamic data for HFC-143a and HFC-125 are listed in Table 3.17 and 3.18, respectively /UNEP,1991, Gosney, 1982/.

Table 3.17 Physical and thermodynamic data for HFC-143a /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
84.04	-47.4°C	73.1°C	38.1 bar	-

Table 3.18 Physical and thermodynamic data for HFC-125 /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
120.02	-48.6°C	66.3°C	36.3 bar	-

HFC-143a is flammable, and the LFL (lower flammability limit) is 7% by volume in dry ambient air. When retrofitting or designing new refrigeration plants, certain safety precautions should be taken (see chapter 3.2.3.2, "Hydrocarbons").

HFC-125 is a *non-flammable* refrigerant.

A crucial disadvantage of HFC-143a and HFC-125 is their *relatively high GWP factor*, which is more than twice as high as that of HFC-134a. They may for this reason be regulated at a future date.

3.2.3 Natural Refrigerants

Natural refrigerants are substances present naturally in the biosphere, and which are harmless to the global environment (zero ODP and very low GWP). Examples of natural refrigerants are air, water, carbon dioxide, nitrogen, the noble gases (for example helium and argon), hydrocarbons and ammonia.

A large number of natural substances have successfully been used as refrigerants over the years. During the first part of this century, ammonia was the dominant refrigerant in medium and large refrigeration plants, and carbon dioxide for shipboard refrigeration. When the halocarbons (CFCs/HCFCs) were introduced, they replaced the natural refrigerants to a great extent due to their alleged safety and harmlessness. However, many accidents have occurred due to suffocation in the heavy CFC/HCFC gases. The halocarbons are also considered harmful to the global environment (ODP/GWP), and now are controlled by the Montreal Protocol.

Some of the natural refrigerants have local environmental effects such as flammability and toxicity, but this are aspects which can be satisfactory handled by *applying proper system design and suitable operating and servicing routines*.

The following natural refrigerants are presented:

- ammonia (NH_3)
- hydrocarbons (propane, iso-butane, butane)

3.2.3.1 Ammonia (R-717)

a) General Aspects - Current Applications

Ammonia (NH_3) has been successfully applied worldwide as a refrigerant for more than a century. In many countries, ammonia is the leading refrigerant within medium- and large chilling, freezing and cold storage plants, and *there is considerable amounts of practical experience with this refrigerant*. Codes, regulations and laws have been developed mainly to deal with the toxic, and to some extent flammable characteristics of ammonia, which if followed provides a high degree of safety.

As ammonia is *expected to be an even more important refrigerant in the future*, it is required to further improve quality in design, installation and operation of systems (authorization of installer firms, certification of operational personnel), and public information.

For *price and availability reasons*, ammonia is very well suited for developing countries, as many countries already have long experience with the use of ammonia as refrigerant. New ammonia technology emerging in the developed countries should be made available to the developing countries.

Current applications and sectors with ammonia as refrigerant are listed in Table 3.19 /UNEP,1991/. Estimated annual share of ammonia in each sector is given in percent of total:

Table 3.19 Current applications and sectors with ammonia as a refrigerant /UNEP,1991/.

AREA OF APPLICATION	% OF TOTAL	REMARKS
Commercial Refrigeration	-	Ammonia is rarely applied due to present safety restrictions and perceived safety problems.
Cold Storage and Food Processing	60%	Most large scale chilling, freezing and cold storage plants use ammonia as refrigerant.
Industrial Refrigeration	35%	Ammonia is together with HCFC-22 the most frequently used refrigerant above -45°C. From -30°C and upwards ammonia is commonly found in parallel to HCFC-22 and CFC-12.
Heat Pumps (Heating only and Heat Recovery)	-	Normally used for larger low-temperature heat pump systems (up to 55°C). Plants designed for 40 bars operating pressure are available and can operate up to 78°C in condensing temperature.

b) Physical and Thermodynamic Data

Some physical and thermodynamic data for ammonia are listed in Table 3.20 /UNEP,1991, Gosney, 1982/.

Table 3.20 Physical and thermodynamic data for ammonia /UNEP,1991, Gosney, 1982/.

Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
17.03	-33.3°C	133.0°C	114.2 bar	58.2°C

c) Retrofitting and New Plants with Ammonia

Ammonia is characterized by the following properties:

- Proven, *long term refrigerant* without global environmental drawbacks (ODP and GWP of zero).

- *Refrigerant price* approximately 1/25 of the forecasted price of HFC-134a. Available worldwide today in very large quantities.

- *Excellent thermodynamic properties*. More efficient than halocarbons with respect to theoretical COP and component efficiencies. At evaporating/condensing temperature -30°C/40°C the theoretical ammonia cycle is approximately 3-4% better than CFC-12/HCFC-22 and 7% better than HFC-134a. The difference in COP increases with increasing condensing temperature.

- *Volumetric refrigerating capacity* (kJ/m^3) is approximately the same as HCFC-22 and 40% higher than with CFC-12 and HFC-134a.

- *Superior transport properties* compared to the halocarbons. Smaller heat exchanger surfaces are needed (also due to high thermal conductivity), and dimensions of piping and components can be reduced considerably.

- *High compressor discharge temperature and pressure ratio*. At low evaporating temperatures two-stage compression is necessary. Energy efficiency will then be improved, typically 30-35% and initial costs may increase 15-20%.

- *Non-compatible* with copper and copper alloys when moisture is present. In new plants all pipes, valves, fittings etc. has to be made of compatible materials. *Ammonia retrofitting is limited to systems made of steel and possibly with aluminum parts*. Because of incompatibility to motor windings only open compressors should be used (hermetic compressors compatible to ammonia have been introduced recently).

- *Non-miscible with mineral oil*. Requires efficient oil separator and oil return system. It can be used together with normal lubricating oils (inexpensive mineral oils). Lubricants that are soluble in ammonia are available, however.

- *Less suitable in centrifugal compressors* because of relatively low molar mass.

- *Toxic with a strong, pungent odor*. A *TLV* of 25 ppm is common, while the lowest reported fatal concentration is about 5,000[3] ppm. The characteristic odor, which is *recognizable at very low concentrations* (less than 10 ppm), provides excellent opportunities for timely repair of leaks and will force the personnel to leave the plant before damaging or threatening concentration are reached.

System safety requires that equipment and machine room is designed according to national and international recommended standards. *Details on such design criteria are given in /ASHRAE, 1983,1985,1987a &1987b, IIAR,1984, ANSI/IIAR/.* Refrigerant charge, application area etc. will determine the necessary safeguards to ensure system safety. *Examples* of such safeguards are:

→ Different kinds of *personal protective equipment*.

→ To maintain system security in case of power failure, an *additional passive ventilating system* should be used. Since ammonia is much lighter than air, an ordinary ventilation duct which leads to the atmosphere is sufficient.

→ For some applications, eg air conditioning or retail refrigeration systems, *special system design* may be necessary to prevent ammonia leakage to public places which could cause panic and dangerous situations. *Examples* of such design are:

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[3] *Ammonia Toxicity Monograph - The Institution of Chemical Engineers 1988.*

- enclose the plant in a reasonable gas tight room or casing
- design aggregates for low refrigerant charge, for example by using hermetic compressors and plate heat exchangers as evaporator and condenser
- indirect distribution system (brine system)

→ *Gas detectors* which activates:

- internal/external alarm system
- emergency ventilation (two-speed fans, etc.)
- water spray system (ammonia is easily absorbed by water)
- emergency shutdown system for compressor, etc.
- sectioning of different parts of the systems by automatic valves to limit refrigerant leak
- water vessel connected to the ammonia pipe line system for absorption of refrigerant in case of serious leaks

- *Flammable and explosive*. The *LEL* is as high as 16% by volume in dry ambient air and the ignition temperature is 630°C. Because of the strong odor it is unlikely that such high concentration can build up and *very few accidents due to fire are actually reported*. Hence, ammonia is not classified as a flammable refrigerant in many countries, and it is only characterized by its toxicity.

3.2.3.2 Hydrocarbons

a) General Aspect - Current Applications

Hydrocarbons are considered to be important refrigerants for the future, replacing R-502, HCFC-22 and in some cases also CFC-12.The hydrocarbons may be used as pure refrigerants (one component) or as components in binary and ternary blends. Some important hydrocarbon refrigerants are listed in Table 3.21.

Table 3.21 Some important hydrocarbon refrigerants

REFRIGERANT	CHEMICAL FORMULA	DENOTION	POSSIBLE REPLACEMENT FOR:
Propane	C_3H_8	HC-290	CFC-12 and R-502
Iso-butane	C_4H_{10}	HC-600a	CFC-12 (higher temp. region)
Butane	C_4H_{10}	HC-600	CFC-114 (lower temp. region)

Hydrocarbons (HCs), especially propane, are well known *refrigerants*, and are being widely used within industries handling flammables, such as *the petrochemical industry and the oil and gas industry*. Hydrocarbons have also recently been used within other sectors, for example transport refrigeration, domestic refrigerators and freezers and heat pumps. Both iso-butane and butane are currently being used as components in binary blends (propane/iso-butane and propane/butane), replacing CFC-12 in domestic refrigerators. Iso-butane is also regarded a possible alternative to CFC-114 in the lower temperature region. At present there is no information available on hydrocarbon replacement for CFC-114 in the high-temperature region.

Hydrocarbons are *long term refrigerants* without global environmental drawbacks (ODP and GWP are zero), and they are available worldwide at a low price. These are aspects of great importance for developing countries.

b) Physical and Thermodynamic Data and Properties

Some physical and thermodynamic data for propane, iso-butane, and butane are listed in Table 3.22 /UNEP,1991, Gosney, 1982/.

Table 3.22 Physical and thermodynamic data for propane, iso-butane, and butane /UNEP,1991, Gosney, 1982/.

Refrigerant	Molar mass	Normal boiling point (NBP)	Critical temperature	Critical pressure	Condensing temp. at 25 bar
Propane	44.10	-42.1°C	96.8°C	42.5 bar	68.1°C
Iso-butane	58.13	-11.7°C	135.0°C	36.7 Bar	108°C
Butane	58.13	-0.4°C	152.1°C	38.0 bar	124°C

Hydrocarbons are characterized by the following properties:

- *Highly flammable*. Maximum explosion pressure for all three are 7.1 bar. The *LEL* by volume in dry ambient air and the ignition temperatures are:

Propane	2.1%	470°C
Iso-butane	1.8%	460°C
Butane	1.5%	365°C

- *Colorless, almost odorless and non-toxic (simple asphyxiants).*

- *Compatible* to most metals, alloys and sealing materials.

- *High solubility* in normal mineral lubrication oils at all operating temperatures.

- Propane, iso-butane and butane have similar liquid density and thermal conductivity, which means that the size of liquid pipes, heat exchanger surfaces (evaporator/condenser) etc. will be +10-20% relative to installations with propane as refrigerant.

- *Transport properties* are better than for CFCs, but not as good as for ammonia. Due to *low molar mass* and *high thermal conductivity*, heat exchanger surface and dimensions on piping and other components can be reduced compared to plants with CFC-12.

- Propane has *lower compressor discharge temperature* than CFC-12. This may positively affect the compressor reliability. At evaporating/condensing temperature -30°C/+40°C, one-stage compression and a reasonable compressor efficiency, the discharge temperature is about 70°C for propane and 80°C for CFC-12.

- For propane the *volumetric refrigerating capacity* (kJ/m^3) is approximately 35-50% higher than CFC-12, depending on the operating conditions. Iso-butane and butane has approximately 50 % and 30% the volumetric refrigerating capacity of CFC-12, respectively.

- In a practical process propane will give *approximately the same COP as CFC-12.*

- Propane is an *excellent refrigerant for centrifugal compressor* because of its near ideal molar mass.

c) Retrofitting and New Plants with Hydrocarbons

Due to the flammability hydrocarbons should only be applied into *smaller systems with low refrigerant charge*. Domestic refrigerators and freezers have a typical refrigerant charge of 50-100 grammes per unit, and only exceptionally more than 300 grammes. For other appliances, a refrigerant charge up to 3-5 kg per unit are considered acceptable by experts. *System design and refrigerant charge should always meet local laws and regulations.*

When retrofitting or designing new refrigerating, air conditioning and heat pump systems with flammable refrigerants, some *basic safety precautions* should be made to ensure the necessary safety during operation and service. *Examples* of such precautions are:

- Design systems with *low refrigerant charge*, for example by using hermetic compressors and plate heat exchangers as evaporator and condenser. Necessary precautions should be made to ensure a gas-tight system by the use of welded pipe connections instead of couplings, improved routines for frequent leakage testing, etc.

- The compressor volume needed is directly depending on the v*olumetric refrigerating capacity* (kJ/m^3) of the refrigerant. For propane the volumetric refrigerating capacity (kJ/m^3) is approximately 35-50% higher than for CFC-12, and with compressor/motor modifications the system should be able are to maintain the same refrigeration capacity. Iso-butane and butane has approximately 50 % and 30% the volumetric refrigerating capacity of CFC-12, respectively, which means that a larger compressor volume is needed in order to achieve the same refrigeration capacity at similar operating conditions.

- Because of higher *condensing pressure* of propane compared to CFC-12, the maximum available condensing temperature are 68°C, compared to 83°C for CFC-12. With iso-butane and butane it is possible to get condensing temperatures at 108°C and 124°C, respectively.

- *Reasonable location* of the system, for example on the roof of the building where a possible leakage would not constitute a safety hazard. Parts of, or the entire system, can be installed in a *gas-tight container* in the engine room. The container is then connected to a separate ventilating system.

- *Adding tracer gas* for the identification of leaks. Several chemicals for tracing leaks have been suggested in the past. Chemical compatibility of the tracer gas with all the materials in the systems should be checked.

- Apply *gas detectors* connected to alarm system and *emergency ventilation* (two speed ventilating fan etc.). Propane has higher density than air and ventilation apertures should be placed close to the floor. To maintain the same safety in case of power failure, an additional passive ventilating system should be used.

- Apply *explosion proof electric devices* (Ex-device) if necessary. Such devices are expensive, and should be kept to a minimum by use of proper system design and operation/service routines.

An advantage with hydrocarbons when retrofitting CFC refrigerating systems, is that remaining chlorine will not cause any problems and charging and service equipment for halocarbons may be used.

3.2.4 Mixtures/Blends

3.2.4.1 Introduction

Refrigerant mixtures or blends represents an important additional possibility for replacement of today's CFC refrigerants. Mixtures can expand the set of acceptable pure refrigerants. The most obvious example is the combination of flammable and non-flammable components to yield a non-flammable mixture.

Mixtures can be categorized into three types:

- Azeotropic mixtures
- Non-azeotropic mixtures
- Near-azeotropic mixtures

An azeotropic mixture consists of two pure refrigerants in a certain rate of mixture so it behaves like a pure substance, with constant evaporating and condensing temperature, and boiling point and dew point is coincident at a given pressure.

Most mixtures are *non-azeotropic* (also called zeotropic mixtures) where evaporation and condensation occur over a temperature range, and the boiling point and the dew point is not coincident. The temperature difference between the dew point and the boiling point is referred to as the refrigerants's *temperature glide*. This temperature glide can be exploited to enhance performance, but *require equipment modification*. Non-azeotropic mixtures and blends are often abbreviated *NARM (non-azeotropic refrigerant mixture)* and *NARB (non-azeotropic refrigerant blend).*

A *NEARM (near-azeotropic, mixture)* consist of two or more pure refrigerants and exhibit such small deviations from azeotropic behavior *to be usable in traditional refrigeration equipment without modification* (small temperature glide, typically 3-4°C).

3.2.4.2 Retrofitting CFC-12 and R-502 Equipment

A number of near-azeotropic binary and ternary blends (two and three compounds) has been introduced recently for retrofitting CFC-12 and R-502, primarily in the domestic and commercial sector. Table 3.23 lists the replacements blends for CFC-12 and R-502 that are commercial available at present.

There are some concerns regarding extensive use of the present blends:

- Most blends contain HCFC-22 and other HCFC refrigerants, which are now controlled by the Montreal Protocol.
- Possible problems of differential leakage and change in the refrigerant composition.
- It is expected that the number of possible blend alternatives will increase rapidly in the near future, and it will be an important task for the chemical companies to agree on a certain standardization.

Table 3.23 Replacement blends for CFC-12 and R-502, available in August 1994./UNEP,1994/.

Replacement for	ASHRAE-no	Composition	
CFC-12	R-401a	HCFC-22/HCFC-124/HFC-152a	52/33/15
	R-401b	HCFC-22/HCFC-124/HFC-152a	61/28/11
	R-401c	HCFC-22/HCFC-124/HFC-152a	33/52/15
	-	R-290/R-600a (propane/isobutane)	50/50
R-502 02	R-402a	HCFC-22/HFC-125/R-290	38/60/2
	R-402b	HCFC-22/HFC-125/R-290	60/38/2
	R-403a	HCFC-22/R-218/R-290	75/20/5
	R-403b	HCFC-22/R-218/R-290	56/39/5
	R-404a	HFC-125/HFC-134a/HFC-143a	44/4/52
	R-407a	HFC-32/HFC-125/HFC-134a	20/40/40
	R-407b	HFC-32/HFC-125/HFC-134a	10/70/20
	R-507	HFC-125/HFC-143a	50/50

a) CFC-12 Replacement Blends

Ternary blends containing HCFC-22, HFC-152a and HCFC-124 in different compositions are alternatives for CFC-12 in refrigeration, air conditioning, and mobile air conditioning applications. The blends have been given the ASHRAE-no R-401a, b, and c, and are intended to replace CFC-12 in existing equipment. Depending on the composition of the blend, the normal boiling point of the refrigerants are adapted to fit different application areas. The different blends have a temperature glide of approximately 4-5°C in the evaporator/condenser (near-azeotropic). Volumetric refrigerating capacity and theoretical energy efficiency is approximately the same as for CFC-12. The ternary blends are not miscible with mineral oils. Alkylbenzene and polyol ester lubricants offer excellent miscibility.

Binary blends containing HCFC-22 and HCFC-142b are also being evaluated, but are not yet commercialized. As long as the HCFC-22 content is at least 30% by weight, the blend is *not* flammable, although HCFC-142b is. The temperature glide is approximately 10°C.

In the domestic sector a binary blend of propane (HC-290) and butane (HC-600) has been introduced in domestic refrigerators. The temperature glide is approximately 3-4°C.

b) R-502 Replacement Blends

There are several blends developed to replace R-502 in existing equipment. Energy efficiency, capacity, discharge temperature and lubricant considerations are important selection criterias.

The near-azeotropic binary blend HFC-125/HFC-143a (R-507) and ternary blends containing HCFC-22, propane and either R-218 (R-403a, R-403b) or HFC-125 (R-402a, R-402b) are candidates in retrofits of R-502 equipment. HFC-based blends containing HFC-125, HFC-134a and either HFC-32 (R-407a, R-407b) or HFC-143a (R-404a) can be used as replacements for R-502 in existing equipment as well as in new installations.

3.3 Refrigerant Data

Table 3.24 Physical and thermodynamic and environmental properties for CFC and non-CFC refrigerants /UNEP,1991/.

Refrigerant	MTW	NBP (°C)	T_c (°C)	P_c (bar)	TLV (ppm)	LFL (%)	Δh_{comb} MJ/kg	ODP	GWP 100 years	A.P.
CFC-11	*137.37*	*23.8*	*198.0*	*44.1*	*1000*	*none*	*0.9*	*1.0*	*3,400*	*I*
CFC-12	*120.91*	*-29.8*	*111.8*	*41.1*	*1000*	*none*	*-0.8*	*1.0*	*7,100*	*I*
CFC-13	*104.46*	*-81.4*	*28.8*	*38.7*	*1000*	*none*	*-3.0*	*-*	*-*	*I*
CFC-114	*170.92*	*3.8*	*145.7*	*32.5*	*1000*	*none*	*-3.1*	*0.8*	*7,000*	*I*
R-500	*99.30*	*-33.8*	*105.5*	*44.3*	*1000*	*none*	*-*	*0.7*	*5,400*	*I*
R-502	*111.65*	*-46.6*	*82.2*	*40.8*	*1000*	*none*	*-*	*0.3*	*4,300*	*I*
HCFC-22	86.47	-40.8	96.2	49.9	1000	none	2.2	0.055	1,600	I
HCFC-123	152.93	27.9	183.8	36.7	10-100	none	2.1	0.02	90	I
HCFC-141b	116.95	32.0	204.7	-	500[4]	7.4	8.6	0.11	590	I
HFC-134a	102.03	-26.1	101.1	40.6	1000[4]	none	4.2	0	1,200	I
HFC-152a	66.05	-24.2	113.5	45.2	1000[4]	none	16.9	0	150	I
HFC-23	70.01	-82.1	25.9	48.2	1000[4]	none	-12.5	0	12,000	I
HFC-32	52.02	-51.8	78.4	58.3	1000[4]	14.6	9.4	0	220	I
HFC-125	120.02	-48.6	66.3	36.3	1000[4]	none	-1.5	0	3,400	S-M
HFC-143a	84.04	-47.4	73.1	38.1		7.1	10.3	0	3,800	M
Ammonia	17.03	-33.3	132.3	113.3	25	15.0	22.5	0	0	I
Propane	44.10	-42.1	96.8	42.6	s.a.[5]	2.1	50.3	0	3[6]	I
Iso-butane	58.13	-11.7	135.0	36.7	s.a	1.8		0		I
Butane	58.13	-0.4	152.1	38.0	s.a	1.5		0		I
CO_2	44.01	subl.	31.1	73.7	5000	none	-	0	1(0)[7]	I

MTW - Molar mass (kg/kmol) *NBP - Normal boiling point (°C)* *T_c - Critical temperature (°C)* *P_c - Critical pressure (bar)*

TLV *Threshold Limit Value (ppm by volume), established by ACGIH*

LFL *Lower Flammability Limit (% by volume in dry ambient air)*

Δh_{comb} *Heat of combustion (MJ/kg). Calculated assuming CO_2, HF (or F_2 if insufficient H), Cl_2 and H_2O (if excess H) as products. Negative and small positive values indicate that reaction with oxygen is not energetically favorable.*

ODP *Ozone Depletion Potential. ODP values are relative to CFC-11 (=1.0) and are based on a semi-empirical method of calculation as presented in the 1991 UNEP/WMP Science Assessment Report (November 1991).*

GWP *Global Warming Potential. GWP are relative to CO_2 and are given for 100 year integration time horizon. Data from the IPCC Scientific Assessment (1992). Data for HFC-23 and HFC-32 are estimates based on limited data and 500 year integration time horizon. GWP is steady-state value (McFarland).*

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[4] *TLV not established by ACGIH. Estimate of comparable index based on limited or incomplete toxicity testing.*

[5] *s.a. = simple asphyxiant*

[6] *GWP of hydrocarbons is due almost entirely to the GWP of the CO_2 resulting from decomposition.*

[7] *Abundant amounts of CO_2 are recovered from waste gas. Thus, the effective GWP of commercial CO_2, for instance used as refrigerant, is zero.*

Volumetric Refrigerating Capacity and Coefficient of Performance (COP)

Table 3.25 *Simplified presentation of relative volumetric refrigerating capacity (q_{vol}), relative theoretical coefficient of performance (COP) and theoretical compressor discharge temperature ($t_{discharge}$) for a number of refrigerants at two operating conditions. Standard vapor compression cycle with throttling, one stage compression and 70% compressor isentropic efficiency, no subcooling or superheating and evaporating/condensing temperatures -30°C/40°C and -5°C/40°C. [1] Two-stage compression necessary. /UNEP,1991/*

REFRIGERANT	Relative q_{vol} (-30°C/40°C)	Relative q_{vol} (-5°C/40°C)	Relative COP (-30°C/40°C)	Relative COP (-5°C/40°C)	$t_{discharge}$ (-30°C/40°C)
CFC-12	*1.00*	*1.00*	*1.00*	*1.00*	*77°C*
R-502	*0.62*	-	*0.88*	-	*73°C*
HCFC-22	0.59	0.62	1.00	0.96	108°C
HFC-134a	1.14	1.02	0.96	0.97	70°C
HFC-152a	1.06	1.03	1.06	1.04	94°C
Ammonia	0.58	0.55	1.02	1.02	96°C[1]
Propane	0.70	0.73	0.99	0.96	70°C

Volumetric Refrigerating Capacity (q_{vol}) relative to CFC-12 (=1.0):
Relative value lower than 1.0 means lower compressor capacity is needed (gives lower compressor costs) compared to an identical application with CFC-12 as refrigerant (favorable).

Theoretical COP relative to CFC-12 (=1.0):
Relative value higher than 1.0 means better COP (in other words *possibly* higher energy efficiency and lower operating costs) than an identical application with CFC-12 as refrigerant (favorable).

The **COP** of an refrigerating, air conditioning or heat pump system is basically independent from the refrigerant applied. Nevertheless, by assuming the same single stage cycle based on isentropic compression, isenthalpic throttling and equal evaporating/condensing temperatures for the refrigerants, a theoretical indication of the relation between COP of different refrigerants is obtained. In practical systems, these figures are generally not reproduced due to differences in working cycle, compressor efficiency, heat transfer characteristics, component design, etc. *Thus, the practical COP is much more a matter of choice of cycle and system design than of the refrigerant.*

Relative Price for Refrigerants
To give an overview of the cost level for some refrigerants, both controlled substances and acceptable alternatives, Table 3.26 summarizes the relative values. The cost values might change over time due to several factors such as:

- Increased production volumes
- Lower production cost for HFCs

- Reduced availability of CFCs

Table 3.26 Approximate relative prices for refrigerants

CFC-12	HCFC-22	HFC-134a	HFC-152a	Ammonia	Propane	CO_2
1	1.5	3-5	1	0.2	0.4	0.1

3.4 Alternative Non-CFC Technology

There is a wide range of alternative refrigeration technologies. These include different types of refrigerants and refrigeration cycles. Some of them, like ammonia-based vapor compression and absorption systems, water-based evaporative cooling systems and hydrocarbon-based vapor compression systems are already in wide use.

Other, such as helium based Stirling cycle systems and zeolite-based adsorption systems are either beginning to enter the commercial market, or will in the near term.

It is important to note, that many of the alternative systems are competitive with or even superior to, conventional vapor compression systems using CFCs, HCFCs, or HFC-134a, in terms of cost and efficiency. The efficiency of the system depends upon the system design, which needs to be optimized for a particular refrigerant, and on the properties of that refrigerant.

In this section we will point out some of the alternative technologies. Not all of them are what one might call *mature* technologies in all applications, but they are under investigation, and *can* have possibilities in the future.

Parts of this section (except 3.4.2) is basically taken from the Greenpeace report "Climbing out of the ozone hole" /Greenpeace, 1992/.

3.4.1 Principle of Vapor Compression Systems

Vapor compression is the most common refrigeration cycle today. This cycle can be found in most domestic, retail and industrial applications. Systems like this uses electrical energy to continually pump a refrigerant between its liquid and gaseous phases, thus causing a cooling effect.

The main components in a vapor compression system, are compressor, throttling valve, evaporator and condenser. Refrigerant evaporates in the evaporator and the low pressure vapor is drawn in to the electrically driven compressor and compressed to high pressure. The high pressure (and temperature) refrigerant condenses in the condenser and finally is expanded to low pressure in the throttling valve before it starts a new cycle.

Several alternative refrigerants for vapor compression systems can be used, including water, ammonia and hydrocarbons. Ammonia and propane-based vapor compression systems have already been in use for several decades.

A German company /Paul, 1992/ is using water as a refrigerant in a modified vapor compression cycle. The water is under vacuum since it can only function as a refrigerant below atmospheric pressure. The system produces chilled water without intermediate heat exchanger which enhances the efficiency of the system. This system is limited to temperatures above freezing. An add-on system employing mixtures of water and ice is also being used so that cooling is produced both by melting and evaporation. Systems like this have to be significantly larger than equal capacity CFC systems because of the large volume of water required. Current applications already include district heating (heat pumps) and mine tunnel cooling plants.

Ammonia has been in use in refrigeration for decades, even before the advent of CFCs. Its superior efficiency and heat transfer properties relative to CFCs has made it the chemical of choice in many large chiller installations using vapor compression cycles. Ammonia systems are widely used today in the food storage, processing and chemicals industry. In the U.K. a large supermarket chain uses ammonia in its two main cold stores. In the U.S. 81% of refrigerated warehouses operate on ammonia systems /UNEP, 1992/. Also in Germany and the nordic countries one can see a similar trend.

Many companies around the world use large ammonia water-chiller machines. The current development trend is towards smaller machines which are being sold and installed as entire units, as opposed to larger machines which require on-site assembly. A company in Sweden /Electrolux, 1991/ manufacture smaller, packaged water-chiller units which cool water in a circulation loop using plate heat exchangers. The volume of ammonia is much less than in more traditional heat exchanger systems. Similar packaged systems are produced both in the U.S. and in Germany.

Hydrocarbons can, in some cases, be used as 'drop-in' substitutes to CFCs in existing conventional vapor compression machines. They have excellent refrigerant properties with thermodynamic efficiencies equal to or above CFCs. Operating temperatures are also comparable.

New hydrocarbon applications are being increasingly used and researched. Hydrocarbons are now used as refrigerants at industrial sites around the world where the facility is set up to meet the standards concerning use of flammable substances. Several producers of domestic refrigerators are now introducing refrigerators using hydrocarbons as refrigerant. Several German manufacturers (for example Foron (Formerly called dkk Scharfenstein), Bosch & Siemens), now produce domestic refrigerators using hydrocarbons.

A U.S company has tested air conditioners using propane finding the test results promising, while scientists form the South Bank Polytechnic in the U.K have retrofitted a domestic refrigerator with propane and produced positive performance results even without design modifications.

3.4.2 Principle of Absorption Systems

Absorption refrigerating systems are heat driven, this means that the process is operated by supply of heat instead of power to a mechanical compressor. In some applications these systems represent an alternative to the traditional vapor compression cycle. They are mainly of present interest within *industrial refrigeration* and as *air conditioning units* (unitary air conditioners and absorption chillers).

In an absorption system it is the ability of liquids and salts to absorb vapor of different refrigerants which is utilized.
The most common *working fluids* are:

- Ammonia (refrigerant) and water (absorbent).

- Water (refrigerant) and lithium bromide (absorbent). These systems are restricted to evaporating temperatures above 0°C, and are primarily used in absorption chillers.

The main components in an absorption system are *evaporator*, *throttling valve* and *condenser*. The mechanical compressor is replaced by a chemical compressor (absorption circuit) consisting of an *absorber*, *solution pump*, *heat exchanger*, *boiler* (or *generator*) and *liquid valve*. This group of components draw vapor from the evaporator, and deliver high pressure vapor to the condenser, just as the mechanical compressor does.

When ammonia and water is the working pair, the absorber is fed with a weak solution of ammonia in water. Because a solution of ammonia and water have a lower vapor pressure than pure ammonia at the same temperature, this weak solution absorbs ammonia vapor from the evaporator. The absorption of ammonia is a strongly exothermic process, and the absorber has to be cooled in order to keep the temperature constant. The strong solution of ammonia and water formed in the absorber is then pumped to a higher pressure by the solution pump and delivered to the boiler or generator via a heat exchanger. In the generator, the strong solution is boiled by heating it, and the ammonia vapor is rectified to nearly pure ammonia and delivered to the condenser. The weak solution is finally cooled down to the absorber temperature in the heat exchanger. A liquid valve maintains the difference in pressure between the generator and the absorber.

In an absorption refrigerating plant the desired cooling/freezing capacity is maintained by the evaporator. *Heat at high temperature* has to be added in the generator, either by using steam or by direct combustion of oil or natural gas. A small amount of electricity has to be added to the system to operate the solution pump. Heat at medium temperature is rejected in the absorber and condenser, and has to be removed by cooling water.

3.4.2.1 Present Applications

Absorption Chillers

The absorption chiller system is *a tried and proven technology* that is mass produced and well supported by trained personnel. Traditionally the single stage units could not compete with vapor compression systems on an efficient basis. Applications were limited to sites that could utilize waste heat as the primary energy source on a cost effective basis. Such sites might be cogeneration systems where waste engine heat or steam was available or where natural gas prices were particularly favorable over electric rates. In the past decade two-stage absorption chillers have been developed and are now produced with *primary energy based efficiencies that approach 50-60% of those of vapor compression systems*[1].

Today three-stage absorption systems are being developed to achieve efficiencies even closer to vapor compression systems. *Absorption chillers are inherently larger and considerably more expensive than mechanical type compression chillers*, so absorption systems to date have had only limited market expansion in the western world. In Japan, where electric rates are much higher, the number of absorption chillers is growing more rapidly.

Another inherent difficulty that will limit the changeover is the inability to retrofit in many existing buildings because their access ways are not large enough to allow for the chiller to be delivered to the existing machine room.

Unitary Air Conditioners

Direct-fired absorption air conditioners also exist in the market today. They use heat, usually from combustion of gas, to create cooling. The refrigerant/absorbent in these absorption cycle machines are usually ammonia and water. Unitary absorption cooling systems using lithium bromide and water are also made in small numbers.

There are presently several drawbacks to residential-sited, ammonia or lithium bromide absorption cycle air conditioners.

- *Costs of the equipment is generally higher* because the units are larger and use more material for a given capacity. This also includes more extensive piping and generally more expensive assembly methods (welded connections).

- They *require more sophisticated materials* to withstand the corrosiveness of lithium bromide. The same corrosiveness also create increased maintenance difficulties.

- The efficiency of gas-fired absorption air conditioners for unitary applications is *between 40 and 60%* of traditional vapor-compression system efficiency[8]. In locations where the electricity price is much higher than the gas price, the operation costs of absorption equipment can still be competitive with electrically driven vapor-compression machines.

Domestic Refrigerators

The absorption cycle can also be utilized in domestic refrigerators. Ammonia and water is used as the working fluid, and the refrigerators can be heated either by an electric heater or by combustion (natural gas, *LPG (liquid petrol gas)* or kerosene).

Small absorption refrigerators with similar cabinet load characteristics consume approximately twice the as much energy as electric driven compression refrigerators. The primary energy consumption of the absorption unit can be less than of vapor compression refrigerators if the absorption units have reduced freezer volume and are heated with high efficiency natural gas burners.

[8] *The efficiency of electricity production is not taken into consideration*

3.4.3 Other Alternatives

3.4.3.1 Adsorption Systems

Adsorption refrigerating systems are similar to the absorption cycle, except that the refrigerant attaches to, and detaches from a solid medium. Heat drives the refrigerant off the solid medium and cooling occurs when it returns to the solid medium by adsorption. Zeolite/water can be used as a refrigerant pair and solar energy, natural gas and waste heat are among the possible heat sources for this system.

Zeolite is a naturally occurring mineral that is hygroscopic: it attracts water. Tests in the U.S. on a heat pump using zeolite, with natural gas as the heat source, produced favorable results. In Germany this technology is being researched for applications such as mobile coolers, domestic refrigerators and automotive air conditioning /Greenpeace, 1992/.

3.4.3.2 Stirling Cycles

The Stirling refrigeration cycle continuously expands (heats) and compresses (cools) a fixed mass of gas without changing physical state. These systems are highly efficient and can be used over a wider range of temperatures than other systems.

Helium is being tested in Stirling systems. These systems are likely to be on the market in the near to mid term.

Small prototype Stirling cycle refrigerators have been successfully tested by a major European refrigerator manufacturer. Field testing is planned for a full size domestic refrigerator /Greenpeace,1992/. Several U.S. companies are conducting research on Stirling cycle machines, looking particularly at domestic refrigeration.

It should be noted that the limited supply of helium could influence the scale of Stirling cycle machine use.

3.4.3.3 Evaporative Cooling

Cooling by evaporation involves the natural cooling effect of water evaporating into air. This process removes heat from liquid water in order for some of the water to evaporate in the air. The system has a long history of use as an inexpensive cooling system. Today, air conditioning and general cooling to remove heat, such as in cooling towers, are the main uses for this technology. Liquid desiccant cooling is a modification of evaporative cooling which allows the use of the technology in high humidity areas. In these systems, a liquid first absorbs the water out of the air and the dried air then enters an evaporation cooler. Since the air is dry, the cooler works at high efficiencies.

3.4.3.4 Liquid Carbon Dioxide and Nitrogen (Gas Expansion)

One rather novel technique which is currently being used to cool highway freight trailers, is gas expansion. It involves spraying a pre-cooled liquid, such as liquid carbon dioxide or nitrogen, into the refrigerated area which causes the liquid to evaporate and hence cool.

3.4.3.5 Air Cycle

/Fleming, 1994/, /Kruse, 1994/, /Murphy, 1994/

Air was used as a working fluid in the first refrigeration plants, but was later replaced by vapor-compression systems using ammonia, SO_2, CO_2 and finally CFC's. Air is environmentally benign and non-toxic, and there is no problem with the availability. The use of air as refrigerant is based on the principle that when gas expands, its temperature at the final pressure is much lower and the gas can be used for cooling purposes. Vice versa, when the air is compressed, its temperature increases and the gas can be used for heating. The air cycle process can be compared to the theoretical Joule Cycle, which consists of two isentropes and two isobars.

The efficiency of the air cycle is dependent on the efficiency of the compressors and expanders, and on the humidity of the air used in the cycle. Recent developments in turbo-machinery have improved the possible energy efficiency of air cycle systems, but for many applications they still do not compete with vapor-compression systems. Air cycle systems can be operated both as open and closed systems. The relative humidity of the moist air has a considerable influence on the COP of the open cycles. If the air used in the open cycle is dry, the COP of the open cycle will be higher than in a closed cycle. The COP of an open cycle decreases with low refrigeration temperatures and high relative humidity. The performance of an air cycle system does not differ as much as that of a vapor-compression unit when operating under conditions different from the design pressure.

One of the main advantageous for the air cycle is the reliability. Even if the operating costs for an air cycle plant is higher than for a vapor-compression plant, it may repay in the long run because of less hours spent for maintenance and repair.

Air cycle is regarded a promising alternative within industrial blast freezing, transport container refrigeration and automotive and railway air conditioning. Also applications which involves very low temperatures, and both heating and cooling loads, may be considered.

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4. HOW TO CONVERT TO NON-CFC REFRIGERANTS AND TECHNOLOGIES

4.1 Introduction

This chapter describes how to convert from CFC refrigerants in refrigerating, air conditioning and heat pump systems to non-CFC alternatives. Detailed descriptions are given for the most common and promising conversions. All conversions described are technically possible, regarding thermodynamic and physical properties of the refrigerants. The grade of maturity differs between the conversions. Conversion to HCFCs, HFC-134a and blends are relatively well documented and has been done in a large scale, while conversions to hydrocarbons are yet in the planning/bench test state.

Retrofitting means replacement of CFC-refrigerants in existing equipment including minor or major modifications or redesign of the plants. The degree of modification will depend on factors like system design and size, retrofit refrigerant etc.

Existing plants which have reached the end of their economic lifetime should be replaced with totally new systems based on natural refrigerants or other non-CFC refrigerants, such as ammonia, hydrocarbons, HCFCs and HFCs.

4.2 Alternative Non-CFC Refrigerants and Equipment

4.2.1 Introduction

Chapter 3 *"CFC and Non-CFC Refrigerants and Technologies"* provides information on the following properties of current CFC and available non-CFC replacement refrigerants:

- Physical and thermodynamic properties
- Price, availability
- ODP, GWP, toxicity, flammability etc.
- Relative refrigerating capacity (compressor costs)
- Relative theoretical COP at different operating conditions (operating costs)

The most important alternative non-CFC refrigerants when retrofitting from CFC-11, CFC-12 and R-502 or when building new refrigeration, air conditioning and heat pump plants are listed in Table 3.1.

Table 3.1 *Alternative non-CFC refrigerants when retrofitting from CFC-11, CFC-12 and R-502 or when building new refrigeration, air conditioning or heat pump plants.*

	CFC - 11	CFC - 12	R - 502
Alternative refrigerants when **retrofitting**	• HCFC-123	• HFC-134a • Blends • HCFC-22 • HFC-152a • Propane (HC-290) (Under Development)	• Blends • HFC- 134a • HCFC-22 • Propane (HC-290) (Under Development)
Alternative refrigerants in **new plants**	• HCFC-22 • HFC-134a • Ammonia • Hydrocarbons	• Ammonia • HFC-134a • HFC-152a • Hydrocarbons	• Two-stage HCFC-22 • Two-stage ammonia • Blends

References about specific details are given in the text. The following references are used in the chapters concerning retrofitting: /Beermann, 1992/, /Bock,1992/, /Carpenter,1992/, /Corr/, /DuPont, 1993a,b,c/, /DuPont, 1992a,b/, /DuPont/, /Haukås,1992a,b,c/, /ICI,1992/, /Landteknikk,1993/, /Prestcold,1988/, /Renz,1993/, /Vieth,1993/.

4.2.2 Required System Modification when Retrofitting from CFC to Non-CFC Refrigerants

In general, alternative refrigerants can not be "dropped into" a system designed for CFCs. Retrofitting existing equipment involves a *thorough and systematic evaluation* of safety, reliability, capacity requirements and energy efficiency. Other aspect, as investment costs, amount of work, price and availability of refrigerants should also be taken into consideration when choosing retrofit refrigerants. Experience has shown that in some applications, the investment costs for retrofitting from CFC-12 to HCFC-22, is almost equal to the investment costs for retrofitting from CFC-12 to HFC-134a. The reason is higher material costs, but limited work when retrofitting to HCFC-22, compared to retrofitting to HFC-134a using the Castrol-method /Schau, 1993/.

The general factors listed on the next page should be taken into consideration regardless of alternative refrigerants to be used and system to be retrofitted.

GENERAL CONSIDERATIONS WHEN RETROFITTING:

1) The unit intended for conversion must be in good technical condition.

2) Perform base line testing prior to the retrofit to determine the unit performance.

3) Consult the manufacturer or equipment owner for maintenance records; information about recommended change in system design, and specific procedures needed when retrofitting.

4) Some alternative refrigerants *may not be compatible* with the original system components or the replacement parts. Review the system maintenance record and the manufacturer's record to determine the systems construction materials. Critical points are metals of zinc, brass, bronze with zinc and sealing materials (elastomers in O-rings, etc.).

5) The most typical modifications required are:

- *Change of lubricant.* Always consider change of lubricant when retrofitting from one refrigerant to another. Consult the compressor manufacturer about the change of refrigerant, to ensure that all modifications required are identified and that correct viscosity of the lubricant is chosen.

- *Adjustment or change of expansion device.* Always adjust or change expansion device when retrofitting from one refrigerant to another.

- *Change of desiccant material.* Always change desiccant filter when retrofitting from one refrigerant to another. Suction line filter should also be considered.

- *Compressor modifications.* Installation of a new compressor or rebuilding of the existing one, decreasing or increasing the compressor speed, etc.

4.2.3 Retrofitting from CFC-11 to HCFC-123

HCFC-123 is presently the only available candidate to replace CFC-11 in existing centrifugal chillers. Current lubricants used with CFC-11 are fully miscible at all operating conditions, and it is not necessary to switch to another lubricant. HCFC-123 is a strong solvent toward plastics and elastomers, and swelling and weight change may occur. Hence, it is necessary to change O-rings and other parts made of plastics or elastomers, with parts qualified by manufacturers for use with HCFC-123. In semihermetic units, non-compatibility with motor winding insulation will require motor replacement. For further details see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

In low pressure systems with CFC-11 and HCFC-123, it is important to reduce refrigerant emission when purging air out of the system. There are purge recovery units available, which captures the refrigerant present when purging, and recycles the refrigerant for re-use. This can reduce the refrigerant emission due to purging up to 99% /Carrier,1993/.

SYSTEM MODIFICATION:

Typical modifications required for retrofitting CFC-11 installations are :

- If a semihermetic compressor is used, switch to an open compressor
- Change of O-rings to materials compatible with HCFC-123
- Adjustment or change of expansion device

- Change of desiccant filter

The compatibility of HCFC-123 with construction materials in the CFC system should be considered. For large centrifugal chillers it may be necessary to replace compressor impellers/gears to ensure the required performance for the system is maintained.

RETROFIT PROCEDURE:

1) Use the compressor to pump the existing refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) Drain the original oil charge from the compressor. If an oil separator is fitted, this should be drained as well.

3) Carry out the equipment modifications as required.

4) Recharge system with new oil of same quality.

5) Evacuate the system and recharge with HCFC-123.

4.2.4 Retrofitting from CFC-12 to HFC-134a

HFC-134a has a low solubility, in other words mineral oil does not mix well in HFC-134a. This will contribute to poor oil transport in the refrigerating system. Poor oil return can yield compressor failure, fouling of expansion device and heat transfer surface, leading to reduced system performance. Hence it is necessary to switch to a *polyol ester lubricant* especially developed for use with HFC-134a. For further details see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

SYSTEM MODIFICATION:

The following modifications will be required for most installations:

- Change of mineral oil to polyol ester lubricant
- Adjustment or change of the expansion device
- Change of desiccant filter
- If necessary, change compressor, or if open compressor is used, increase speed

The compatibility of the HFC-134a with the construction materials in the CFC system must be considered. For large systems with centrifugal compressors it may be necessary to replace compressor impellers and gears to ensure that the required performance of the system is maintained.

In order to avoid formation of carbon acids, chlorine and copper plating during operation, it is important to keep the system humidity as well as the remaining content of CFC-12 and mineral oil as low as possible. Residual chlorine, from both CFC-12 and mineral oil should not exceed 200 ppm in HFC-134a. By using normal evacuation methods, levels of 40-60 ppm residual chlorine can be achieved (6.5 - 2.5 mbar vacuum). The remaining content of mineral oil in the polyol ester lubricant should not exceed 1 - 5%. System humidity should be kept less than 100 - 200 ppm.

RETROFIT PROCEDURE:

Several procedures have been developed. There are two procedures, that are now commonly accepted: *Castrol-method* and *Forced cleaning-method*. The method for retrofitting depends on the design, complexity, and size of the system. The Castrol-method has an advantage when retrofitting large and complex systems, while the forced cleaning method seems to be best with smaller systems, for instance hermetic compressors or other compressors without oilplugs.

Castrol-method:

1) Use the compressor to pump the existing refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) Drain the original mineral oil charge from the compressor. If an oil separator is already fitted, this should be drained as well.

3) Recharge the system with the new polyol ester lubricant.

4) Evacuate the system and run the refrigeration kit using CFC-12 as refrigerant.

5) After running for a period of time sufficient to produce a homogeneous mineral oil/ester lubricant mixture, the lubricant charge should be drained and replaced with new ester lubricant.

6) Restart the refrigeration equipment using CFC-12. Repeat the process of draining oil and recharging with new ester lubricant until the mineral oil concentration in the ester lubricant is below 1%. On-site methods to determine the mineral oil content has been and will be further developed, to achieve satisfying accuracy. One appropriate method is as follows /Carpenter,1992/:

   A volume of 10 ml of lubricant/mineral oil mixture is added to a clean, dry container capable of holding 250 ml. A 100 ml volume of reagent-grade methanol is added at room temperature and the mixture stirred vigorously for 10 seconds to ensure adequate mixing. The container is then left to stand until the liquid is clear and a well-defined lower layer is apparent. This lower layer is the residual mineral oil. The lower layer is drawn into a graduated syringe or measuring cylinder or jar (1-5 ml capacity) and the volume of the mineral oil is determined. The results are expressed as a percentage by volume. This procedure involves the use of methanol and caution should always be used.

7) At this stage, remove and recover the CFC-12. Required equipment modifications should be carried out, such as replacing expansion device and desiccant filter.

8) If necessary, change or rebuild the compressor.

9) After evacuation of residual CFC-12, recharge the system with HFC-134a.

Forced cleaning method:/Landteknikk,1993/, /AKA,1993/

1) Flush the system with CFC-12 in a closed circuit, using a forced cleaning station. Since mineral oil is soluble in CFC-12, the oil will be washed of the system. The mineral oil is separated from the refrigerant in a oil separator. In most units, required flushing time is 1 - 4 hours.

2) Carry out required equipment modifications, such as replacing expansion device and desiccant filter.

3) If necessary, change or rebuild the compressor.

4) Recharge the system with HFC-134a and polyol ester lubricant.

There are portable forced cleaning stations on the market. For most refrigeration systems they can be connected to existing service connections. The retrofit procedure can be done on-site in one operation, making it possible to retrofit smaller systems which could not tolerate high retrofit costs, or systems where retrofits has to be done within a limited period of time. In larger systems it might be necessary to repeat the flushing prodecure.

4.2.5 Retrofitting from CFC-12 to Blends

Blends can be tailor-made to fit almost any refrigeration purpose, and can be retrofitted into many refrigeration systems with only minor adjustments. Blends are therefore expected to play an important role in the phase-out of CFCs. Especially near-azeotropic blends (NEARB) have possibilities as retrofit refrigerants. One of the disadvantages with blends, is the problem of detecting gas and liquid fraction after leakages.

Blends can be used when retrofitting to HFC-134a is difficult or costly, for example in systems where it is difficult to change the oil. Some blends can use both alkylbenzenes and polyol ester lubricants, and even in some cases mineral oil. The rest of mineral oil in the system is therefore less critical when retrofitting to blends than when retrofitting to HFC-134a. Some manufacturers recommend to move 90 % of the mineral oil in the system /Lawson, 1993/, /DuPont, 1993b,c/

SYSTEM MODIFICATION:

Typical modifications required for retrofitting of CFC-12 installations are :

- Change of mineral oil
- Adjustment or change of the expansion device
- Change of desiccant filter

The compatibility of the blend with construction materials in the CFC system is usually not a problem. However, it should always be considered.

RETROFIT PROCEDURE:

1) Use the compressor to pump the existing refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) Drain the original oil charge from the compressor. If an oil separator is fitted, this should be drained as well.

3) Carry out the required equipment modifications.

4) Recharge the system with new lubricant.

5) Evacuate the system and recharge it with the blend.

4.2.6 Retrofitting from CFC-12 to HCFC-22

HCFC-22 has approximately 40% larger volumetric refrigerating capacity than CFC-12. When retrofitting it is necessary to adapt the compressor (refrigerating) capacity, by changing compressor and motor or by reducing the motor drive speed for open compressors. HCFC-22 will give higher system pressure than CFC-12. This may disable retrofitting from CFC-12 to HCFC-22 due to pressure limitations. It is important to check maximum working pressure of components, especially if operating at high condensing temperature. For further details see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

SYSTEM MODIFICATION:
The following modification will be required for most installations:

- Change of compressor or reduction of compressor speed
- Change of expansion device
- Change of desiccant filter
- Install oil separator, as mineral oil is not as miscible with HCFC-22 as with CFC-12

For compressors with an internal oil pump it is recommended to install crankcase heater, due to the relative densities of liquid HCFC-22 and oil.

RETROFIT PROCEDURE:

1) Use the compressor to pump the existing refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) Drain the original oil charge from the compressor. If an oil separator is already fitted, this should be drained as well.

3) Carry out the equipment modifications as required, such as replacing expansion device, desiccant filter and any compressor modifications.

4) Recharge compressor with the new lubricant.

5) Evacuate the system and recharge with HCFC-22.

4.2.7 Retrofitting from CFC-12 to HFC-152a

Because of the flammability HFC-152a should only be retrofitted into smaller systems with low refrigerant charge, such as domestic and commercial refrigerators with hermetic systems. HFC-152a should never be retrofitted into refrigeration plants with electrical equipment that may cause ignition, without taking precautions to avoid accidents. Necessary safety precautions must be taken: system design and refrigerant charge should always meet local codes and regulations. For further details see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

HFC-152a has approximately 5% less volumetric refrigerating capacity than CFC-12.

Systems using HFC-152a as refrigerant should use lubricants based on polyalkylene glycol (PAG lubricants) or esterbased lubricants.

The retrofit procedure from CFC-12 to HFC-152a is technically possible, regarding thermodynamic and physical properties of the refrigerants, but it is still on the planning/bench test state.

SYSTEM MODIFICATION:

Modification required for small commercial and domestic installations are :

- Change of lubricant
- Adjustment or change of expansion device
- Change of desiccant filter

The compatibility of HFC-152a with the construction materials and elastomers in O-rings etc. in the original CFC-12 system should always be considered.

RETROFIT PROCEDURE:

1) Use the compressor to pump the existing refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) Drain the original oil charge from the compressor. If an oil separator is already fitted, it should also be drained as well.

3) Carry out the equipment modifications as required, such as change of desiccant filter etc.

4) Recharge system with the new lubricant.
5) Evacuate the system and recharge with HFC-152a.

4.2.8 Retrofitting from CFC-12 to Propane (HC-290)

Please see Appendix.

4.2.9 Retrofitting from R-502 to Blends

Blends can be tailor-made to fit almost any refrigeration purpose, and can be retrofitted into many refrigeration systems with only minor adjustments. Blends are therefore expected to play an important role in the phase-out of CFCs. Especially near-azeotropic blends (NEARB) have possibilities as retrofit refrigerants. One of the disadvantages with blends, is the problem of detecting gas and liquid fraction after leakages.

Retrofitting to a blend is at the moment one of the few available retrofit solutions for R-502.

Blends can use both alkylbenzenes and polyol ester lubricants, and some can even use mineral oil. The rest of mineral oil in the system is therefore less critical when retrofitting to blends than when retrofitting to HFC-134a. Some manufacturers recommend to move 90 % of the mineral oil in the system /Lawson, 1993/, /DuPont, 1993b,c/.

SYSTEM MODIFICATION:

Typical modifications required for retrofitting R-502 installations are :

- Change of mineral oil
- Adjustment or change of the expansion device
- Change of desiccant filter

The compatibility of the blend with construction materials in the CFC system is usually not a problem, but it should always be considered.

RETROFIT PROCEDURE:

1) Use the compressor to pump the existing refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) Drain the original oil charge from the compressor. If an oil separator is fitted, this should be drained as well.

3) Carry out the equipment modifications as required.

4) Recharge the system with new lubricant.

5) Evacuate the system and recharge it with the blend.

4.2.10 Retrofitting from R-502 to HCFC-22

To a certain extent the same considerations must be made when redesigning a R-502 system for HCFC-22, as when redesigning a CFC-12 system. HCFC-22 operates with a slightly lower pressure then R-502 at the same operating conditions and the volumetric refrigerating capacity is slightly higher for HCFC-22 than R-502. Hence, it is possible *to use the same compressor when retrofitting.*

For a low temperature system, with evaporating temperatures below -25°C, it is recommended to use a two-stage system, due to the higher compressor discharge temperature when using HCFC-22. It is not advisable to operate with discharge temperatures above 120°C for a longer period of time.

SYSTEM MODIFICATION FOR ONE-STAGE SYSTEMS:

Typical modifications required for most installations are :

- Change of expansion device
- Change of desiccant filter
- Installation of oil separator, as mineral oil is not so miscible with HCFC- 22 as with R-502

For compressors with internal oil pump it is advisable to install a crankcase heater, because of the differences in densities between liquid HCFC-22 and oil.

RETROFIT PROCEDURE FOR ONE-STAGE SYSTEMS:

1) Use the compressor to pump the existing refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) Drain the original oil charge from the compressor. If an oil separator is fitted, this should be drained as well.

3) Carry out equipment modifications as required.

4) Recharge the system with the new lubricant.

5) Evacuate the system and recharge it with HCFC-22

SYSTEM MODIFICATION FOR TWO-STAGE SYSTEMS:
The discharge temperature is the major limiting factor for the application range of HCFC-22 compressors operating. Particularly with *suction gas cooled* compressors, where the refrigerant is used to cool the motor, the operating range is limited. One way to solve this problem is to convert to two-stage compression. This can be done either by internally compounded machines or by series compression system. Compound compression allows evaporating temperatures down to -50°C. The former is the simplest from an installation point of view, but the latter allows more flexibility, and gives the possibility to add cooling loads at the intermediate stage.

Typical modifications required for most installations are :

- Change of compressor or compressor system
- Change of expansion device
- Change of desiccant filter
- Installation of oil separator, as mineral oil is not so miscible in HCFC- 22 as in R-502

For compressors with internal oil pump it is advisable to install crankcase heater, due to the differences in densities between liquid HCFC-22 and oil.

RETROFIT PROCEDURE FOR TWO STAGE SYSTEM:
1) Use the existing compressor to pump the refrigerant charge into the receiver, if fitted and large enough. If not, use an alternative drum.

2) If change to internal compound compressor, install this. If change to two compressors in series, install the new compressor system, including external intermediate cooling system.

3) Carry out required equipment modifications, such as replacing expansion device, driers, filter and any other modifications.

4) Recharge the system with the new lubricant of same quality.

5) Evacuate the system and recharge with HCFC-22.

4.2.11 Retrofitting from R-502 to Propane (HC-290)
Please see Appendix

4.3 New Equipment with Non-CFC Refrigerants

4.3.1 HCFC-22

HCFC-22 is, together with ammonia, considered to be the primary mid-term non-CFC replacement refrigerant in the temperature range above -45°C. HCFC-22 can easily replace CFC-12, R-500 and R-502 in most new systems. For low temperature purposes, i.e below -25°C, two-stage compression is required. This may increase the initial costs by 10-15%, but improved efficiency may compensate for this difference.

For further details regarding new refrigeration, air conditioning and heat pump plants with HCFC-22, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

4.3.2 HFC-134a

HFC-134a is regarded an important alternative in the phase-out of CFC-12 and R-500 in applications operated at medium to high evaporation temperatures, such as mobile air conditioning and refrigeration equipment, some stationary air conditioning equipment (air- and water-cooled), domestic refrigerators and heat pumps. HFC-134a is not very well suited for low temperature applications (freezing), with evaporating temperatures below -20°C.

The most important change in application of HFC-134a is the requirement for new synthetic lubricants. HFC-134a is immiscible with conventional lubricants used with CFC-12, such as mineral oils and alkylbenzenes. Nearly all larger compressor manufacturers have recommended the use of HFC-134a with polyol ester lubricants.

For further details regarding new refrigeration, air conditioning and heat pump plants with HFC-134a as refrigerant, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

4.3.3 HFC-152a

HFC-152a is an alternative to CFC-12 in various applications. HFC-152a has an ODP of zero, the GWP factor is very low and its thermodynamic and physical properties regarding pressures, volumetric refrigerating capacity, and energy efficiency are very similar to CFC-12.

Because of the flammability, HFC-152a should only be used in smaller units with low refrigerant charge, such as domestic and commercial refrigerators and freezers or in small air conditioning units. System design and refrigerant charge should always meet local codes and regulations. For instance is HFC-152a used in small hermetic heat pumps designed for HCFC-22, with only minor modifications /Tokle,1992/.

For further details regarding new refrigeration, air conditioning and heat pump plants with HFC-152a as refrigerant, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

4.3.4 Hydrocarbons

Propane, iso-butane, butane and other hydrocarbons have excellent thermodynamic properties. Propane is a well known flammable refrigerant, and is widely used in larger refrigerating plants within the petrochemical and oil and gas industry. Except for this application, due to its flammability the hydrocarbons should only be used in smaller hermetic units with low refrigerant charge, such as domestic and commercial refrigerators and freezers. There are now several refrigerators on the market, using pure isobutane or mixtures of hydrocarbons (propane/butane and propane/iso-butane) as refrigerants. Hydrocarbons are being introduced in other application areas as well, for example propane in small, special designed, air to air heat pumps and in air conditioning units originally designed for HCFC-22 /Friends of the Earth, 1993/, /Granryd,1993/, /Haukås,1992a,b/, /James,1992/, /Treadwell,1991/, /Proceedings from IIR in Hannover, 1994/. System design and refrigerant charge should always meet local codes and regulations.

For further details regarding new refrigeration, air conditioning and heat pump plants with hydrocarbons as refrigerant, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

4.3.5 Ammonia (NH_3)

Regarding thermodynamic, economic and environmental aspects, ammonia is an excellent alternative for replacing CFCs in new equipment. With zero ODP and GWP, it is a long term refrigerant alternative and there is considerable practical experience with this refrigerant. Hence ammonia is expected to be an even more important refrigerant in the future.

Due to safety considerations (toxicity and flammability) the use of ammonia has been limited to large industrial applications. Today, however, increased research and development activities in many countries, focus on smaller systems and improved safety. Work is also being initiated in the fields of hermetic compressor design, reduced refrigerant charge, insulation features, indirect systems and leakage detection /Brendeng,1990/, /Haua,1990/, /Nesje, 1994/, /Møller, 1994/.

Recommended practices limit the use of ammonia in public buildings to systems that utilizes a secondary heat transfer fluid (brine system). This will confine the ammonia to the machine room where alarm and ventilating devices can ensure the necessary safety.

For further details regarding new refrigeration, air conditioning and heat pump plants with ammonia as refrigerant, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

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5. DOMESTIC REFRIGERATION

5.1 Introduction

Domestic refrigeration includes household freezers and refrigerators. The annual sale of freezers and refrigerators was in 1994 approximately 56 millions units worldwide, 15-18 millions in developing countries. The CFC consumption in this area is still limited, since the refrigerant charge is small in each unit. The CFC consumption was in 1990 estimated to 9,526 metric tonnes worldwide, of which 2,957 metric tonnes in the developed countries /UNEP,1991a/.

With increasing emphasis on global warming, the TEWI will assume even greater importance. The TEWI is the sum of *direct warming* from the emissions of chemicals used in the product and *indirect emissions* from power generation to run the unit over its lifetime. For domestic refrigeration, operated on CFC substitutes, the indirect contribution is about a hundred times greater than the direct contribution from the refrigerant. This is due to the long running time. An average compressor runs from 60 000 to 90 000 hours without failure. *Therefore, in this sector it is more important to select a refrigerant with high energy efficiency than with low GWP (global warming potential).*

5.1.1 Current Equipment and Refrigerants

Domestic refrigeration is described as small units, with an average charge from 140 grams (in India) to more than 200 grams in (Eastern Europe). The vapor-compression cycle is used in most units, operating with CFC-12 as a refrigerant.

5.2 Alternative Non-CFC Refrigerants and Equipment

Chapter *3, "CFC and Non-CFC Refrigerants and Technologies"* provides information on different properties for the current CFCs and available non-CFC refrigerants in the domestic refrigeration area, for example:

- physical and thermodynamic properties
- ODP, GWP, toxicity, flammability etc.
- price, availability
- relative refrigerating capacity (investment costs)
- relative theoretical COP (operating costs)

5.2.1 Retrofitting with Non-CFC Refrigerants

Most manufacturers consider that there will be a sufficient supply of CFC-12 available from production and reclaim sources to satisfy the needs until a total phase out is accomplished. *HFC-134a* can be used as retrofit, with a developed procedure for flushing out CFC-12. A *ternary blend*, HCFC-22/HFC-152a/HCFC-124, is also discussed as a retrofit. Among the hydrocarbons, *propane* is viewed as a promising retrofit. For the Article 5 countries, propane offers such advantages as wide availability and low cost. The explosion and fire risk are limited due to the small charges used in domestic refrigeration.

Retrofitting from CFC-12 to HFC-134a, see chapter 5.2.1.1

Retrofitting from CFC-12 to Blend: HCFC-22/HFC-152a/HCFC-124, see chapter 5.2.1.2

Retrofitting from CFC-12 to Hydrocarbons, see chapter 15.

For domestic refrigerators and freezers, the small charges makes retrofitting rather extravagant compared to the actual use. Retrofitting may be interesting when refrigerators and freezers are taken back to the manufacturer for service, using *the forced cleaning method*, which has given excellent results in retrofitting small hermetic compressors/Landteknikk,1993/.

5.2.1.1 Retrofitting from CFC-12 to HFC-134a

HFC-134a can be used as a retrofit, if the method for flushing out CFC-12 and recharging with HFC-134a is further developed. A compressor change might be necessary, and the oil has to be replaced by a polyol ester lubricant /Vieth,1993/. For more detailed retrofitting procedure, see chapter *4.2.4 "Retrofitting from CFC-12 to HFC-134a"*.

5.2.1.2 Retrofitting from CFC-12 to Blends

Ternary blends with HCFC-22/HFC-152a/HCFC-124 (R-401a and R-401b) are considered as service (drop-in) refrigerants in domestic refrigeration. The blends requires an alkylbenzene lubricant, which makes it difficult to retrofit with the blend when the unit is serviced in the field. When the refrigerator is brought back to the shop for repair, oil change is a simple process. A large amount of mineral oil can remain in the system (20 - 30%).

5.2.2 New Equipment with Non-CFC Refrigerants

HFC-134a, hydrocarbons, and HFC-152a are the most promising alternatives for new units at present. *HFC-134* has also been investigated /Vineyard,1991/.

HFC-134a, see chapter 5.2.2.1

Hydrocarbons, see chapter 5.2.2.2

HFC-152a, see chapter 15

5.2.2.1 HFC-134a

HFC-134a is the leading candidate in replacing CFC-12 in refrigerators and freezers in the short term. Selection of this chemical as the primary replacement for CFC-12 has been based mainly on demands from the automotive air-conditioning sector for a substitute with pressure limits and thermodynamic properties comparable to CFC-12. Recent tests with HFC-134a refrigerators shows from 1% less to 7% higher energy consumption compared to CFC-12 /Fischer,1991/. For more information, see chapter *3.2.2. "HFC Refrigerants"*, and chapter *4.3.2 "HFC-134a"*.

5.2.2.2 Hydrocarbons

Hydrocarbons have very good thermodynamic properties, but are flammable. They are well suited as refrigerants for freezers and refrigerators, due to small refrigerant charges. System design and refrigerant charge must always meet local laws and regulations in order to ensure safety during operation and service. For more information, see chapter *3.2.3. "Natural Refrigerants"*, and chapter *4.3.4 "Hydrocarbons"*. Many manufacturers are now developing domestic refrigerators with hydrocarbon refrigerants (pure R-600a and blends of R-600a and R-290), and some of these are already commercially available. /IIR Conference Hannover, 1994/.

5.2.3 Examples of Successful Conversions to Non-CFC Refrigerants and Equipment

5.2.3.1 New Equipment with Non-CFC Refrigerants

Greenfreeze

Foron (Formerly called: dkk Scharfenstein), Germany, are manufacturing a refrigerator called Greenfreeze.

Refrigerant:	Propane/butane mixture, approximately 20 gm
Insulation:	Expanded polystyrene, not blown with CFCs
Lubricant:	Normal mineral oil
Dimension:	82.5 x 55 x 60 cm (height/width/depth) - 127 litres
Energy consumption:	0.67 kW

Siemens KD37R00

Refrigerant:	Iso-butane
Insulation:	Pentane
Lubricant:	Information not provided
Dimension:	187 x 66 x 66 cm (height/width/depth) - 364 litres
Energy consumption:	0,36 kWh/24 hours

Siemens (several sizes and types)

Refrigerant:	HFC-134a
Insulation:	Pentane
Lubricant:	Information not provided
Dimension:	From 136 litres up to 235 + 89 litres (both refrigerator and freezer)
Energy consumption:	0.29 - 0.6 kw/100 litres

Bosch KDR3700

Refrigerant:	Iso-butane
Insulation:	Pentane
Lubricant:	Information not provided
Dimension:	187 x 66 x 66 cm (height/width/depth) - 364 litres
Energy consumption:	0.10 kw/100 litres (0,36 kWh/24 hours)

Bosch (several sizes and models)

Refrigerant:	HFC-134a
Insulation:	Pentane
Lubricant:	Information not provided
Dimension:	From 144 litres up to 178+168 litres (both refrigerator and freezer)
Energy consumption:	0.23 - 0.61 kw/100 litres

Electrolux - RP1448SLG and TR1066SLG

Refrigerant:	HFC-134a
Insulation:	HFC-134a
Lubricant:	Information not provided
Dimension:	288 litres - 184+101 litres (both refrigerator and freezer)
Energy consumption:	0.12, 0.46 kw/100 litres

Gram (several sizes and models)

Refrigerant:	HFC-134a
Insulation:	HCFC-142b, HCFC-22, HFC-134a
Lubricant:	Information not provided
Dimension:	112+23 litres - 217 litres (both refrigerator and freezer)
Energy consumption:	0.14 - 0.56 kw/100 litres

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6. COMMERCIAL REFRIGERATION

6.1 Introduction

6.1.1 Current Equipment and Refrigerants

The majority of commercial refrigerating systems are used in food merchandising and food service applications such as supermarkets, food stores, restaurants, cafeterias, commercial and institutional kitchens. The design of commercial refrigeration systems and the type of refrigerants used depend on the required operating temperatures.

- Fresh fruits and vegetables → air-temperatures from 0°C to about 13°C
- Fresh meat and dairy products → medium air-temperatures from -2°C to 2°C
- Frozen meat and frozen food → low temperatures from -18°C to -30°C

Table 6.1 shows the most commonly used refrigerants in commercial refrigeration (operating temperatures). An estimation of the percentage distribution between the refrigerants in these applications in the 1986-91 time period is also given /UNEP,1991a/.

Table 6.1 The most commonly used refrigerants within commercial refrigeration /UNEP,1991a/.

Refrigerant	CFC-12	HCFC-22	R-502
Operating temperature range	-15°C to 15°C	down to -37°C	down to -45°C
Percentage of distribution	69%	8%	23%

Commercial refrigeration in *developing countries* primarily uses CFC-12 as refrigerant, to a less extent R-500, R-502 and HCFC-22 in limited amounts. Small amounts of CFC-13, R-503, FC-14 and BFC-13B1 are used in low temperature cascade systems (two or more stages) for special applications.

6.2 Alternative Non-CFC Refrigerants and Equipment

6.2.1 Retrofitting with Non-CFC Refrigerants

Retrofitting existing equipment involves a thorough and systematic evaluation for safety, reliability, energy efficiency and capacity requirements. The choice of refrigerant will depend upon the current refrigerant being used, plant design, type of compressor etc.

There are numerous system designs in the field of commercial refrigeration. Smaller systems are equipped with hermetic compressors. Due to compressor costs, there is a trend towards hermetic design for higher capacities and lower evaporating temperatures, where semi-hermetic compressors have previously been used. Open type compressors are also used, but to a lesser degree /UNEP,1993a/. In many cases the condensing systems are factory assembled and the evaporator system are connected on site.

Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"* provides essential information on different properties for the current CFCs and available non-CFC refrigerants used in commercial refrigeration:

- physical and thermodynamic properties
- ODP, GWP, toxicity, flammability etc.
- price and availability
- relative refrigerating capacity (investment costs)
- relative theoretical COP (operating costs)

The following retrofit possibilities are presented:
CFC-12 to HCFC-22, see chapter 6.2.1.1
CFC-12 to HFC-134a, see chapter 6.2.1.2
CFC-12 to Blends, see chapter 15
CFC-12 to HFC-152a or hydrocarbons, see chapter 15
R-502 to HCFC-22, see chapter 6.2.1.3
R-502 to Blends, see chapter 6.2.1.4
R-502 to hydrocarbons, see chapter 15

6.2.1.1 Retrofitting from CFC-12 to HCFC-22

From a technical point of view HCFC-22 replace CFC-12 to some extent in both medium and low temperature applications. One of the major problems when retrofitting may be higher compressor discharge temperature for single stage operation (especially at low operating temperatures using hermetic suction gas cooled compressors), making the refrigerant more susceptible to chemical brakedown. The volumetric refrigerating capacity of HCFC-22 is about 40% higher than that of CFC-12, depending on the operating conditions, and change of compressor and motor will be necessary to maintain the same refrigerating capacity.

The retrofit procedure from CFC-12 to HCFC-22 is commercially applied. For details on the retrofitting procedure, see chapter 4.2.6, *"Retrofitting from CFC-12 to HCFC-22"*.

6.2.1.2 Retrofitting from CFC-12 to HFC-134a

HFC-134a is quite similar to CFC-12 regarding thermodynamic and physical properties, and it is regarded as a promising alternative to CFC-12 in *medium temperature applications*. HFC-134a is less suitable at low temperature (freezing) applications due to lower energy efficiency than that of CFC-12 and 10-30% lower volumetric refrigerating capacity, depending on the temperature conditions.

In most cases the retrofit can be done without any modification or rebuilding, except of changing lubricant, expansion device and desiccant filter. Mineral oils used with CFC-12 are not miscible with HFC-134a, and it is recommended to change to a polyol ester based lubricant. For details on the retrofitting procedure, see chapter 4.2.4, *"Retrofitting from CFC-12 to HFC-134a"*. Retrofitting from CFC-12 to HFC-134a is commercially applied, and most refrigerants manufacturers will be able to give examples /ICI,1992/, /Renz, 1993/.

HFC-134a is expensive and is not readily available worldwide. For these reasons and the performance limitations, application of HFC-134a as a retrofitting refrigerant will most likely occur at a reduced rate in the developing countries compared to Europe, Japan and the USA.

6.2.1.3 Retrofitting from R-502 to HCFC-22

To a less extent, the same considerations must be taken into account when redesigning a R-502 system to HCFC-22 as when redesigning a CFC-12 system. Since the volumetric refrigerating capacity of the two refrigerants are very similar, change of compressors or compressor modifications is not required in the medium temperature range.

In the low temperature range, the conversion from R-502 to HCFC-22 in existing systems can result in higher compressor discharge temperatures, making the refrigerant more susceptible to chemical brakedown. This can be solved by using single-stage reciprocating, rotary or scroll compressors with liquid injection (USA/Japan), internally compounded compressors with inter-stage cooling (two-stage inter cooled), two stage systems (externally compounded) or air-cooled and/or liquid-injected screw compressors, However, there is an increase in complexity and costs associated with the most of the mentioned /UNEP,1991a/.

For more details on the retrofitting procedure, see chapter 4.2.10, *"Retrofitting from R-502 to HCFC-22"*.

6.2.1.4 Retrofitting from R-502 to Blends

Binary blends containing HCFC-22 and HFC-23 and ternary blends containing HCFC-22, a hydrocarbon (propane, HC-290) and other components (HFC-218 or HFC-125 among others) are strong candidates to replace R-502 in existing equipment. Energy efficiency, volumetric refrigerating capacity, discharge temperature and lubricant considerations are important selection criteria. For further information on refrigerant blends, see chapter 3.2.4, *"Mixtures/blends"*. For more details on the retrofitting procedure, see chapter 4.2.9, *"Retrofitting from R-502 to Blends"*.

6.2.2 New Equipment with Non-CFC Refrigerants

New Equipment with Non-CFC Refrigerants
HCFC-22, see chapter 6.2.2.1
HFC-134a, see chapter 6.2.2.2
Ammonia, see chapter 6.2.2.3
Flammables - Hydrocarbons and HFC-152a, see chapter 15

6.2.2.1 HCFC-22

HCFC-22 is regarded as an important mid-term replacement for CFC-12 and R-502 in new commercial refrigerating systems, both for medium and low temperature purposes. For the latter, i.e temperatures below -25°C, systems with two-stage compression and intermediate cooling is required. This may increase the initial costs by 10-15%, but improved efficiency may compensate for this difference. For further details on HCFC-22 as refrigerant in commercial refrigerating systems, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

6.2.2.2 HFC-134a

HFC-134a is a promising candidate in medium temperature applications, but is not very well suited for low temperature (freezing) applications, with evaporating temperatures below -20°C. An important aspect using HFC-134a as a refrigerant is correct choice of lubricant, and nearly all larger compressor manufacturers have recommended polyol ester lubricants. For further details on HCFC-22 as refrigerant in commercial refrigerating systems, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

6.2.2.3 Ammonia (NH_3)

Regarding thermodynamic, economic and environmental aspects, ammonia is an excellent alternative for replacing CFCs in new equipment. Due to safety considerations (toxicity and flammability) ammonia has not been applied within commercial refrigeration until recently.

However, there are increased research and development activities focusing on smaller systems and improved safety. Work have also been initiated in the fields of hermetic compressor design, reduced charge size, indirect systems among others.

By using indirect systems (brine systems), the quantity of refrigerant needed can be substantially reduced, and thus confining the ammonia to the machine room where safeguards as gas detectors, alarm and venting devices can ensure the necessary safety. Increased energy consumption due to pumping of the secondary refrigerant and the use of a two step system (extra temperature difference) must always be taken into consideration.

There has been installed some ammonia plants in commercial refrigeration the last years. One of the largest shopping centres in Sweden, has installed a ammonia systems to replace CFC-11. By using indirect system, the refrigerant charge was reduced from 3 tons to 100 kg, and the refrigeration plant is placed in a machine room /SCANREF,1992/.

Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"* provides more detailed information on ammonia, for instance examples of different safeguards to ensure system safety.

6.2.3 Examples of Successful Conversion to Non-CFC Refrigerants and Equipment

6.2.3.1 Retrofitting with Non-CFC Refrigerants

Retrofitting from CFC-12 to HFC-134a in supermarket. /ACHR News,1993a/

Cooling produce cases are converted from CFC-12 to HFC-134a. in several of Quality Markets Supermarkets. The Castrol-method was used for the retrofitting, and it was necessary with two lubricant changes to remove the mineral oil. Laboratory test showed 3% mineral oil in the polyol ester lubricant after the second lubricant change. New display cases was installed. Expansion device was kept, but compressor oil filter and filterdrier were changed to components fully compatible with HFC-134a.

Owner:

Name: Quality Markets
Address: Jamestown, New York
Country: USA

Contractor:

Name: TDH Refrigeration Inc.
Country: Buffalo, USA

Retrofitting from CFC-12 to HFC-134a in supermarket II. /ACHR News,1993b/
After costumers demand, the complete CFC-12 systems in the store were retrofitted to HFC-134a. System retrofit was completed over a five-day period. A flushing procedure removed the old mineral oil, and a polyol ester lubricant was added. New filterdryers were installed, while expansion valves and crankcase pressure regulator valves were not changed.

Owner:

Name: Market Basket Supermarket
Address: Woburn, Massachussets
Country: USA

Contractor:

Name: Excel Refrigeration
Country: Tewksbury, USA

6.2.3.2 New Equipment with Non-CFC Refrigerants

Ammonia in shopping centre /SCANREF,1992/.
One of the largest shopping centres in Sweden, with 90 shops and 11 restaurants, has installed a ammonia systems to replace CFC-11. By using indirect system, the refrigerant charge was reduced from 3 tons to 100 kg, using two refrigeration units - STAL-Litzell VRX 257 E. The refrigeration plant is placed in a machine room, containing gas detection systems and a separate ventilation system. The conversion to ammonia and indirect system was done in cooperation with Dr. Ing. Lena Åhlby of Greenpeace.

Owner:

Name: Svenska Bostäder, Skärholmens Centrum
Address: Stockholm
Country: SWEDEN

Contractor:

Name: Excel Refrigeration
Country: Tewksbury, USA

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UNEP : *Report of the UNEP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee.* Pursuant to Article (6) of the Montreal Protocol on Substances that Deplete the Ozone Layer. (RWR-570-LK-91423-al.) December 1991a.

UNEP : *Report of the UNEP Technology and Economic Assessment Panel.* Pursuant to Article (6) of the Montreal Protocol on Substances that Deplete the Ozone Layer. (ISBN 92-807-1314-0.) December 1991b.

COLD STORAGE AND FOOD PROCESSING

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7. COLD STORAGE AND FOOD PROCESSING

7.1 Introduction

The cold storage and food processing sector includes a variety of applications within storage, chilling and freezing of food and other perishable products. The temperature level may vary from 10 - 15°C to below -60°C (superfreezing).

The frozen food supply exceed 24 million metric tonnes per year worldwide, and it is expected that the volume of both chilled and frozen food will increase in the years to come. The size of the refrigeration market in this sector is roughly estimated at US$ 3,000-5,000 million annually, and the increase in the refrigeration market is estimated at 2-3% per year /UNEP,1993a/.

7.1.1 Current Equipment and Refrigerants

Refrigeration systems for cold storage and food processing are in general large, and have large refrigerant charge in relation to the refrigeration effect. Typical specific charge may be up to 5 -10 kg refrigerant/kW cooling effect.

Most large scale chilling, freezing and cold storage plants, also in developing countries, utilize ammonia as refrigerant, where as certain areas and countries rely heavily on CFCs and to a great extent HCFC-22. Table 7.1 gives a rough estimate for the refrigerant consumption for cold storage and food processing worldwide.

Table 7.1 Estimated refrigerant consumption for cold storage and food processing /UNEP, 1991a/

Refrigerant	Estimated consumption
CFCs	28.500 tonnes/year
HCFC-22	25.000 tonnes/year
Ammonia	78.500 tonnes/year

7.2 Alternative Non-CFC Refrigerants and Equipment

Chapter 3 *"CFC and Non-CFC Refrigerants and Technologies"* provides information on different properties for current CFCs and available non-CFC refrigerants in the cold storage and food processing area, for example:

- physical and thermodynamic properties
- ODP, GWP, toxicity, flammability etc.
- price, availability

- relative theoretical COP (running costs)
- relative refrigerating capacity (investment costs)

7.2.1 Retrofitting with Non-CFC Refrigerants

Large systems have a technical lifetime up to 20-30 years. Without regulations, existing CFC system could be in operation a couple of decades into the next century. Hence, from an economic point of view, it may be attractive to retrofit plants with new refrigerants.

HCFC-22 is regarded the most attractive refrigerant for retrofitting of both CFC-12 and R-502 systems, and it is expected that HCFC-22 will play an important role in the phase out of CFC in existing systems.

When retrofitting from CFCs to ammonia, most components in large refrigeration systems will be compatible since steel is the main construction material. Few components are made of copper or copper alloys. However, all elastomers in O-rings, etc. have to be replaced with compatible materials.

Some available non-CFC refrigerants for retrofitting from CFC-12 and R-502 are listed below:

- HFC-134a
- HCFC-22
- ammonia

7.2.1.1 Retrofitting from CFC-12 to HFC-134a

HFC-134a can be used as retrofit for CFC-12. In most cases it can be done without any modification or rebuilding, except of changing lubricant, expansion device and desiccant filter. The mineral oil must be replaced by a polyol ester lubricant. In some cases, especially when centrifugal compressor are used, it may be necessary to change compressor (impellers and gears) to maintain the system performance. For details on the retrofitting procedure, see chapter *4.2.4 "Retrofitting from CFC-12 to HFC-134a"*.

7.2.1.2 Retrofitting from CFC-12 to HCFC-22

From a technical point of view, retrofitting from CFC-12 to HCFC-22 can be done rather easily in most cases. Adaption of compressor refrigerating capacity and management of compressor oil and oil return will normally be the most pressing problems. Exceptions to easy retrofit may be found in low temperature plants in hot climates (high ambient temperature), where a changeover from one-stage to two-stage compression may be required in some cases.

For details on the retrofitting procedure, see chapter *4.2.6, "Retrofitting from CFC-12 to HCFC-22.*

7.2.1.3 Retrofitting from CFC-12 to Ammonia

Ammonia is expected to be an important refrigerant for retrofit in countries where it is already commonly used. Most components in large CFC-system are compatible with ammonia. Therefore, retrofit to ammonia is possible, both for technically and economically reasons.

A change from CFCs to ammonia may imply improved system efficiency, due to better compressor efficiency, reduced temperature span (more efficient heat exchangers), reduced pressure drops and less pump work in systems with pump circulation.

Retrofitting may involve rebuilding or installation of new compressors, change of oil return system, change of all copper fittings and valves, change of refrigerant pumps and in some cases change of refrigerant lines. A retrofit is done in a dairy in Norway /Sabroe,1993/, /Kvia,1993/, see the example in chapter *7.2.3, "Examples of Successful Conversion to Non-CFC Refrigerants and Equipment"*.

For more details on the use of ammonia as refrigerant, see chapter *4.3.5, "Ammonia (NH_3)"* and chapter *3.2.3, "Natural refrigerants"*.

7.2.1.4 Retrofitting from R-502 to HCFC-22

To a less extent, the same considerations must be taken into account when redesigning a R-502 system to a system with a non-CFC refrigerant as when redesigning a CFC-12 system. In many cases, the retrofitting procedure is more simple, especially when retrofitting to HCFC-22, since the volumetric refrigerating capacity of the two refrigerants are very similar. In some cases, retrofitting from one to two-stage compression may be required.

For more details on the retrofitting procedure, see chapter *4.2.10, "Retrofitting from R-502 to HCFC-22.*

7.2.2 New Equipment with Non-CFC Refrigerants

Ammonia and HCFC-22 are the primary replacement refrigerants in new plants. New refrigerants, such as HFC-134a or near-azeotropic blends with properties similar to CFC-12, may gain some market share towards the end of the decade.

7.2.2.1 HCFC-22

HCFC-22 will evidently be an important factor in the CFC phase out within the cold storage and food processing sector. In many countries where ammonia is not presently used, HCFC-22 will be the first choice in many new applications.

From a technical point of view, there are only minor differences in designing a HCFC-22 system, compared to a CFC-12 system. In regions with hot climate, it may be necessary to use two-stage compression after a transfer from CFC-12 to HCFC-22, due to the higher condensing pressure of HCFC-22.

For further details, see chapter *4.3.1, "HCFC-22"* and chapter *3.2.1, "HCFC Refrigerants"*.

7.2.2.2 Ammonia (NH_3)

Ammonia is a naturally produced refrigerant, and the application of ammonia as a working fluid is believed to increase worldwide. However, the introduction in countries where it is presently not used, may take some time.

Efforts to reduce the charge per unit cold produced have progressed, and lower charge may be the key to the introduction of ammonia in smaller cold store applications, where use of CFC plays an important role today.

For price and availability reasons, among others, ammonia is well suited for developing countries. *It is therefore most important that the new ammonia technology is made available to developing countries.*

For more details on the use of ammonia as refrigerant, see chapter *4.3.5, "Ammonia (NH_3)"* and chapter *3.2.3, "Natural refrigerants"*.

7.2.3 Examples of Successful Conversion to Non-CFC Refrigerants and Equipment

7.2.3.1 Retrofitting with Non-CFC Refrigerants

Retrofitting from CFC-12 to HFC-134a. /Mirinz Meat Research,1993a,b/
The plant was installed in 1987, and retrofitted in 1992/93. So far there has been no problems with the replacement refrigerant. Refrigeration capacity is about 3 kW.

Owner/consultant:

Name:	Mirinz Meat Research
Address:	PO BOX 617, Hamilton
Country:	NEW ZEALAND
Phone no.:	+ 64 7 855 6159
Fax no.:	+ 64 7 855 3833

Retrofitting from CFC-12 to Ammonia in diary in Norway /Sabroe,1993/, /Kvia,1993/
In 1978 Rogalandsmeieriet installed a CFC-12 heat pump from Sabroe for production of hot water with a temperature of 76-78°C. To meet the coming CFC-12-restrictions, the unit was in 1992 retrofitted into a two-stage heat pump using ammonia. In the new plant the condensing temperature is reduced from 80°C to 77°C, and the outlet water temperature is reduced to 71-73°C. To achieve a condensing temperature of 77°C, the second stage in the heat pump uses a compressor with 40 bar design pressure. The existing compressor was kept and is now used in the low stage. There have been some problems with unstable operation, and it also turned out to be necessary to put in a new evaporator and condenser designed for the new process. Since the last modification, the heat pump has been in constant operation without any problems for about one year.

Owner:

Name:	Rogalandsmeieriet, avd. Nærbø
Address:	Torlandsveien 1, 4350 Nærbø
Country:	NORWAY
Phone no.:	+ 47 51 43 30 99

***Consultant*:**

Name:	Sabroe
Address:	PB 53, 1313 Vøyenenga
Country:	NORWAY
Phone no.:	+ 47 67 13 95 67

Retrofitting from HCFC-22 to NH_3/Vikool Refrigeration,1993a,b/

Consultant/*contractor:*

Name:	Vikool Refrigeration
Address:	PB 57, Mt. Gravatt 4122
Country:	AUSTRALIA
Phone no.:	+ 61 7 877 6400
Fax no.:	+ 61 7 343 8371

Owner:

Name:	Frigmobile Pty. Ltd
Address:	Queensport Rd., Murarric, Qld. 4172
Country:	AUSTRALIA
Phone no.:	+ 61 7 390 4188
Fax no.:	+ 61 7 390 4814

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INDUSTRIAL REFRIGERATION

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8. INDUSTRIAL REFRIGERATION

8.1 Introduction

Industrial refrigeration corresponds to a wide range of applications and operating conditions, within chemical, pharmaceutical and petrochemical industries, the oil and gas industries, civil engineering, the metallurgical industry, industrial ice-making, sport facilities, etc. Food-processing and cold storage which are usually defined as industrial refrigeration are described separately in chapter 7.

8.1.1 Current Equipment and Refrigerants

Industrial refrigeration systems are in general large, ranging from 100-200 kW up to several MW refrigeration capacity. The industrial sector is characterized by:

- Relatively large refrigerant charge
- No public access to areas where equipment containing refrigerant is located
- Operation and maintenance performed by well qualified personnel
- Refrigeration system often linked to a production system

The importance of energy efficiency, refrigerant prices, and system availability may be stronger than concerns regarding toxicity and flammability.

The temperature range in industrial refrigeration varies from well above the freezing point down to the boiling point of nitrogen (-196°C) and even lower, but the major part of applications are operating from -20°C and above.

The most common refrigerants are listed in Table 8.1. The oil and gas industry and the petrochemical industry, where hydrocarbons are commonly used, are not included.

Table 8.1 Refrigerants for industrial refrigeration, corresponding to temperature range, /UNEP, 1991/.

-70°C to -45°C	Above -45°C	Above -30°C	5 - 10°C
CFC-13 BFC-13	Ammonia HCFC-22 R-502	CFC-12[1] Ammonia HCFC-22	CFC-11[2]

1 *Commonly used in turbocompressors operating below the freezing point.*

2 *Used to a certain extent for medium-sized systems for chilled process production (turbochillers).*

8.2 Alternative Non-CFC Refrigerants and Equipment

Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*, provides information on different properties for current CFC and available non-CFC refrigerants in the industrial refrigeration sector:

- physical and thermodynamic properties
- ODP, GWP, toxicity, flammability etc.
- price, availability
- relative refrigerating capacity (investment costs)
- relative theoretical COP (operating costs)

8.2.1 Retrofitting with Non-CFC Refrigerants

Due to the long expected lifetime of industrial refrigeration systems, the replacing refrigerants should be available for a certain period for economic reasons. Temperature level, application area, material compatibility and system pressure are parameters to take into account when evaluating the various alternative refrigerants. Some replacements are defined as transitional substances, like HCFC-22, according to the Montreal Protocol, but will play a relatively important role for several reasons for the phase out of the CFCs. For more long term solutions, natural refrigerants will play an important role, particularly ammonia.

8.2.1.1 Retrofitting from CFC-12 and R-502 to HCFC-22

From a technical point of view, apart from turbocompressor systems, HCFC-22 is a suitable refrigerant for retrofitting. Necessary modifications required for the system equipment may be moderate in volume and cost. However, for low temperature applications, it might be necessary with two-stage compression, which increases the conversion costs. For details regarding the retrofitting procedure, see chapter 4.2.6, *"Retrofitting from CFC-12 to HCFC-22"*, and chapter 4.2.10, *"Retrofitting from R-502 to HCFC-22"*.

8.2.1.2 Retrofitting from CFC-12 to HFC-134a

HFC-134a is a viable replacement for CFC-12 at moderate temperatures. For turbocompressor systems, HFC-134a is practically the only solution. Change of impeller and gear for the compressor system might be required because of lower volumetric capacity running at low temperatures, and will increase the cost of retrofit. In general, using HFC-134a results in lower energy efficiency and lower volumetric capacity compared to CFC-12 in low temperature applications and is therefore less suitable. For more details about the retrofitting procedure, see chapter 4.2.4, *"Retrofitting from CFC-12 to HFC-134a"*.

HFC-134a is expensive and is not readily available worldwide. For these reasons and the performance limitations, application of HFC-134a as a retrofitting refrigerant will most likely occur at a reduced rate in the developing countries compared to Europe, Japan and the USA.

8.2.1.3 Retrofitting from CFC-11 to HCFC-123

For industrial centrifugal chillers, HCFC-123 is the only available candidate for replacing CFC-11. Seals and gaskets have to be replaced. For open compressor systems, the retrofit is rather straightforward, while for semihermetic compressor, special precautions regarding the motor-winding insulation must be taken. For more detailed description of the retrofitting procedure, see chapter 4.2.3, *"Retrofitting from CFC-11 to HCFC-123"*.

In low pressure systems with CFC-11 and HCFC-123, it is important to reduce refrigerant emission when purging air out of the system. There are purge recovery units available, which captures the refrigerant present when purging air, and recycles the refrigerant for re-use. This can reduce the refrigerant emission due to purging up to 99% /Carrier,1993/.

8.2.1.4 Retrofitting from CFC-13 to HFC-23

HFC-23 is a refrigerant very similar to CFC-13, and retrofitting is therefore rather simple. However, special consideration must be made due to the low oil solubility (0.1-0.2%), and oil return systems must therefore be included /Haukås,1991/.

In the case of BFC-13, a more costly rebuilding is needed, using HFC-23, in addition to another higher temperature refrigerant in cascade.

8.2.2 New Equipment with Non-CFC Refrigerants

For temperatures above -45°C, HCFC-22 and ammonia are the most frequently used refrigerants in new equipment today, except in industries handling hydrocarbons. In the case of HCFC-22, the contribution is supposed to decrease, when the new HFCs are fully introduced in the market, while the use of ammonia is expected to increase.

8.2.2.1 Ammonia (NH_3)

In countries were ammonia has been accepted and is widely used, this will be a natural replacement for CFC-12 and R-502 in the industrial sector. Introduction of compact, low charge refrigeration systems which are under development, will strengthen the use even more. For more details, see chapter 3.2.3, *"Natural Refrigerants"* and chapter 4.3.5, *"Ammonia"*.

8.2.2.2 HCFC-22

Technically, HCFC-22 can easily replace CFC-12. However, special concern has to be taken for low temperature applications, where two-stage compression must be considered. For more details, see chapter 3.2.1, *"HCFC Refrigerants"* and chapter 4.3.1, *"HCFC-22"*.

8.2.2.3 HFC-23

HFC-23 is a suitable replacement for CFC-13, and to a large extent also for BFC-13. However, BFC-13 can be condensed by ambient air or water, while HFC-23 only can be used together with a higher boiling refrigerant in cascade systems. Even though the high GWP for HFC-23, the relatively limited amount required for this particular application, will probably not result in restricted use. For more details, see chapter 3.2.2, *"HFC Refrigerants"*.

8.2.2.4 Hydrocarbons

Within certain industries such as the oil and gas industry and the petrochemical industry, the hydrocarbons are commonly used. They may fit into almost any temperature range and have proven excellent properties as refrigerants. For more details, see chapter 3.2.3, *"Natural refrigerants"* and chapter 4.3.4, *"Hydrocarbons"*.

8.2.2.5 HFC-134a

Even though the non-negligible GWP of HFC-134a, this refrigerant is expected to be of some importance in industrial applications, especially in countries with local safety restrictions regarding natural refrigerants like ammonia and hydrocarbons.

The relatively *high refrigerant cost* will influence on the total system cost, due to the normally high refrigerant charge in industrial applications. This might result in development of low charge refrigerant systems. Concerning the oil problems with HFC-134a, mineral oils may be used instead of the polyol ester lubricants, since the additional cost caused by advanced oil return systems will probably not increase the investment cost significantly. For turbocompressor units, the small amounts of oil entering the compression chamber is almost negligible. For temperatures below -20°C, special precautions must be made due to the increasing energy consumption compared to CFC-12. In such cases a two-stage compression system could be needed, resulting in increasing investment costs. For more details, see chapter 3.2.2, *"HFC Refrigerants"* and chapter 4.3.2, *"HFC-134a"*.

8.2.2.6 Mixtures

Non-azeotropic mixtures have been used in the oil and gas industry for years in certain applications. In the future, mixtures might be more common in use, particularly in condensation of industrial gases. Gliding temperatures might lead to improved thermodynamic performance, compared to one-component refrigerants. For more details, see chapter 3.2.4, *"Mixtures/blends"*.

8.2.2.7 HCFC-123 and HCFC-141b

For low pressure industrial chillers, HCFC-123 is supposed to play an important role replacing CFC-11, even though it is considered as a transitional refrigerant. For more details, see chapter 3.2.1, *"HCFC Refrigerants"*.

In low pressure systems with CFC-11 and HCFC-123, it is important to reduce refrigerant emission when purging air out of the system. There are purge recovery units available, which captures the refrigerant present when purging air, and recycles the refrigerant for re-use. This can reduce the refrigerant emission due to purging up to 99% /Carrier,1993/.

References

Carrier: *Refrigerant Containment Systems for Centrifugal Chillers. Product specification of "Prevent", a retro-fit, high-efficiency purge.* Order No. 18794-20, August 1992.

Haukås, H. T.: NTH-SINTEF Refrigeration Engineering, Norway: *Alternative Kuldemedier, Hvor står vi ?, Hvilke praktiske problemer må vi håndtere på veien fremover ?; (Alternative Refrigerants, where are we?, Which practical problems will we have to deal with?)* Kuldedagene'91, 26.-28. april 1991.

UNEP : *Report of the UNEP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee.* Pursuant to Article (6) of the Montreal Protocol on Substances that Deplete the Ozone Layer. (RWR-570-LK-91423-al.) December 1991.

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9. AIR CONDITIONING AND HEAT PUMPS (AIR-COOLED SYSTEMS)

9.1 Introduction

9.1.1 Current Equipment and Refrigerants

Air-cooled air conditioners and heat pumps ranging from about 2 kW to 420 kW cooling capacity comprise a vast majority of the air conditioning market. The units can either be operated to cool and dehumidify air or in reversed position to heat air in everything from small rooms to large commercial structures. Essentially all the units are electrically driven vapor-compression systems.

An estimated 1,400 million kW of air cooled air conditioners and heat pumps are installed worldwide. Nearly all of these unitary units use *HCFC-22* as refrigerant.

Air-cooled air conditioners and heat pumps can be divided into four categories, based primarily on capacity:

- Unitary room air conditioners
- Duct-free split systems
- Ducted split systems
- Commercial unitary systems

9.1.1.1 Unitary Room Air Conditioners

Unitary room air conditioners range in capacity from about 2 kW to 10 kW. They all use hermetic rotary, reciprocating or scroll compressors. The units are applied in small shops and offices as well as apartments. They can be mounted in the window, through a wall, or being a free standing mobile unit.

9.1.1.2 Duct-free Split Systems

The duct-free split systems range in capacity from about 2 kW to 20 kW. The systems comprise a compressor and heat exchanger unit installed outside the place to be cooled or heated. The outdoor unit is connected via refrigerant piping to one or more fan coils (heat exchangers) in the space to be conditioned. For smaller capacities hermetic rotary compressors are used while larger models use hermetic scroll or reciprocating compressors. Duct-free split systems can be applied to commercial buildings, schools, apartments and free-standing residences.

9.1.1.3 Ducted Split Systems

The ducted split air conditioning systems range in capacity from about 5 kW to 20 kW. They are applied in central, forced-air heating and cooling systems. A compressor-bearing unit outside the space to be cooled or heated is connected to a single indoor heat exchanger (coil) installed within the duct system. The cooled or heated air is distributed to each room of the residential, commercial or institutional building.

9.1.1.4 Commercial Unitary Systems

Commercial unitary systems range in capacity from about 20 kW to 420 kW. These units are applied in many different ways. Some of the smaller units are mounted on the roofs on individual offices, shops or restaurants or on the ground. Multiple units with one or more compressors are used to cool entire shopping centers, schools, hospitals, exhibition halls or other large commercial structures. Other commercial unitary products include split systems and indoor packaged units.

9.2 Alternative Non-CFC Refrigerants and Equipment

9.2.1 Retrofitting with Non-CFC Refrigerants

After more than 40 years of experience, HCFC-22 has generally been accepted as the most viable refrigerant for unitary air conditioners and heat pumps. However, the HCFCs including HCFC-22 are now *controlled by the Montreal Protocol*. A 90% reduction of HCFCs is to be achieved before the year 2020, with a total phase out by the year 2030. Developing countries are permitted a ten year grace period in their HCFC phase out compared to the developed countries (see chapter 2, "Environmental Aspects" for further details). HCFC retrofits will not be mentioned in this edition of the catalogue.

9.2.2 New Equipment with Non-CFC Refrigerants

9.2.2.1 HFC-134a

HFC-134a is the most promising refrigerant to use in unitary air conditioning equipment /UNEP, 1991/. There are, however, some significant barriers to overcome before such a changeover is feasible:

- **Redesign**: Significantly redesigns are necessary to achieve equivalent efficiency and capacity as with HCFC-22. Such redesign will include enlarged heat exchangers and refrigerant piping, approximately 40% larger compressor volume and re-sized motors.

- **Increased costs**: To maintain the energy efficiency for the units it is necessary to increase the refrigerant charge (HFC-134a cost typically 3-4 times more than HCFC-22). This along with increased material and compressor costs, will increase the equipment costs with typically 10 to 30% (depends on the cooling efficiencies) /UNEP,1991/

- **Choice of lubricant - material compatibility**: HFC-134a is incompatible with mineral oils used in current air conditioners and heat pumps, and polyol ester based lubricants are recommended. The material compatibility of HFC-134a and the new lubricants with the construction materials and elastomers in O-rings etc. in the traditional HCFC-22 systems should be considered.

9.2.2.2 Unitary Absorption Cooling Systems

See chapter 3.4, *"Alternative Non-CFC Technology"* for information on absorption systems.

References

UNEP : *Report of the UNEP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee*. Pursuant to Article (6) of the Montreal Protocol on Substances that Deplete the Ozone Layer. (RWR-570-LK-91423-al.) December 1991.

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10. AIR CONDITIONING (WATER CHILLERS)

10.1 Introduction

10.1.1 Current Equipment and Refrigerants

The second way of providing air conditioning in commercial buildings is by using water chillers. Water chillers cool water, or a water/glycol (brine) mixture, which is then pumped through a heat exchanger in an air handler for cooling and dehumidification of air.

Water chillers are manufactured with capacities from about 7 kW to about 35,000 kW. Two types of compressors are used, see Table 10.1:

- positive displacement compressors (reciprocating/scroll/screw)
- centrifugal compressors (turbo compressors)

Table 10.1 Water chillers for air conditioning - capacity and compressor types /UNEP,1991a/

CAPACITY	COMPRESSOR TYPE
7.0 kW - 850 kW	reciprocating/scroll/screw
140 kW - 6,000 kW	reciprocating/screw
350 kW - 35,000 kW	centrifugal

10.1.1.1 Water Chillers with Positive Displacement Compressors

HCFC-22 is the most commonly used refrigerant in water chillers with positive displacement compressors. *CFC-12* is rarely used, due to larger and more costly compressors.

10.1.1.2 Water Chillers with Centrifugal Compressors

Table 10.2 shows the most commonly used refrigerants in water chillers with centrifugal compressors. CFC-11 is used in almost 80% of all centrifugal chillers in 1991; CFC-12 is used in 10% /UNEP,1991a/.

Table 10.2 Commonly used refrigerants in water chillers with centrifugal compressors /UNEP,1991a/

REFRIGERANT	CHILLER CAPACITY	COMMENTS
CFC-11	350 - 10,000 kW (average 1,900 kW)	Low maximum pressure. Large impellers and piping. Evaporator side operates below atmospheric pressure.
HCFC-22	3,500 - 35,000 kW (average 7,000 kW)	Chillers with capacity as low as 1,000 kW are available today.
CFC-12	350 - 4,500 kW (average 2,800 kW)	Must meet pressure vessel code requirements in several countries.
R-500	1,000 - 7,000 kW (average 4,600 kW)	Replaces CFC-12 in order to extend capacity range.
CFC-114	440 - 1,400 kW	Naval centrifugal chillers (refrigerant pressure above atmospheric pressure).

10.2 Alternative non-CFC refrigerants and equipment

As CFC production will be reduced and ultimately phased out, the functions performed by air conditioning water chillers will have to be supported in one of the following ways /UNEP,1991a/:

1) Retrofit (modification) to allow operation with alternative refrigerants
2) Early scrapping replacement with non-CFC chillers
3) Continued operation with CFCs:
    - available from production, until production ceases or is insufficient
    - available after being recovered from other units converted to non-CFCs

Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"* provides information on different properties for the current CFCs and available non-CFC refrigerants:

- physical and thermodynamic properties
- ODP, GWP, toxicity, flammability etc.
- price and availability
- relative refrigerating capacity (investment costs)
- relative theoretical COP (operating costs)

10.2.1 Retrofitting with Non-CFC Refrigerants

Several possibilities exists for retrofitting existing CFC refrigerants in water chillers with alternative non-CFC refrigerants. The choice of refrigerant will depend upon the current refrigerant being used, chiller capacity, type of compressor etc. Only CFC-11 and CFC-12 retrofits will be presented.

10.2.1.1 Retrofitting from CFC-11 to HCFC-123

HCFC-123 is the most important candidate to replace CFC-11 in existing centrifugal chillers (short and mid-term refrigerant). Currently a number of new centrifugal chillers are being operated with HCFC-123. Because HCFC-123 is toxic it is recommended that exposure of personnel to HCFC-123 in an 8 hour workaday should be limited to a 10 ppm (or lower) time-weighted-average concentration /UNEP,1991a/. This means that machinery rooms for HCFC-123 chillers must be equipped with sensitive detectors, adequate ventilation systems, and means to alert operators in the event of a significant leak or spill.

In low pressure systems with CFC-11 and HCFC-123, it is important to reduce refrigerant emission when purging air out of the system. There are purge recovery units available, which captures the refrigerant present when purging air, and recycles the refrigerant for re-use. This can reduce the refrigerant emission due to purging up to 99% /Carrier,1993/.

For details on the retrofitting procedure, see chapter 4.2.3, *"Retrofitting from CFC-11 to HCFC-123"*.

10.2.1.2 Retrofitting from CFC-12 to HFC-134a

CFC-12 has been used in centrifugal chillers with refrigerating capacity from 350 kW to approximately 4,500 kW /UNEP,1991a/. In 1991 HFC-134a became available for retrofit in centrifugal chillers. Its use requires about 15% higher impeller tip speed than CFC-12, so impeller and/or gearbox replacement is necessary. Mineral oils used with CFC-12 are not miscible with HFC-134a, and it is recommended to change to a polyol ester based lubricant. For more details on the retrofitting procedure, see chapter 4.2.4, *"Retrofitting from CFC-12 to HFC-134a"*.

10.2.1.3 Retrofitting from CFC-12 to blends

Blends can be tailor-made to fit specific needs, but there might be problems after leakages due to disturbance of the fractions of the mixture compounds. Therefore, blends are most suitable for sealed systems and for larger units where the composition more easily can be determined.
For more details, see chapter 3.2.4 *"Mixtures/blends"* and chapter 4.2.5 *"Retrofit from CFC-12 to blends"*.

10.2.2 New Equipment with Non-CFC Refrigerants

10.2.2.1 HCFCs

HCFCs are needed to allow the most rapid phase out of CFCs in critical applications such as air conditioning where good alternatives are not available. Improved design and maintenance of systems to reduce leakage, design to minimize refrigerant charge quantities in systems, improved service practices and reclaiming of refrigerant during servicing, are practical and reasonable ways to reduce the emission of HFCs into the atmosphere to further minimize their environmental effects.

HCFC-123 is an alternative refrigerant to CFC-11 in new water chillers with centrifugal compressors. HCFC-123 achieves excellent efficiency, and has a very low ODP and GWP.

HCFC-22 is the best available choice for chillers using positive displacement compressors, and it is comparable to HCFC-123 in centrifugal systems. The extensive use of HCFC-22 in chillers today, including the rapid development of new HCFC-22 chiller design to replace CFC chillers in manufacturers' product lines, imply that HCFC-22 will be needed to serve these chillers through their lifetime or until better alternatives are available.

Even if the HCFCs are regarded as very important refrigerants to achieve an early transition from the CFCs, they are now *controlled by the Montreal Protocol.* A 90% reduction of HCFCs is to be achieved before the year 2020, with a total phase out by the year 2030. Developing countries are permitted a ten year grace period in their HCFC phase out compared to the developed countries (see chapter 2, *"Environmental Aspects"* for further details).

10.2.2.2 HFC-134a

HCFC-134a is an alternative to CFC-12 in water chillers with positive displacement compressors. HFC-134a is quite similar to CFC-12 regarding thermodynamic and physical properties. At moderate evaporating temperatures the volumetric refrigerating capacity and COP for air conditioning systems will be about the same as that of CFC-12. Because HFC-134a is not miscible with mineral oils, polyol ester lubricants is recommended.

For further details regarding air conditioning applications with HFC-134a as refrigerant, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies".*

10.2.2.3 Ammonia

Ammonia is an excellent refrigerant with zero ODP and GWP, though toxic and flammable. It is mainly used in medium- and large chilling, freezing and cold storage plants, which are somewhat removed from the general public.

Codes, regulations and laws have been developed mainly to deal with the toxic (and to some extent flammable) characteristics of ammonia, which if followed, provide a high degree of safety. Recommended practice (ASHRAE Std. and ISO/DIS 5149) limits the use of ammonia in public buildings to those system that utilize a secondary heat transfer fluid (indirect distribution systems/brine systems), thus confining the ammonia to the machine room where safeguards as gas detectors, alarm and venting devices can ensure the necessary safety. Systems requiring more than 500 kg of ammonia should generally not be used at all in public buildings /UNEP,1991a/.

For further details regarding air conditioning applications with ammonia as refrigerant, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies".*

10.2.2.4 Absorption Chillers

See chapter 3.4, *"Alternative Non-CFC Technology"* for information on absorption systems.

10.2.3 Examples of Successful Conversion to Non-CFC Refrigerants and Equipment

10.2.3.1 Retrofitting with Non-CFC Refrigerants

Retrofitting from CFC-12 to HFC-134a in a centrifugal chiller

The chiller is installed in the Swiss Credit Bank in Zürich /Sulzer, 1993/.

Type:
2 centrifugal chillers with heat recovery

Manufacturer/contractor:

Name:	Sulzer Friotherm Ltd
Address:	Postfach, CH-8401 Winterthur
Country:	Switzerland
Phone no.:	+41-52-262-8080
Fax no.:	+41-52-262-0003

Owner:

Name:	Swiss Credit Bank
Address:	Zürich
Country:	Switzerland

Retrofitting from CFC-12 to HFC-134a in centrifugal chiller i Houston /ACHRN, 1993/

The chiller is installed in Texas Medical Center

Type:
Centrifugal chiller

Manufacturer/contractor:

Name:	Carrier Building Systems & Services Division
Address:	Houston, Texas
Country:	USA
Phone no.:	
Fax no.:	

Owner:

Name:	Texas Medical Center Central Heating and Cooling Services Cooperative Association
Address:	Houston, Texas
Country:	USA

References

ACHRN - Air Conditioning, Heating and Refrigeration News: *"Big Houston CFC-12 chiller is retrofitted to use HFC-134a"* Notice in ACHRN p. 14, 12 July 1993.

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Sulzer Friotherm AG: *Conversions from CFC-12 to HFC-134a.* Letter to NTH-SINTEF Refrigeration Engineering, 9 March 1993

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UNEP : *Report of the UNEP Technology and Economic Assessment Panel.* Pursuant to Article (6) of the Montreal Protocol on Substances that Deplete the Ozone Layer. (ISBN 92-807-1314-0.) December 1991b.

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11. TRANSPORT REFRIGERATION AND AIR CONDITIONING

11.1 Introduction

The transport refrigeration market includes road transport, railcars, ships and intermodal containers for the transport of refrigerated cargoes, and also refrigeration on board of all types of ships.

Refrigerated transport is an international business, not only in terms of trade, but also in terms of equipment supply. Hence, there is really no distinction between different countries, other than the fact that many manufacturing countries are developing countries dependent on refrigerated transport to maintain export trades and for domestic transport of perishable goods.

11.1.1 Current Equipment and Refrigerants

SHIPS

In the shipping sector the applications for CFCs and HCFCs are as follows:

CFC-11	in marine air conditioning and for cleaning out marine refrigeration machinery.
CFC -12	marine air conditioning and provision room refrigeration in ships.
HCFC-22	marine air conditioning and provision room refrigeration in newer ships, most central cargo refrigeration plants, fish freezers and fishing vessel refrigerated storage, liquid gas tanker re-liquefaction plants.
CFC-114	air conditioning in some larger plants, including naval vessels.
R-502	very occasional use for low temperature refrigeration.

Air conditioning and provision room refrigeration plants have a typical refrigerant charge of 150 to 300 kg. Central cargo refrigeration plants contain from 2 to 4 tonnes.

RAILCARS

There are usually two refrigerating units per railcar, each of a nominal 10 kW capacity input and each containing 15 kg of CFC-12.

CONTAINERS

Refrigeration units contain about 5 kg of CFC-12 per railcar.

ROAD TRANSPORT REFRIGERATION

The trailer units typically have a refrigerating capacity of 6 to 10 kW, with a 10 kg refrigerant charge. This is valid if the system is designed for a cargo space temperature -18°C and 38°C ambient temperature. Truck units have a refrigerating capacity of 1.5 to 5 kW and contain about 6 kg refrigerant charge, the smaller units may have 3 kg charge. CFC-12 and R-502 are used in all unit sizes, R-502 in the smallest and some HCFC-22 is used in newer trailer units.

TRANSPORT AIR CONDITIONING

CFC-12 and R-502 are the most commonly used refrigerants in air conditioning units in busses and coaches. As most existing systems use long lengths of polymeric tubing, leakage rates are relatively high.

Table 11.1 show the world-wide use of refrigerants in transport refrigeration.

Table 11.1 World-wide transport refrigeration requirements. All emissions and use figures are tonnes per annum. /UNEP, 1991a/

1990 Situation	Ships	R/cars	Containers	Road freight	Transport air conditioning	Total
CFC pool, tonnes	9000	2250	1650	7000	3000	22900
CFC emission	2000	5	400	1750	1800	5955
CFC for new products	0	90	100	500	300	990
HCFC pool, tonnes	31000	0	0	0	1800	32800
HCFC emission	16100	0	0	0	600	16700
HCFC for new products	2400	0	0	0	90	2490

11.2 Alternative Non-CFC Refrigerants and Equipment

Chapter 3 *"CFC and Non-CFC Refrigerants and Technologies"* gives information on the following properties of current CFC and available non-CFC refrigerants in the transport refrigeration area.

- physical and thermodynamic properties
- price, availability
- ODP, GWP, toxicity, flammability etc.
- relative refrigerating capacity (investment costs)
- relative theoretical COP (operational costs)

Some use is made of total loss refrigerants (either liquid nitrogen or carbon dioxide) for transport of frozen cargoes either in containers over periods of a few days where no power supply is available or for delivery trucks in noise-sensitive areas. The high energy requirements by liquefaction of gases does not make it an alternative to be encouraged on a larger scale.

SHIPS
Some of the CFC-12 plants in marine air conditioning and provision room refrigeration could use HFC-134a as long as the room temperature is above -18°C without rebuilding refrigeration plants.

RAILCARS
The wide range of ambient temperatures encountered by the railcar units make it difficult to convert existing units to alternative refrigerants. HFC-134a may be used, but the room temperature should not be too low and the ambient temperature too high (limitation).

CONTAINERS
The situation for the containers is very much as for the railcars. Approximately the same operating conditions make it difficult to find a new refrigerant for the existing containers. HCFC-22 is one substitute, but then it is necessary to install new refrigeration units.

ROAD TRANSPORT REFRIGERATION
CFC-12 and R-502 are used in all size of units, R-502 primarily in the smallest. HCFC-22 is now used to some extent in newer trailer units. HFC-134a could be used as a refrigerant in chilled trailer units. For freeze transportation, blends and perhaps propane are considered as the best alternatives.

TRANSPORT AIR CONDITIONING
The most important retrofit refrigerants in this area are HFC-134a and HCFC-22. Many of the existing systems are already using HCFC-22.

11.2.1 Retrofitting with Non-CFC Refrigerants

The CFC alternatives currently under consideration for transport refrigeration applications are HCFC-22, HFC-134a and some types of blends. In the future, alternative HFCs such as HFC-125 or locally hazardous alternatives as propane should be considered.

The following retrofittings are presented:

CFC-12	→	HFC-134a, see chapter 11.2.1.1
CFC-12	→	HCFC-22, see chapter 11.2.1.2
R-502	→	Blends, see chapter 11.2.1.3
R-502	→	Propane, see chapter 15

11.2.1.1 Retrofitting from CFC-12 to HFC-134a

HFC-134a can be used as a retrofit refrigerant. For details on the retrofit procedure, see chapter *4.2.4 Retrofitting from CFC-12 to HFC-134a.* See also example later in this chapter /Thermo King,1993a,b/.

11.2.1.2 Retrofitting from CFC-12 to HCFC-22

It is possible to change from CFC-12 to HCFC-22, but it is important to be aware of the increased pressure in the system and the increased capacity (reduced compressor speed or new compressor is necessary). For details on the retrofit procedure, see chapter *4.2.6 Retrofitting CFC-12 to HCFC-22.*

11.2.1.3 Retrofitting from R-502 to Blend

Blends are possible retrofit refrigerants for R-502 in smaller units in road transport. For details on the retrofit procedure, see chapter *4.2.9 Retrofitting from R-502 to Blends.* See also example later in this chapter /Thermo King,1993a,b/.

11.2.2 New Equipment with Non-CFC Refrigerants

In all types of transport refrigeration, current emphasis is on the production of equipment which is either operated with or can be converted to HCFC-22. In the particular case of mobile smaller units on trucks and on containers, there is optimism regarding the future of HFC-134a with polyol ester based lubricants. However, the situation is made more difficult due to increased food quality and food safety requirements by certain countries and regions (such as the European Community), which could require closer temperature control and lower cargo carriage temperatures.

Food store, air conditioning and central cargo plant on board ships, are almost universal for new equipment in new ships. It is possible to use ammonia for larger marine plants, but the combination of safety precautions and the need to use indirect rather than direct refrigeration systems, would increase the capital and operational costs substantially.

11.2.3 Examples of Successful Conversion to non-CFC Refrigerants and Equipment

11.2.3.1 Retrofitting with Non-CFC Refrigerants

Retrofitting from R-502 to 69L (blend)/Thermo King,1993a,b/

Thermo King has converted 150 units for road transport refrigeration in Norway.

Main data:

Refrigerant charge:	Up to 9 kg
Compressor:	Open type with 2 to 4 cylinders
Evaporating temperature:	-28°C
Condensing temperature:	30°C

System modifications:

Change of desiccant filter. The same lubricant can be used.

Manufacturer/contractor:

Name:	Thermo King Norge
Address:	Alfaset 3,Industriv.6, 0668 Oslo 6.
Country:	Norway
Phone no.:	(47) 22 32 12 60
Fax no.:	(47) 22 30 63 64

Retrofitting from CFC-12 to HFC-134a/Thermo King,1993a,b/

Thermo King has converted 5 units for road transportation in Norway.

Main data:

Refrigerant charge:	Up to 9 kg
Compressor:	Open type with 2 to 4 cylinders
Evaporating temperature:	0°C

The units are maintained every 500 running hour.

System modifications:

Change of desiccant filter

Manufacturer/contractor:

Name:	Thermo King Norge
Address:	Alfaset 3,Industriv.6, 0668 Oslo 6.
Country:	Norway
Phone no.:	(47) 22 32 12 60
Fax no.:	(47) 22 30 63 64

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12. VEHICLE AIR CONDITIONING

12.1 Introduction

The main area of vehicle air conditioning is climatization of the passenger compartment in motorcars (automobiles), but climatization of the passenger and personnel zones in for example trains, trucks, and buses are also examples of vehicle air conditioning. In the present chapter, only the refrigerating circuit is considered, as this involves use of CFC and HCFC refrigerants.

Sun radiation through windows and heat transmission through the structure of the compartment makes climate cooling a necessity in large parts of the world, in order to avoid unacceptably high temperatures. As a means to increase the comfort and safety of driving, climate cooling is regarded as more or less indispensable in temperate and warm climates.

12.1.1 Current Equipment and Refrigerants in Passenger Car Air Conditioning

By far the largest area in terms of the number of systems, and also in terms of refrigerant use, is air conditioning in passenger cars. Such systems are normally installed at the assembly line at the car manufacturer, but add-on kits are also available. Of the annual worldwide car production of some 40-45 million cars, mini-vans and light trucks, about 50% are delivered from the factory with an air conditioning system as standard equipment /UNEP,1991/.

Since climate cooling was introduced in some US car models in the 1940's, CFC-12 has been the preferred refrigerant, in practice covering 100% of the market. In 1990, the worldwide consumption of CFC-12 for vehicle air conditioning was about 130.000 metric tonnes /UNEP,1991/.

The refrigerating system is an ordinary CFC-12 vapor compression circuit, with the compressor belt driven from the car engine, i.e. open compressor with shaft seal, and refrigerant-to-air heat exchangers. Both reciprocating (axial piston) and sliding vane compressors are commonly used, and some car models use scroll machines. Flexible hose connections are necessary between the compressor and the rest of the system, both to allow relative movement of the engine and to limit noise transmission. The condenser is placed in front of the radiator, cooled by the ambient air flow. The evaporator is placed within the climate control unit in front of the passenger compartment. This unit also comprises the heater core, fans, dampers and duct system for ventilating, heating and cooling the passenger compartment. Both recirculating air and fresh air can be cooled by the evaporator. The refrigerating capacity is usually in the range from 3 to 5 kW at 40°C ambient air temperature.

A receiver with filter/drier element is usually installed on the liquid line close to the condenser. The expansion valve may be of a thermostatic type, or an orifice or capillary tube may be used. In the latter case, the system also comprises an accumulator between the evaporator and the compressor. The compressor is normally regulated on/off by a magnetic clutch ("cycling clutch"), which is controlled by an evaporator thermostat that limits the minimum temperature to about 0°C to avoid frost formation. In some systems the compressor displacement may be continuously regulated in correspondence with the suction pressure.

12.1.2 Equipment and Refrigerants in Other Areas of Vehicle Air Conditioning

Air conditioning systems for cooling of trucks, buses and trains are mainly based on CFC-12 vapor compression equipment, although some systems may use HCFC-22. Various concepts are used for distribution of cooled air, and for providing the condenser with cooling air. The compressor may be installed in several locations. Compressors are generally of the open type, driven by the main engine via a belt drive, or by a special engine or electric motor. A number of evaporator units may be distributed throughout the cooled compartment, or the cooled air may be distributed by a duct system.

The cooling capacity of a typical bus system may be in the order of 25 kW, and the system may comprise as much as 120 m of refrigerant lines (split system). In buses, the climate control unit may be located on the roof, in the rear, or with the components located at different places in the vehicle (for instance engine compartment, under the ceiling, in connection with the luggage compartment.)

12.2 Alternative Non-CFC Refrigerants and Equipment

At present, the primary replacement refrigerant for vehicle air conditioning is HFC-134a, both for retrofit and for new systems. The use of blends has been proposed by the chemical manufacturers as drop-in replacements, but the motor vehicle industry and service workshops are reluctant towards introducing more refrigerant types and mixtures than the existing CFC-12 and the replacement HFC-134a (plus their lubricants). This is quite understandable, considering the practical problems associated with repair/servicing of systems and recycling of refrigerant if numerous alternatives and blends are brought into use.

In a longer term perspective and with increased focus on environmental problems, the continued use of HFC-134a in vehicle (motorcar) air conditioning may be prohibited. This will of course depend on the availability of good alternatives. At present a number of concepts are being investigated and evaluated throughout the world, representing potential replacement technology for HFC-134a systems.

12.2.1 Retrofitting with Non-CFC Refrigerants

Most car manufacturers and several national or international organizations already have considerable practical experience in relation to retrofitting of CFC-12 systems. In any case, before attempting to retrofit a specific system, the vehicle manufacturer's representative should be consulted for specific requirements and advice in relation to the retrofit operation.

12.2.1.1 Retrofitting from CFC-12 to HFC-134a

As already stated, HFC-134a is the primary refrigerant candidate for retrofitting. A change over to this fluid also involves change of lubricant. The following changes in the system are usually recommended in relation to the retrofit operation (check with manufacturer's representative) /Deklava,1992/, /Nishimura,1993/:

- *Change of lubricant.* The conventional mineral oil is insoluble in HFC-134a liquid, and the system design is such that solubility is regarded as necessary for safe lubricant circulation back to the compressor. Two possible lubricant types which are soluble in HFC-134a have been identified: PAG-based (Polyalkylene glycol) and ester-based (polyolester) fluids.

- *Change of desiccant material.* Owing to the smaller size of the HFC-134a molecule and chemical compatibility problems with conventional CFC-12 drier materials, the desiccant (drier) must be changed. Molecular sieve materials XH-6, XH-7 and XH-9 can be used with HFC-134a. The industry generally recommends use of XH-7 in HFC-134a mobile air conditioning systems. It is generally recommended to increase the amount of desiccant material by 10-20% in relation to the original amount in the CFC-12 system, due to the higher hygroscopicity of HFC-134a and its lubricants.

- *Replacement of hoses.* Permeation rates through conventional CFC-12 hoses e.g. based on nitrile rubber are generally unacceptably high with HFC-134a. Improved hoses e.g. with Polyamide (Nylon) barrier material have been developed, which reduces the permeation rate considerably. Some recently installed CFC-12 A/C system may already have such hose materials, to limit the emission of CFC-12 and the moisture influx.

- *Change to elastomer seal materials that are compatible with HFC-134a and lubricant.* Depending on the recommendations given by the car manufacturer, O-rings and static sealings in the system and the compressor should be replaced. NBR (Nitrile butadiene rubber), HNBR (Hydrogenated NBR), Neoprene and Nylon are regarded as compatible with ester-based lubricants and HFC-134a. Viton and SBR are not recommended /Smith,1993/. In systems with PAG lubricant, NBR and HNBR are claimed to have poor resistance /Nishimura,1993/, while EPDM (Ethylene propylene rubber) and IIR (Isobutylene isoprene rubber) have good resistance. In some cases, it may be required to replace the compressor shaft seal as well.

- *Replacement or adjustment of high-pressure cut-out switch.* High-side pressures are generally somewhat higher with HFC-134a than with CFC-12, thus a higher set-point may be required.

- *Replacement or adjustment of expansion valve or orifice tube (optional).* In systems with thermostatic expansion valve, the static superheat setting should be increased by about 3 degrees K. Orifice tube systems may require a smaller tube dimension.

A new standard for service fittings in HFC-134a systems has been developed by the Society of Automotive Engineers, Inc. (SAE). It may be questioned whether these fittings should be installed on retrofitted systems, at least if some kind of disconnectable adaptor is used. In such cases there is considerable risk for mistakes and cross-contamination of refrigerant containers, refrigerating circuits and recycling/recovery equipment. The best solution would be to install new HFC-134a fittings that are not disconnectable, and to clearly identify the system as retrofitted to HFC-134a, e.g. by attaching special warning labels.

There is still no clear choice of lubricant for retrofit purposes. Although most car and system manufacturers seem to prefer ester-based lubricants, both PAGs and esters are being evaluated and recommended. Both these lubricant types are considerably more hygroscopic than mineral oil, and should therefore be handled more carefully.

Since vehicle air conditioning systems in new car models based on HFC-134a use PAG as lubricant, this is recommended by some manufacturers also for retrofit purposes, to avoid bringing yet another lubricant into the workshops. Others claim that ester lubricants are less hygroscopic and more tolerant to remaining chlorine than PAG-based fluids, and therefore recommend this lubricant for retrofit.

The following general retrofit procedure has been proposed /Deklava,1992/, /Smith,1993/, /Deklava, 1993/:

1) CFC-12 recovery
2) Flushing of the system to remove mineral oil
3) Removal and draining of the compressor (optional)
4) Addition of new synthetic lubricant (ester or PAG)
5) Re-assembly of the system (including change of parts)
6) Evacuation
7) Recharging with HFC-134a

In order to remove as much mineral oil as possible during CFC-12 recovery, the engine and A/C system may be operated first to warm up the system and dissolve as much oil as possible in the refrigerant /Wu,1992/.

It is being disputed whether stage 2 (flushing) should be included in the retrofit procedure. The objective is to remove as much mineral oil (and dissolved CFC-12) as possible from the system, and the need to flush depends on the tolerance to residual oil and chlorine. In addition, it is a question of available flushing agents. Assuming that most of the oil is located in the compressor, it may be a better solution to remove and drain this instead of flushing. In view of the possible difficulties in removing residual oil (with dissolved CFC-12), the best retrofit result may be obtained with an ester-based lubricant which has a better reported tolerance towards chlorine.

ICI has investigated use of per- and trichloroethylene as flushing agents, with good results /Deklava,1992/. The low Acceptable Exposure Limit (AEL) of less than 50 ppm is disadvantageous, however. It is also possible to flush the system with liquid (high-pressure) CFC-12. The procedure outlined in /Smith,1993/ recommends the use of a conventional CFC-12 recovery rig. By repeated stages of recovery, oil separation from the recovered CFC-12, and re-charging with CFC-12, the intention is to flush as much mineral oil as possible out of the system. CFC-11 should not be used as a flushing agent, due to compatibility problems with HFC-134a.

In step 4, the lubricant is added directly to the compressor, and in step 5 (assembly) hoses, desiccant, O-rings and other components may be replaced in accordance with recommendations from the vehicle or air-conditioning system manufacturer. The recommended charge of HFC-134a in the retrofitted system should also be checked. Usually, the refrigerant mass should be 5-10% lower than with CFC-12.

Most sources report that performance (capacity) of the air conditioning system is about the same after retrofit as before, possibly with a slight reduction at idling and high ambient air temperatures /Pettersen,1991/.

In /UNEP,1991/, the retrofit operation is estimated to take between 120 and 220 minutes including flushing, with parts cost in the range from USD 90 to 130. Estimated retrofit time requirements in /Deklava,1992/ are between 120 and 195 minutes with flushing and 90-150 minutes without.

Information from Volvo on the Scandinavian market indicates a total retrofit cost of about USD 350 (including parts and labor). The operation requires nearly four hours in the workshop.

12.2.1.2 Retrofitting from CFC-12 to Blends

As already mentioned, there is considerable reluctancy in the industry towards retrofit solutions based on other refrigerants than HFC-134a. Mixtures based on HCFC-22, HFC-152a and HFC-124 /Kanno,1991/, /Buth,1992/ has been proposed as retrofit blends for vehicle air conditioning systems, although differences in hose permeation rates probably will lead to loss of the HCFC component over some time (preferential leak). In addition, blend recycling equipment has not been developed so far.

A retrofit to this 3-component blend will also require change of desiccant (probably to molecular sieve XH-9) and may also require change of lubricant to alkylbenzene /Kanno,1991/, /Buth,1992/.

In the United States, a number of blends or chemicals claimed to replace CFC-12 have been introduced by local "entrepreneurs". Behind such names as "GHG", "Alaska Cool" and "Arctic Chill", which are claimed to be safe CFC-12 substitutes, one may find combinations of HCFC-22, HCFC-142b, HFC-152a, R-176, isobutane and even some CFC-12 (!). Some of these compounds will destroy the existing CFC-12 desiccant which may lead to clogging of the expansion device, and some are flammable or explosive. If systems containing such blends are brought to a workshop for service or repair, there is considerable risk of contaminating recycling equipment and of spreading these compounds to other vehicles through containers.

12.2.2 New Equipment with Non-CFC Refrigerants

Future solutions for new equipment with non-CFC-free refrigerants are presented in chapter 15.

12.2.2.1 HFC-134a

At present, all vehicle manufacturers have converted or are just about to convert their production and/or installation of air conditioning equipment to systems based on HFC-134a, which will be the replacement refrigerant for CFC-12.

Some of the modifications that are required in relation to the CFC-12 equipment are mentioned in the retrofit section above, e.g. change of lubricant, desiccant, hose and elastomer materials, expansion means and pressure cut-out switch. In addition, the following design changes are generally made in new HFC-134a air conditioning systems:

- In connection with the first tests with HFC-134a as refrigerant, problems of copper plating in some systems was encountered and widely discussed. At present, these effects are claimed to be caused by too high moisture content. Although the problem can be eliminated by keeping moisture low and by improved lubricants and additives, most manufacturers avoid copper in their HFC-134a circuits /Marquart, 1993/.

- In order to reduce the refrigerant consumption, HFC-134a systems are generally built with reduced charge. Although this does not affect the leakage rate directly, it leads to earlier detection of leaks and reduced refrigerant emission before a loss in capacity is sensed and the system is repaired. Another positive effect is reduction in the weight of the air conditioning system and reduction in refrigerant costs. By reducing the volume of the receiver and the heat exchangers, a weight reduction of some 0.2-0.4 kg may be obtained.

- HFC-134a may give a somewhat reduced cooling capacity at high ambient air temperatures and low compressor speed (idling), and will also give higher saturation pressures in the high side. The condenser is therefore generally improved to compensate for this, by increasing the heat transfer surface and/or by enhancing the heat transfer efficiency.

- The compressor design is usually changed somewhat when adapted to HFC-134a. These changes may involve new elastomer materials, new magnetic clutch design, new materials and modified design of valves and bearings, and a new shaft seal.

- Systems for HFC-134a have different charge/service fittings, with metric dimensions, as recommended by SAE.

In new systems, the primary lubricant alternative to day is PAG-based fluids. This is in contrast to decisions made in other fields of refrigeration, air-conditioning and heat pumps, where the industry has decided to use ester-based lubricants in new systems for HFC-134a. The differences between performance of PAG and esters are not very large, however, and their characteristics are to a large extent determined by various additives.

12.2.3 Examples of Successful Conversion to non-CFC Refrigerants and Equipment

12.2.3.1 Retrofitting with Non-CFC Refrigerants

The automotive industry and chemical companies have a number of retrofit programs (fleet studies) all over the world. Such investigations are being performed in the United States, Japan, Europe and Australia, and elsewhere. In order to get detailed information and results from these programs, the best solution is to contact the car manufacturers or the chemical (refrigerant) producing companies. Lubricant producers may also provide useful information.

In the United States, the Environmental Protection Agency (US EPA) has requested SAE to investigate possible industry standards for retrofitting of CFC-12 systems. This work on development of guidelines will eventually lead to recommended refrigerant/lubricant combinations, recommended service equipment, retrofit procedures and labelling requirements.

The following organizations may possibly provide information on retrofit of CFC-12 systems to HFC-134a:

Mobile Air Conditioning Society (MACS)
P.O. Box 97
East Greenville, Pennsylvania 18041
U.S.A.
Phone: 1 215 541-4500
Fax: 1 215 679-4977

Society of Automotive Engineers, Inc. (SAE)
400 Commonwealth Drive
Warrendale, Pennsylvania 15096-0001
U.S.A
Phone 1 412 776-4841
Fax 1 412 776-5760

In /Dekleva,1992/ and /Dekleva,1993/, results from fleet retrofit studies are reported. Vehicles range in age from 1985 to 1992, and ten different types of compressors and varying expansion valves/orifice tubes are included. All systems are based on ester lubricant after retrofit. Preliminary results are good, indicating essentially equivalent capacity and no particular problems of operation. Long-term effects remain to be investigated, however.

12.2.3.2 New Equipment with Non-CFC Refrigerants

All the major car producers of the world are now about to introduce (if not already introduced) air conditioning systems based on HFC-134a in the new models. All manufacturers of components and parts for mobile air conditioning systems have adapted their products to HFC-134a and synthetic lubricants. New systems for other vehicles are also generally being based on HFC-134a now.

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Wu, W.T., R. McNary, and R. Thomas: *Problems and Solutions in Retrofit of Automobile Air-Conditioning Systems to R-134a.* The 1992 International CFC and Halon Alternatives Conference, Proceedings pp 707-714, Washington DC September 29 - October 1, 1992.

HEAT PUMPS

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13. HEAT PUMPS

13.1 Introduction

The scope of this section is heat pumps for heating only and heat recovery. Dual mode units, also used for cooling are not included.

13.1.1 Current Equipment and Refrigerants

Heat pumps contribute to a significant reduction in CO_2 releases, in order of 10 million tons, assumed that the alternative heating would be based combustion of oil. Heat pumps have a wide range of application areas, within residential and commercial space heating and industrial heating applications. The most common principle is the vapor compression cycle, used with reciprocating-, screw- and turbo-compressors. Absorption heat pumps are also used in a small scale, especially for industrial applications. The most common refrigerants in the heat pump sector are *CFC-12, HCFC-22* (condensing temperatures up to 60°C), and *R-500* (replaces CFC-12 in order to extend capacity range). In industrial applications *ammonia* is used as well.

In addition to mechanical and thermal vapor compression systems, open-type heat pumps are also used in industrial heat pump application, with process vapor as refrigerant.

13.1.1.1 Residential and Commercial Heat Pumps

The plant sizes varies from a few kW for single room heaters, 50 - 500 kW for office buildings and up to several MW for district heating systems. Heat sources are ambient air, sea- and lake water, sewage water, soil, rocks and industry waste water. Heat pumps are also used in heating, dehumidification and heat recovery from swimming pools and skating rinks, in addition to heating of process water for fish-farm plants. Annually operation hours typically vary from 1000 hours to 5000 hours. The heat is normally distributed by water or by air, at temperatures between 40°C and 80°C. Average refrigerant charge is estimated to be about 1.0 kg/kW /UNEP, 1991 a/.

13.1.1.2 Industrial Heat Pumps

The heat pump units in industrial sector varies from about 100 kW up to several MW. Industrial waste heat is often used as heat source. Condensing temperatures can be in the range from 80°C to 120°C and even higher. Because of high heat source temperatures, units in the industrial sector often gain high COP. Annually operation hours are typically 8000 hours. Average refrigerant charge is estimated to be about 1.0 kg/kW, varying from 0.5 to 2.5 kg/kW. Applications vary over a wide range. Typical applications for industrial heat pumps are heating of process water, drying, distillation, vapor production, and evaporation processes.

13.2 Alternative Non-CFC Refrigerants and Equipment

Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"* provides information on different properties for current CFC and available non-CFC refrigerants in the heat pump sector, for example:

- physical and thermodynamic properties
- ODP, GWP, toxicity, flammability etc.
- price, availability
- relative refrigerating capacity (investment costs)
- relative theoretical COP (operating costs)

13.2.1 Retrofitting with Non-CFC Refrigerants

Many heat pumps have a long remaining life time, on average close to ten years. CFC production will be reduced and ultimately phased out in a few years. To avoid preliminary scrapping of existing heat pumps, there are two options available. Refrigerants can be recovered/recycled or the heat pump can be retrofitted with alternative refrigerants.

HFC-134a, HCFC-22 and blends can be used as retrofit refrigerants in the heat pump sector. No refrigerants can be retrofitted without minor or major system modifications.

13.2.1.1 Retrofitting from CFC-12 to HFC-134a

The thermodynamic and physical properties of HFC-134a and CFC-12 are quite similar, and studies have shown that CFC-12 and HFC-134a have almost identical COP for evaporation temperatures above -10°C /Haukås, 1991/. HFC-134a can be used as a retrofit. The most promising procedure seems to be the *Forced Cleaning Method* (flushing method), see chapter 4.2.4 *"Retrofitting from CFC-12 to HFC-134a"* for further information. Since HFC-134a is not miscible with mineral oils, the mineral oil has to be replaced by a polyol ester based lubricant. For details on the retrofitting procedure, see chapter 4.2.4.

13.2.1.2 Retrofitting from CFC-12 to HCFC-22

When retrofitting from CFC-12 to HCFC-22, the temperature requirement has to be lowered in some applications. Most heat pumps are designed for a maximum pressure of 25 bar, which means that the condensing temperature can not exceed 60°C with HCFC-22 as a refrigerant. (80°C with CFC-12.) The heating capacity increases significantly, about 40 %, when retrofitted with HCFC-22. It might be necessary to change to a smaller compressor or if open type compressor is used, reduce the compressor speed to obtain the same heating capacity. For details on the retrofitting procedure, see chapter 4.2.5. *"Retrofitting from CFC-12 to HCFC-22"*.

13.2.1.3 Retrofitting from CFC-12 to blends

Blends can be tailor-made to fit specific needs, but there might be problems after leakages due to disturbance of the fractions of the mixture compounds. Therefore, blends are most suitable for sealed systems and for larger units where the composition more easily can be determined.
For more details, see chapter 3.2.4 *"Mixtures/blends"* and chapter 4.2.5 *"Retrofit from CFC-12 to blends"*.

13.2.2 New Equipment with Non-CFC Refrigerants

Several refrigerants can replace CFCs in new equipment. Many of them are toxic or flammable and they are likely not to meet current building codes. Special safety precautions has to be considered. Excellent references for designing plants with toxic and flammable refrigerants are: *ASHRAE Handbooks* /ASHRAE, 1983, 1985, 1987/, *"American National Standard for Equipment, Design and Installation of Ammonia Mechanical Refrigeration Systems"* /IIAR, 1985/, *"ASHRAE Standard 34-1989, Number Designation and Safety Classification of Refrigerants"* /ASHRAE, 1989/, and *BS 4434 1989* /BSI, 1989/.

13.2.2.1 HCFC-22

Though it is a transitional refrigerant, HCFC-22 will be of vital importance in the phase out of CFCs. HCFC-22 can easily replace CFC-12 in most heat pump applications. The temperature requirement has to be taken into consideration, since most heat pumps are designed for a maximum pressure of 25 bar. With 25 bar condensing pressure, the condensing temperature can not exceed 60°C with HCFC-22 as refrigerant. (80°C with CFC-12.) For more details, see chapter *3.2.1. "HCFC Refrigerants"* and chapter *4.3.1. "HCFC-22"*.

13.2.2.2 Ammonia (NH_3)

Ammonia is one of the best alternatives to CFCs in new equipment, regarding thermodynamic, economic and environmental aspects. With zero ODP and GWP, it is an excellent long-term alternative. In countries were ammonia is accepted and widely used, it is a natural replacement for CFC-12 and R-502, especially in the industrial sector. Introduction of compact, low charge refrigeration systems which are under development, will strengthen the use even more. Systems to be operated with a condensing pressure of 40 bar and condensing temperature of 78°C are already manufactured and tested (see example) /Eggen ,1991/. Since ammonia is flammable in some concentrations with air and also toxic, safety precautions has to be taken to ensure safety during operation and service. For more details, see chapter *3.2.3. "Natural Refrigerants"* and chapter *4.3.5. "Ammonia"*.

13.2.2.3 HFC-134a

Even though the non-negligible GWP, HFC-134a is expected to be an important short-term alternative to CFC-12 in the heat pump sector, especially in countries with local safety restrictions regarding natural refrigerants like ammonia and hydrocarbons. Traditional mineral oils can not be used with HFC-134a, and a polyol ester oil is recommended by most manufacturers. Studies have shown that CFC-12 and HFC-134a yields almost identical COP for evaporation temperatures above -10°C /Haukås, 1991/. For more details, see chapter 3.2.2 *"HFC Refrigerants"* and chapter 4.3.2 *"HFC-134a"*.

13.2.2.4 HFC-152a

With zero ODP and negligible GWP, HFC-152a can be a replacement for CFC-12 in heat pump units. HFC-152a has, in fact, better COP than both CFC-12 and HFC-134a, and it is compatible with mineral oil lubricants. Since HFC-152a is flammable and has no odor, precautions and safety measures has to be taken to ensure safety during operation and service. System design and refrigerant charge must always meet local laws and regulations. Especially in compact heat pumps with low refrigerant charge and proper safety precautions, this can be a mid-term and long-term alternative.

In Norway a hot tap water heat pump, originally designed for HCFC-22, has been retrofitted to HFC-152a /Tokle, 1992/. The heat pump has never been charged with HCFC-22.

For more details on retrofitting from CFC-12 to HFC-152a, see chapter 3.2.2 *"HFC Refrigerants"* and chapter 4.3.3 *"HFC-152a"*.

13.2.2.5 Hydrocarbons

Hydrocarbons are thermodynamically excellent refrigerants, but they are also flammable. In compact heat pumps with low refrigerant charge and hermetic compressors, propane can be an excellent long-term alternative when the proper safety precautions are taken. Also in large industrial heat pumps, with proper safety precautions, hydrocarbons are good alternatives. System design and refrigerant charge must always meet local laws and regulations in order to ensure safety during operation and service. For more details, see chapter 3.2.3 *"Natural refrigerants"* and chapter 4.3.4 *"Propane (HC-290)"*.

In Norway, a heat pump plant with propane as refrigerant has been in operation since 1993. The heat pump has a heating capacity of 45 kW, and is used for residential heating in a church at Lillehammer /SINTEF, 1993/, /Stene, 1994/.

13.2.3 Examples of Successful Conversion to Non-CFC Refrigerants and Equipment

13.2.3.1 Retrofitting with Non-CFC Refrigerants

Retrofitting from R-500 to HFC-134a in District Heating Plant in Hammarby, Sweden

The district heating plant was installed in 1986. The heat pump has a two-stage centrifugal (turbo) compressor. It was retrofitted in 1991, and there have been no major problems with the plant during the last two years. After the retrofitting, the heating capacity decreased with 2 - 4 %, while the maximum operating temperature increased from 85°C to 90°C. There was no significant change in COP.

Main data:

Lubricant:	Synthetic; Polyalphaolefin. Same as used before
Heat source:	Cleaned waste water, temperatures 8 - 20°C
Heating capacity:	25 MW

System modification:

Compressor impellers are changed (not gears).
Change of desiccant filter.
Change of all O-rings, sealings and gaskets to new in same materials.

Manufacturer/contractor:

Name:	ABB STAL AB
Address:	61220 Finspång
Country:	SWEDEN
Phone no.:	+ 46 122 81 214

Consultant:

Name:	Stockholm Energi AB, Teknisk & Miljø
Address:	PB 39101, 10054 Stockholm
Country:	SWEDEN
Phone no.:	+46 8 782 82 00
Fax no.:	+46 8 662 18 47

Owner:

Name:	Stockholm Energi AB
Address:	PB 91725, 12017 Stockholm
Country:	SWEDEN
Phone no.:	+ 46 8 74 97 712

13.2.3.2 New Equipment with Non-CFC Refrigerants

Heat Pump with Ammonia in District Heating Plant at Bodø Military Air Base, Norway

At Bodø Military Air Base, Norway, a district heating plant was installed in 1992 to deliver heat for 36 buildings. The heat demand is 3.8 MW and 11 GWh/year. The district heating plant is based on a heat pump with two-stage reciprocating compressors and ammonia as refrigerant.

Main data:

Heat source:	Sea water
Heating capacity on the heat pump:	2 MW
Maximum system pressure:	40 bar
Maximum condensing temperature:	73°C

Manufacturer/contractor:

Name:	Sabroe Kulde AS
Address:	PB 1845, 7002 Trondheim
Country:	NORWAY
Phone no.:	+ 47 73 91 90 66
Fax no.:	+ 47 73 91 97 11

Consultant:

Name:	Flatheim VVS-rådgiveren
Address:	PB 1883, 8017 Bodø
Country:	NORWAY
Phone no.:	+47 75 58 30 00
Fax no.:	+47 75 58 30 13

Owner:

Name: Forsvarets Bygningstjeneste, avdeling Bodø
Address: PB 345, 8001 Bodø
Country: NORWAY
Phone no.: +47 75 53 70 00
Fax no.: +47 75 56 37 15

References

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.:

- *ASHRAE Handbook: - FUNDAMENTALS*. Atlanta, USA 1985. ISSN 82-643223.
- *ASHRAE Handbook - REFRIGERATION, Systems and Applications*. ISBN 0-910110-70-0. ISSN 1041-2344. Atlanta, USA 1987.
- *ASHRAE Handbook - HVAC Systems and Applications*. ISBN 0-910110-50-6. Atlanta, USA 1987
- *ASHRAE Handbook - EQUIPMENT*. ISSN 0737-0687. Atlanta, USA 1983.

ASHRAE Standard 34-1989, Number Designation and Safety Classification of Refrigerants. American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta. 1989.

BSI - British Standard Institute: *BS 4434 1989, Specifications for Safety Aspects in the Design, Construction and Installation of Refrigerating Appliances and Systems*. British Standard Institute, 1989.

Clark, E. M., et. al.: *Retrofitting Existing Chillers With Alternative Refrigerants*. ASHRAE Journal, pp. 38 - 41, April, 1991

Eggen, G., NTH-SINTEF Refrigeration Engineering, Norway: *Prototyp- og demonstrasjonsanlegg for varmepumpe. Årsrapport 1990. (Prototype- and Demonstration Heat Pumps. Annual Report 1990)*. Trondheim, Norway 1991.

Haukås, H.T., NTH-SINTEF Refrigeration Engineering, Norway: *Alternative kuldemedier*, Kuldedagene 91 (*Alternative refrigerants*, Norwegian Refrigeration Meeting 91). Hell Rica Hotel, Stjørdal, Norway 1991.

IIAR - International Institute of Ammonia Refrigeration: *American Standard for Equipment, Design and Installation of Ammonia Mechanical Refrigeration Systems*. ANSI/IIAR-2-1984. Approved by The American National Standards Institute, July 24, 1985.

SINTEF Refrigeration Engineering: Prototype- and Demonstration Heat Pumps with Propane as Refrigerant. Assistance under construction (Contacts: Geir Eggen/Tor Lystad) Trondheim Norway 1993.

Stene, J. et. al.: *Norwegian Heat Pump Status and Policy Review*. SINTEF Report STF11 A94005. ISBN 82-595-8415-8. SINTEF Refrigeration Engineering, Trondheim Norway 1994

Tokle, T.: *Driftserfaringer med varmepumpe med HFK-152a til tappevannsberedning. (Operation Experiences with Hot Tap Water Heat Pump with HFC-152a)*. SINTEF Report STF11 A92004. SINTEF Refrigeration Engineering, Trondheim, Norway 1992.

UNEP : *MONTREAL PROTOCOL. 1991 Assessment. Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee*. Pursuant to Article (6) of the Montreal Protocol on Substances that Deplete the Ozone Layer. (RWR-570-LK-91423-al.) December 1991 a.

UNEP : *MONTREAL PROTOCOL. 1991 Assessment. Report of the Technology and Economic Assessment Panel*. Pursuant to Article (6) of the Montreal Protocol on Substances that Deplete the Ozone Layer. (ISBN 92-807-1314-0) December 1991 b.

SUPPLIER'S LIST FOR REFRIGERATION, AIR CONDITIONING AND HEAT PUMPS: TECHNOLOGIES AND PRODUCTS

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14. SUPPLIER'S LIST FOR REFRIGERATION, AIR CONDITIONING AND HEAT PUMPS: TECHNOLOGIES AND PRODUCTS

This supplier's list consists of names and addresses of manufacturers, suppliers, consultants, and organizations that offer equipment, chemicals, services or information within refrigeration, air conditioning and heat pumps sector, included retrofitting. The supplier's list is not comprehensive, and therefore we recommend that the readers consult local supplier's as well as the catalogue.

14.1 Alternative Refrigerants

Two industry research programmes are working with problems concerning the introduction of new non- CFC refrigerants:

AFEAS - Alternative Fluorocarbons Environmental Acceptability Study
The West Tower Suite 400
1333 H Street NW
Washington DC 20005
USA
Tel: (1) 202 898 09 06
Fax: (1) 202 798 12 06

PAFT - Programme for Alternative Fluorocarbon Toxicity Testing
c/o ICI
PO Box 13, The Heath
Runcorn, Cheshire WA7 4QF
United Kingdom
Tel:(44) 928 513 145
Fax:(44) 928 511 418

NAMES AND ADDRESSES FOR REFRIGERANT MANUFACTURERS:

Akzo Chemicals International BV
Chemicals Division
Stationstraat 247, PO Box 48
3800 AE Amersfoort
The Netherlands
Tel: (31) 33 676 315
Fax: (31) 33 676 157
Telex: 79276
(Member of AFEAS and PAFT)

Allied-Signal Inc.
Fluorine Products Division
Buffalo Research Laboratory
20 Peabody Street
Buffalo, NY 14210
USA
Tel: (1) 716 827 6243
Fax: (1) 716 827 6207
Telex: 7105221213 ALCRBUF
(Member of AFEAS and PAFT)

Asahi Glass Co., Ltd.
Performance Chemicals Division
2-1-2 Marunouchi, Chiyoda-ku
Tokyo 100
Japan
Tel: (81) 3 3218 5414
Fax: (81) 3 3211 7672
Telex: J29859 ASAGLACH
(Member of AFEAS and PAFT)

Aussimont S.p.A.
via Principe Eugenio 1/5
20155 Milano
Italy
Tel: (39) 2 6270 3586
Fax: (39) 2 6270 3985
Telex: 310679 MONTED
(Member of AFEAS and PAFT)

Central Glass Co. Ltd
Chemicals Technical Planning
Kowa-Hitotsubashi Building
7-1, Kanda-Nishikicho, 3-chome
Chiyoda-ku
Tokyo 101
Japan
Tel: (81) 3 3259 7481
Fax: (81) 3 3293 2145
(Member of PAFT)

Chemicals and Plastics India Ltd.
8, Cathedral Road
Madras-600 086
India
Tel: (91) 44 473333
Fax: (91) 44 869359
Telex: 041-8479 GEON IN

Daikin Industries, Ltd.
Safety, Health and Environ. Division
1-1, Nishi-Hitotsuya, Settsu-shi
Osaka 566
Japan
Tel: (81) 6 349 5336
Fax: (81) 6 349 2578
Telex: J63930
(Member of AFEAS and PAFT)

E.I. du Pont de Nemours & Co., Inc.
Du Pont Chemicals,
Fluorochemicals Laboratory
Chestnut Run Plaza, PO Box 80711
Wilmington, Delaware 19880-0711
USA
Tel: (1) 302 999 3413
Fax: (1) 302 999 5340
(Member of AFEAS and PAFT)

Elf Atochem S.A.
4 Cours Michelet
La Défense 10, Cédex 42
92091 Paris la Defense 10
France
Tel: (33) 1 49 00 75 53
Fax: (33) 1 49 00 70 21
Telex: 611922 ATO
(Member of AFEAS and PAFT)

Elf Atochem N.A., Inc.
Elf Atochem North America, Inc.
2000 Market Street
Philadelphia, PA 19103-3222
USA
Tel: (1) 215 419 7851
Fax: (1) 215 419 7057
(Member of PAFT)

Gujarat Fluorochemicals Ltd.
A/6 Connaught Pl
New Dehli 110 001
India
Tel: (91) 31 3324245
Fax: (91) 31 3325128
Telex: 31-62585 SMAS-IN

Hankook Shinwha Co. Ltd
Taiwha B/D 9FL
194-27, Insa-dong Chongro-ku
Seoul 110-290
Korea
Tel: (82) 2 722 3961
Fax: (82) 2 720 5513
(Member of PAFT)

Hoechst AG
F+E/GB-A
Building D 729, Brüningsstrasse 45
D-6230 Frankfurt am Main 80
Germany
Tel: (49) 69 305 5973
Fax: (49) 69 331 507
Telex: 412340 HOEDG D
(Member of AFEAS and PAFT)

ICI Chemicals & Polymers Ltd.
General Chemical Business Group
PO Box 13, The Heath Runcorn
Cheshire WA7 4QF
United Kingdom
Tel: (44) 928 513 145
Fax: (44) 928 511 418
Telex: 94028500 ICIC-G (ID#: NJC3)
(Member of AFEAS and PAFT)

Jinan Chemical
c/o NEPA
N° 115 Xizhimennei
Nanxiaojie
Beijing 100035
China
Tel: (86) 1 601 1193
Fax: (86) 1 601 1194
Telex: (222359 NEPA CN

LaRoche Chemicals Inc.
Airline Hwy., PO Box 1031
Baton Rouge, LA 70821
USA
Tel: (1) 504 356 8467
Fax: (1) 504 356 8595
Telex: 784581 LAROCHECHBTR
(Member of AFEAS)

Navin Fluorine Industries
Mafatlal Centre
Nariman Point
Bombay 400 021
India
Tel: (91) 22 202 4547
Fax: (91) 22 202 7856
Telex: 011 84241 MGMC IN

Rhône-Poulenc Chemicals, Ltd.
St. Andrews Road
Avonmouth
Bristol BS11 9HP
United Kingdom
Tel: (44) 272 823 631
Fax: (44) 272 820759
Telex: 44256 ISChem
(Member of AFEAS and PAFT)

Showa Denko K.K.
13-9 Shiba Daimon 1-chome
Minato-ku
Tokyo 105
Japan
Tel: (81) 3 5470 3161
Fax: (81) 3 3436 2625
(Member of PAFT)

Solvay S.A.
Direction Alcalis/Produits organiques
rue du Prince Albert 33
B-1050 Brussels
Belgium
Tel: (32) 2 509 6708
Fax: (32) 2 509 6505
Telex: 21337
(Member of AFEAS and PAFT)

Solvay Fluor & Derivate GmbH
Mans-Böckler-Allee 20
30173 Hannover
Germany
Tel: (49) 51 18 57 29 21
Fax: (49) 51 18 57 21 66
(Member of PAFT)

SRF Limited
Chemical Business Group
Express Building
9-10, Bahadur Shah
Zafar Marg
New Dehli-110 002
India
Tel: (91) 11 331 8155
Fax: (91) 11 332 4052
Telex: (31) 65824

Ulsan Chemical Co. Ltd.
Head Office and Plant
290, Maeam-Dong, Ulsan
Kyungnam
Republic of Korea
Tel: (82) 75 7011
Fax: (82) 75 1745

14.2 Units

AEG
PO Box 100105
Kassel 34123
Germany
Tel: (49) 561 - 50 20
Fax: (49) 561 - 50 22777
(Domestic refrigerators & freezers)

Aquaterm Energi AS
Verftsgt. 6
6400 Molde
Norway
Tel: (47) 71 25 77 22
Fax: (47) 71 25 43 95
(heat pumps)

Albers Air Conditioning Corporation
The old school
Hawkley
LISS
Hants
GU33 6NF
United Kingdom
Tel: (44) 73084 388
Fax: (44) 73084 588
(air conditioning)

Bauknecht
Hausgeraete am Wallgraben 99
70565 Stuttgart
Germany
Tel: (49) 711 - 78 860
Fax: (49) 711 - 78 86103
(Domestic refrigerators & freezers)

Bosch BSHG
Hochenstraße 17
D-80076 München
Germany
Tel: (49) 89 4590 01
Fax: (49) 89 4590 2347
(domestic refrigerators/freezers)

Brema Icemakers
Via Rivolta 5-7
20010 Pogliano
Milonese, Milano
Italy
Tel: (39) 29 34 31 63
Fax: (39) 2 93 54 92 22
(ice-machines)

British Gas
326 High Holborn
London WCIV TPT
United Kingdom
Tel: (44) 71 242 0789
Fax: (44) 71 430 1255
(absorption chillers & chiller heaters)

Caravell
8831 Løgstrup
Denmark
Tel: (45) 86 64 22 83
Fax: (45) 86 64 20 28
(domestic refrigerators/freezers)

Carrier-Ebara
Carrier Distribution Ltd
Priory House
Marsh Road, Alperton Lane,
Wembley
United Kingdom
Tel: (44) 8 19 91 20 00
Fax: (44) 8 19 98 09 93
(all applications, incl. ice machines, AC water chillers, room AC, heat pumps)

Cervematica S.A. - "Servematic"
Export division
Canduxer 16 S/A 1,
08021 Barcelona
Spain
Tel: (34) 3 201 5599
Fax: (34) 3 209 9117
Telex: 97881 CERB-E
(ice-machines)

Christopia Energy Systems
78, Ch. du Moulin de la Clue
Quartier Cayrègues
06140 Vence
France
Tel: (33) 1 93 24 61 16
Fax: (33) 1 93 24 29 38
Telex: 461140 CRISTOP F
(chillers)

CKD Chocen Ltd.
565 38 Chocen
Czechoslovakia
Tel: (42) 468 953
Fax: (42) 468 951222
Telex: 198 300 ckd c
(chillers and heat pumps)

Corona Corp.
7-7, Higashi-shinbo,
Sanjo, Niigata
Japan
Tel: (81) 256 32 2111
Fax: (81) 256 35 8530
(room air conditioners)

Daikin Industries
Shinjuku-Sumitomo Bldg. 34F
2-6-1 Nishi Shinjuku
Tokyo
Japan
Tel: (81) 3 3344 8374
Fax: (81) 3 3344 8026
(many applications, incl. marine container refriger.)

Derby
9620 Ålestrup
Denmark
Tel: (45) 98 64 11 19
Fax: (45) 98 64 16 64
(domestic refrigerators/freezers)

Dunham-Bush, Inc.
101 Burgess Road
Harrisonburg
VA 22801
USA
Tel: (1) 703 434 0711
Fax: (1) 703 434 2448
(water chillers)

Ecozeo S.A.
Rue du Soleillet
75020 Paris
France
Tel: (33) 1 40 33 79 69
Fax: (33) 1 43 58 14 15

Elcold
9500 Hobro
Denmark
Tel: (45) 98 52 22 22
Fax: (45) 98 52 46 85
(domestic refrigerators/freezers)

Electrolux AB
Luxbacken 1
10545 Stockholm
Sweden
Tel: (46) 8 738 6000
Fax: (46) 8 656 4478
(domestic refrigerators/freezers)

Fichtel & Sachs AG
Bereich Energietechnik
97417 Schweinfurt
Germany
Tel: (49) 9721 651 222
Fax: (49) 9721 651 230

A/S Finsam International Inc
PB 3064 EL
0207 Oslo 2
Norway
Tel: (47) 22 44 18 60
Fax: (47) 22 55 87 05
Telex: 78050 FINSAN
(refrigeration units intermodal containers, ice machines)

Formost Airconditioning and Refrigeration LTD.
Unit 9, Wilford Lane Industr.
Esate, Ruddington Lane, Wilford
Nottingham NG11 7EP
United Kingdom
Tel: (44) 602 455 033
Fax: (44) 602 455 567
(chillers and heat pumps)

Foron Hausgeräte GmbH
(Earlier DKK Scharfenstein)
Arnsfelder Str. 4
09518 Niederschmiedeberg
Germany
Tel: (49) 3735 605 201
Fax: (49) 3735 605 251
(domestic refrigerators/freezers)

Frigor
8800 Viborg
Denmark
Tel: (45) 86 62 64 00
Fax: (45) 86 62 34 40
(domestic refrigerators/freezers)

Fujitsu General Ltd.
1116, Suenaga, Takatsu-ku
Kawasaki, Kanagawa
Japan
Tel: (81) 44 866 1111
Fax: (81) 44 888 4901
Telex: 3842511 GENECOJ
(room air conditioners)

Brdr. Gram AS
Aage Gramsvej
DK 6500 Vojens
Denmark
Tel: (45) 74 54 14 21
Fax: (45) 74 59 02 90
Telex: 50523 gramv
(all applications, incl. ice machines)

Hitachi Zosen Corporation
3 - 22 Sakurajima 1 Chome Konohana-Ku
Osaka 554
Japan
(all applications)

Hoshizaki Electric Co. Ltd
Minamiyakata Sakae
Toyoake Aichi 470-11
Japan
(ice-machines)

IVT Energy AB
PO Box 1012
57328 Tranås
Sweden
Tel: (46) 14 01 70 80
Fax: (46) 14 01 76 09
(heat pumps)

KKW Kulmbacher Klimageräte-Werk GmbH
Postfach 1569
8650 Kulmbach
Germany
Tel: (49) 92 21 709 0
Fax: (49) 92 21 709 333

Kryotherm
PO Box 701
94128 Piteå
Sweden
Tel: (46) 91 11 61 40
Fax: (46) 91 11 42 84
(heat pumps)

Kværner Eureka AS
Joseph Kellers vei
3408 Tranby
Norway
Tel: (47) 32 85 90 00
Fax: (47) 32 85 10 40
Telex: 76 480 KEUPD N
(many applications, incl. heat pump, transport refriger.)

Liebherr Hausgeräte GmbH
PO Box 1161
88411 Ochsenhausen
Germany
Tel: (49) 7352 9280
Fax: (49) 7352 928370
(domestic refrigerators/freezers)

Matsushita Electric Ind. Co. Ltd.
1006, Kadama
Kadoma-city
Osaka
Japan
Tel: (81) 6 908 1121
Fax: (81) 6 282 5703
Telex: J63426 MATSUSITA
(room air conditioners)

Mayekawa Mfg. Co. Ltd.
Okubo Moriya-Machi
Kitasooma-Gun
Ibaragi
Japan
Tel: (81) 297 48 1364
Fax: (81) 297 48 5170
(chillers for many applications)

Mitsubishi Electric Corp.
2-3, Marunouchi 2-chome
Chiyoda-ku
Tokyo 100
Japan
Tel: (81) 3 32 18 31 17
Fax: (81) 3 32 18 23 70/24 51
(all applicatons, incl. room air cond.)

Normann Energiteknikk
PB 2054 Grünerløkka
0505 Oslo
Norway
Tel: (47) 22 37 79 55
Fax: (47) 22 35 58 05
(heat pumps)

Norsk Kjøleindustri - "Svalbard"
PO Box 233
4033 Forus
Norway
Tel: (47) 51 80 17 10
Fax: (47) 51 80 17 20
(ice-machines)

Novema AS
PO Box 60
1481 Hagan
Norway
Tel: (47) 67 06 04 50
Fax: (47) 67 06 14 88
(heat pumps & air conditioning)

Osaka Gas Co. Ltd.
Gas Utilization R&D Dept.
2-95 Chiyozaki
3-Chome, Nishi-Ku
Osaka 550
Japan
Tel: (81) 6 581 8651
Fax: (81) 6 584 0573
Telex: 64969 Ogradc J
(domestic refrigerators)

Pido International Co. Ltd.
55/103-4 Soi Udomkiati
Suthisan Rd.
Bkk. 10310
Thailand
Tel: (66) 2 277 6132
Fax: (66) 2 276 1928
(centrifugal Chillers)

Robur
Covrad Dravo
Sir Henry Parkes Road
Canley
Coventry CV5 6BN
United Kingdom
Tel: (44) 2 03 67 55 44
Fax: (44) 2 03 67 60 29
(many applications, incl. absorption chillers)

Sabroe Refrigeration A/S
Christian X' vej
8000 Århus C
Denmark
Tel: (45) 86 27 12 66
Fax: (45) 86 27 44 08
(many applications, incl. chillers & ice machines)

Sanyo Electric
Air Cond. & Refrig. Business Headquarters
Compressor division
1-1-1 Sakata, Oizumi-machi
Ora-gun, Gunma
Japan
Tel: (81) 2 76 61 80 97
(many appl., incl. absorption chillers & room air conditioners)

Siemens BSHG
Hochenstraβe 17
D-80076 München
Germany
Tel: (49) 89 4590 01
Fax: (49) 89 4590 2347
(domestic refrigerators/freezers)

Snyder General Corp.
13600 Industrial Park Blvd.
PO Box 1551
Minneapolis, MN 55441
USA
Tel: (1) 612 553 5091
(centrifugal chillers)

Springkool Systems Inc.
PO Box 326 Killen
Alabama 35645
USA
(comfort air conditioning)

Stal Refrigeration Corp.
Bensalem
Pennsylvania 19020
USA
(all applications)

Stiebel Eltron GmbH & Co. KG
Dr. Stiebel Strasse
3450 Holzminden
Germany
Tel: (49) 55 31 702 1
Fax: (49) 55 31 702 480

Sulzer Friotherm AG
Postfach
8401 Winterthur
Switzerland
Tel: (41) 52 262 80 80
Fax: (41) 52 262 00 03
Telex: 896 060 11
(chillers & heat pumps)

Thermax
Birdsall Air Conditioning Ltd
Unit 6 Frogmore Road
Apsley
Hemel Hempstead
Hertforshire HP3 9RW
United Kingdom
Tel: (44) 4 42 21 25 01
Fax: (44) 4 42 24 89 89
(many applications, incl. absorption chillers)

Trane UK Ltd
10 St Pauls Square
Birmingham B3 1QU
United Kingdom
Tel: (44) 6 75 44 35 34
Fax: (44) 6 75 44 35 67
(chillers and air conditioning)

Vestfrost
6700 Kvaglund
Tel: (45) 79 14 22 22
Fax: (45) 79 14 23 55
Denmark
(domestic refrigerators/freezers)

Whirlpool Italia
SRL via B.Borghi 27
21025 Comerio
Italia
(refrigerators, freezers, ice-machines)

York International Ltd
Gardiners Lane South,
Basildon,
Essex SS14 3HU
United Kingdom
Tel: (44) 2 68 28 76 76
Fax: (44) 2 68 28 17 65
(all appl., incl. absorption chillers and ice machines)

14.3 Compressors

Bitzer Kühlenmaschinenbau GmbH & Co
Postfach 240
D-7032 Sindelfingen
Germany
Tel: (49) 70 31 93 20
Fax: (49) 7 03 19 21 06

Blissfield Mfy
626 Depot St.
Blissfield
Michigan 49228
USA
Tel: (1) 517 486 2121
Fax: (1) 517 486 2128

Bock GmbH & Co
Postfach 1129
Kisslingstrasse 20
7440 Nürtingen
Germany
Tel: (49) 7 02 23 10 16

Carlyle Compressor Company
PO Box 4803
Syracuse,
New York 13221
USA
Tel: (1) 31 54 33 44 53
Fax: (1) 31 54 32 73 13

CKD Chocen Ltd.
565 38 Chocen
Czechoslovakia
Tel: (42) 468 953
Fax: (42) 468 951222
Telex: 198 300 ckd cohen

Copeland
1675 W. Campbell Road
Sidney,
Ohio 45365
USA
Tel: (1) 51 34 98 30 11
Fax: (1) 51 34 98 37 93

Danfoss GmbH
Carl-Legien-Str.8
postf.100453
6050 Offenbach/Main
Germany
Tel: (49) 69 8902 192
Fax: (49) 69 8902 319
Telex: 4 - 152876

EBARA Corporation
ASAHI Bldg. 6-7 Ginze 6 - chome
Chue-ku
Tokyo 104
Japan
Tel: (81) 3 3289 6480
Fax: (81) 3 3574 1813

Electrolux Compressor Company
Luxbacken 1
10545 Stockholm
Sweden
Tel: (46) 8 738 6000
Fax: (46) 8 656 4478

Embraco - Empresa Brasileira de Compressors SA
Rua Rui Barbosa 1020
89200 Joinville SC
Brazil
Tel: (55) 474 25 31 88
Fax: (55) 474 41 27 66

Frigopol Kältemaschinen
Gunter Knapp Strasse
8042 Graz
Austria
Tel: (43) 3 16 49 11 47

Brødrene Gram AS
Aage Gramsvej
DK 6500 Vojens
Denmark
Tel: (45) 74 541421
Fax: (45) 74 590290
Telex: 50523 gramv

Hans Göldner Kältemaschinenfabrik AG
Hohnerstarsse 6
79 Ulm
Germany
Tel: (49) 73 13 39 53

Hitachi Ltd
Air Conditioning and Product Dept.
Home Comfort Appliance Operation Houshold Alliances Div.
Hitachi Atago Bldg,
15-12, Nishi Shimbashi 2-chome,
Mianto-ku
Tokyo 105
Japan
Tel: (81) 3 35 02 21 11
Fax: (81) 3 35 06 16 22

Howden Compressors Ltd
133 Barfillan Drive
Glasgow G52 1BE
Scotland

Kværner Eureka AS
Joseph Kellers vei
3408 Tranby
Norway
Tel: (47) 32 85 90 00
Fax: (47) 32 85 10 40
Telex: 76 480 KEUPD N

Maneurop S.A.
B.P. 331
01603 Trévoux cedéx
France
Tel: (33) 74 00 28 29
Fax: (33) 74 00 52 44

Matsushita Electric Industrial Co Ltd
Overseas Industry Support Sales Office
Central PO Box 288
Osaka 530-91
Japan
Tel: (81) 62 82 54 75
Fax: (81) 62 82 57 48

Mayekawa Mfg. Co. Ltd.
Okubo Moriya-Machi
Kitasooma-Gun
Ibaragi
Japan
Tel: (81) 297 48 1364
Fax: (81) 297 48 5170

Mitsubishi Electric Corp.
2-3, Marunouchi 2-chome
Chiyoda-ku
Tokyo 100
Japan
Tel: (81) 3 32 18 31 17
Fax: (81) 3 32 18 23 70/24 51

Necchi Compressors s.r.l.
Viale della Repubbica 10-27100,
Pavia
Italy
Tel: (39) 3 82 59 51
Fax: (39) 38 23 12 11

Rotorex International
1114 Avenue of the Americas
30th floor
New York, NY 10036
USA
Tel: (1) 21 29 44 07 40
Fax (1) 21 29 44 07 90

SABROE Refrigeration A/S
Chr.X's Vej 201
PO Box 1810
DK-8270 Hoejbjerg
Denmark
Tel: (45) 86 27 12 66
Fax: (45) 86 27 44 08

Sicom
Rua Coronel José Augusto
de Oliviera Salles,478
São Carlos
Brasil
Tel: (55) 1 62 71 12 12
Fax: (55) 1 62 72 70 02

Sulzer Bros. Ltd.
Dep. BG-K/5975 CH-8405 Winterthur
Switzerland
Tel: (41) 52 2623710
Fax: (41) 52 2620003

Tecumseh Products Company
International Division
100 East Patterson, Tecumseh
Michigan
USA
Tel: (1) 51 74 23 84 11
Fax: (1) 51 74 23 85 26

Toshiba Corporation
International Operations-Consumer Products,
Air Conditioner & Compressor Dept.
2-1, Shibaura 1-chome
Minato-ku
Tokyo 105
Japan
Tel: (81) 3 54 94 51 54

Türk Elektrik Endüstrisi A.S
Topkapi 34020
Istanbul
Turkey
Tel: (90) 15 44 26 06
Fax: (90) 15 67 75 47

Vilter Manufacturing Corporation
2217 South First Street
Milwaulkee
Wiscounsin 53207-1105
U.S.A
Tel: (1) 41 47 44 01 11
Fax: (1) 41 47 44 34 83

York International Corporation
Gardiners Lane South,
Basildon,
Essex SS14 3HU
United Kingdom
Tel: (44) 2 68 28 76 76
Fax: (44) 2 68 28 17 65

14.4 Heat Exchangers

Alfa-Laval
Landerigrend
22186 Lund
Sweden
Tel: (46) 46 36 7000
Fax: (46) 46 36 4950

CKD Chocen Ltd.
565 38 Chocen
Czechoslovakia
Tel: (42) 468 953
Fax: (42) 468 951222
Telex: 198 300 ckd c

EXAIR Corporation
1250 Century Cir. N,
Cincinnati
Ohio 45246-3309
USA
Tel: (1) 51 36 71 33 77
Fax: (1) 51 36 71 33 63

Brdr. Gram AS
Aage Gramsvej
DK 6500 Vojens
Denmark
Tel: (45) 74 541421
Fax: (45) 74 590290
Telex: 50523 gramv

Kværner Eureka AS
Joseph Kellers vei
3408 Tranby
Norway
Tel: (47) 32 85 90 00
Fax: (47) 32 85 10 40
Telex: 76 480 KEUPD N

Mayekawa Mfg. Co. Ltd.
Okubo Moriya-Machi
Kitasooma-Gun
Ibaragi
Japan
Tel: (81) 297 48 1364
Fax: (81) 297 48 5170

Thermco International Phoenix
8260 East Gelding Drive, Suite 103
Scottsdale
Arizona 85260
USA
Tel: (1) 602 948 8580
Fax: (1) 602 948 8416

Toshiba Corporation
2-4 Suehiro-cho
Tsurumi-ku
Yokohama 230
Japan
Tel: (81) 45 509 5114
Fax: (81) 45 509 5135

TT Coil AS
Egebaekvej 98
2850 Naerum
Denmark
Tel: (45) 42 803444

Vikool Refrigeration
407 Creek Road
Mt. Gravatt, Qld. 4122
Australia
Tel: (61) 7 8776400
Fax: (61) 7 3438371

14.5 Lubricants

Castrol
Burmah Castrol House
Pipers Way
Ewindon
Wiltshire
SN3 IRE
United Kingdom
Tel: (44) 79 35 12 712
Fax: (44) 79 35 13 505

DEA Mineraloel AG
Produktentwicklung ung Anwendungstechnik
Alte Schleuse 23
2102 Hamburg 93
Germany
Tel: (49) 40 75202 01
Fax: (49) 40 75202244

Deutche Shell Aktiengesellshaft
PAE Labor
Hohe-Schaar-Strasse 36
2102 Hamburg 93
Germany
Tel: (49) 40/75 191 (1) 583 (Sprock)
Fax: (49) 40/75 19 1-5 66

Fuchs Mineraloelwerke
Friesenheimer Strasse 15
6800 Mannheim 1
Germany
Tel: (49) 621 37 01 462
Fax: (49) 621 37 01 570
Telex: 463 163

ICI Chemicals and Polymers
PO Box 90 Witon
Middleborough
Cleveland TS6 8JE
United Kingdom
Tel: (44) 642 454 144 (Eston Grange)
Fax: (44) 642 454 144
Telex: 587 461 ICI WWC G

Mobil Oil AS Norway
Karoline Kristiansen vei 7
0661 Oslo
Norway
Tel: (47) 22 07 88 00
Fax: (47) 22 07 88 52

14.6 Special Equipment

The companies in this list provide control/automation, service and safety equipment.

A'Gramkow A/S
Augustenborg landevej 19
6400 Sønderborg
Denmark
Tel: (45) 74 43 36 36
Fax: (45) 74 43 36 46
(performance test systems)

Bright Solutions Inc.
PO Box 33111
Bloomfield Hills
Missouri 48303
USA
Tel: (1) 313 645 1086
Fax: (1) 313 641 1716
(Leak detection, ultraviolet ligjts)

Carrier Transcontinental Company Ltd.
Goldvale House
Church Street West
Woking
United Kingdom
Tel: (44) 483 727 041
Fax: (44) 483 729 978
Tel:: 859925 CARICO G
(purge recovery units, refrig. & lubric. control)

Christonik APS
Mørkhøj bygade 30
2860 Søborg
Denmark
Tel: (45) 31 67 3344
Fax: (45) 31 67 3633
(refrigerant alarm systems)

CPS Products Inc.
Hialeah
Florida 33013
USA
Tel: (1) 305 687 4121
Fax: (1) 305 687 3743
(leak detection)

Danfoss GmbH
Carl-Legien-Str.8
postf.100453
6050 Offenbach/Main
Germany
Tel: (49) 69 8902 192
Fax: (49) 69 8902 319
Telex: 4 - 152876
(refrigeration control systems)

Eagle Creek Technology
6666 E. 75th Street
Suite 500
Indianapolis
Indiana 46250
USA
(leak detectors)

Galileo Vacuum Systems, Inc.
PO Box 989
64 Field Road
Somers
Connecticut 06071
USA
Tel: (1) 203 763 4004
Fax: (1) 203 763 4111

Halozone Technologies Inc.
4000 Nashua Drive
Mississauga
Ontario
Canada L4V 1P8
Tel: (1) 905 405 8200
Fax: (1) 905 405 8333/8334
(automatic purge units)

Kværner Eureka AS
Joseph Kellers vei
3408 Tranby
Norway
Tel: (47) 32 85 90 00
Fax: (47) 32 85 10 40
Telex: 76 480 KEUPD N
(refrigeration control systems)

Rochester Gauges Inc.
PO Box 29242
11616 Harry Hines Blvd.
Dallas
Texas 75229
(control equipment)

Sentech Corporation
PO Box 42905
2020 Production Drive
Indianapolis
Indiana 46242-0905
Tel: (1) 317 247 0460
Fax: (1) 317 247 5130
(leak detection)

Sieger Limited
Hatch Pond House
4 Stinsford Road
Nuffield Estate
Poole, Dorset BH17 7RZ
United Kingdom
Tel: (44) 202 676161
Fax: (44) 202 678011
(monitoring equipment)

Spectronics Corp.
956 Brush Hollow Road
PO Box 483
Westbury
New York 11590
USA
Tel: (1) 516 333 4840
Fax: (1) 516 333 4859
(leak detection)

SPX Australia
2/8 Gladstone RD
Castle Hill
Sydney
N.S.W. Australia
Tel: (61) 634 4999
Fax: (61) 680 4862
(leak detectors)

Thermco International Phoenix
8260 East Gelding Drive, Suite 103
Scottsdale
Arizona 85260
USA
Tel: (1) 602 948 8580
Fax: (1) 602 948 8416
(different equipment)

TIF Instruments, Inc.
9101 NW 7th Ave
Miami
Florida 33150
USA
Tel: (1) 305 757 8811
Fax: (1) 305 757 3105
(test equipment)

Yokogawa Corporation of America
2 Dart Road
Newman
Georgia 30265
USA
Tel: (1) 404 253 7000
Fax: (1) 404 251 2088
Telex: 244880
(leak detectors)

Zellweger SA
33 rue du Ballon
F-93166 Noisy le Grand
Cedex France
Tel: (33) 1 43 05 70 00
Fax: (33) 1 43 05 77 08
(monitoring equipment)

14.7 Refrigerant Recovery, Recycling, and Reclamation Equipment

Within its 1993 work programme under the Multilateral Fund, UNEP IE is preparing a worldwide technical directory of refrigerant recovery, recycling and reclamation equipment. Accompanying this hardcopy catalogue will be a computerized database version and a brochure on recovery, recycling and reclamation.

This directory is designed to assist developing countries in their technical decision-making on ODS phase-out activities in the refrigeration sector. The directory will contain the following elements:

- a global survey of recovery, recycling and reclamation equipment and manufacturers worldwide
- criteria for selection of equipment
- a section dealing with operating guidelines for the recovery, recycling and reclamation equipment, aimed at establishing broad operating principles
- general maintenance guidelines, showing the most frequent problems and the solutions in tabular form
- international regulatory activities, selected country regulatory activities dealing with recycling, standards for equipment, and equipment certification

The following documents will be included as annexes to the technical directory:

- typical formats of technical spesifications used while inviting for bids for the equipment
- methods of preparing technical comparative statements while selecting the equipment
- a typical case of ordering of equipment, starting from the invitation of the bids

A preliminary draft of this directory is already available. The final version is expected to be available from UNEP IE in late 1994.

14.8 Trade and Professional Associations/Research and Development Organizations, Training Institutes, and Consultants

TRADE AND PROFESSIONAL ASSOCIATIONS

International:

Alternative Fluorocarbons Environmental Acceptability Study - AFEAS
The West Tower Suite 400
1333 H Street NW
Washington DC 20005
USA
Tel: (1) 202 898 09 06
Fax: (1) 202 798 12 06

International Institute of Ammonia Refrigeration - IIAR
1101 Connecticut Ave, NW
Washington, DC 20036
USA
Tel: (1) 202 857 1110
Fax: (1) 202 223 4579

International Institute of Refrigeration - IIR
177 Boulevard Malesherbs
75017 Paris
France
Tel: (33) 1 4227 3235
Fax: (33) 1 4763 1798

Programme for Alternative Fluorocarbon Toxicity Testing - PAFT
c/o ICI
PO Box 13, The Heath
Runcorn, Cheshire WA7 4QF
United Kingdom
Tel: (44) 928 513 145
Fax: (44) 928 511 418

Algeria:

Association Algérienne du Froid & de la Climatisation
51, rue des Fusillés
Hussein-Dey
Alger
Tel: (213) 2 76 53 84/85

Argentina:

Asociacion Argentina del Frio
Avenida de Mayo 1123, Plso 5°
1085 buenos Aires
Argentina
Tel: (54) 1 381 1862/7544
Fax: (54) 1 382 2517

Austria:

Osterreichischer Kälte- und Klimatechnicsher Verein
PO Box 352
A-1045 Wien
Tel: (43) 1 222 501 05 3227
Fax: (43) 1 222 504 3615

Australia:

Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH)
191 Royal Parade
Parkville Vlc. 3052
Australia
Tel: (61) 3 347 4941
Fax: (61) 3 347 8571

Belgium:

Belgium Refrigeration Association
34 rue Marianne
B-1180 Bruxelles
Belgium
Tel: (32) 2 345 9923

Brazil:

Instituto Brasileiro do Frio
Avenida Rio Branco, 1492
CEP 01206-001
Sao Paulo (SP)
Brazil
Tel: (55) 11 221 5777
Fax: (55) 11 222 4418

ABRAVA - Associacao Brasileira de Refrigeracao, ar Condicionado, Ventilacao e Aquecimento
Avenida Rio Branco, 1492
CEP 01206-001
Sao Paulo (SP)
Brazil
Tel: (55) 11 221 5777

Bulgaria:

Institut de la Technique du Froid
5 rue Kamenodelska
1000 Sofia 2
Bulgaria
Tel: (359) 2 83 16 93
Fax: (359) 2 83 33 81

Burkina-Faso:

Association des Ingenieurs et Techniciens Frigoristes du Burkina - AITFB
B.P. 7047
Ouagadougou
Burkina-Faso

Canada:

Heating, Refrigeration and Air Conditioning Institute of Canada
5468 Dundas Street West, Suite 308
Erobicoke Ont. M9B 6E3
Canada
Tel (1) 416 239 8191
Fax: (1) 416 239 1983

Corporation des Maitres Entrepreneurs en Réfrigeration du Québec
3600 Barclay
Suite 420
Montréal Qc. H3S 1K5
Canada
Tel: (1) 514 735 1131
Fax: (1) 514 735 3509

Association de l'Industrie des Aliments Surgelés du Québec Inc.
9960 Côte de Liesse
Lachine Qc. H8T 1A1
Canada
Tel: (1) 514 636 5114
Fax: (1) 514 636 7606

China:

Beijing Snow Flake Electrical Appliance Group Corporation
Beijing, 100075
China
Tel: (86) 01 507 3631-379

Chinese Association of Refrigeration
Bldg 11 South N°1 Lane
2nd Section of Sanhile
XI Cheng District
100 045 Beijing
China
Tel: (86) 1 853 6259
Fax: (86) 1 853 6262

Colombia:

Asociacion Colombiana del Acondicionamiento y de la Refrigeracion (ACAIRE)
Apartado Aereo 47418
Bogota
Colombia
Tel: (57) 1 256 0547/256 0046

Congo:

Association Congolaise de Froid et de la Climatisation (ACFC)
B.P. 14.437 Brazzaville
Congo

Cuba:

Instituto de Refrigeracion y Climatisation (IRC)
Calle 45, No 8414 E/84 y 86
Marianao, Zona Postal 14
Ciudad Habana
Cuba
Tel: (53) 22 4222 / 20 3733

Denmark:

Dansk Köleforening
c/o A.K.B.
Vestergade 28
DK-4000 Roskilde
Denmark
Tel: (45) 46 32 2111
Fax: (45) 46 32 2133

Europe:

European Committee of Manufacturers of Refrigeration Equipment - CECOMAF
Rue des Drapiers 21
1050 Brussels
Belgium
Tel: (32) 2 510 2518
Fax: (32) 2 510 2563

European Council of Chemical Manufacturers Federations - CEFIC
Avenue E. Van Nieuwenhuyse, 4
1160 Brussels
Belgium
Tel: (32) 2 676 7211
Fax: (32) 2 676 7300

Finland:

Finnish Society of Refrigeration
PO Box 37
SF-00801 Helsinki
Finland
Tel: (358) 0 759 1166
Fax: (358) 0 755 7246

France:

French Institute of Refrigeration - AFF
17 rue Guillaume Appollinaire
B.P. 193 75006 Paris
France
Tel: (33) 1 45 44 5252
Fax: (33) 1 42 44 0042

Germany:

German Refrigeration Society - DKV
Pfaffenwaldring 10
D-70569 Stuttgart
Germany
Tel: (49) 711 685 3200
Fax: (49) 711 685 3242

Ghana:

National Refrigeration Airconditioning Workshop Owners Association - NARWOA
PO Box 84
James Town
Accra
Ghana
Tel: 21 66 48 86

India:

All-India Air Conditioning and Refrigeration Association
Post Box 193
New Delhi 110001
India

Italy:

Associazione Italiana Condizionamento dell'Aria Riscaldamento Refrigerazione (AICARR)
Viale Monte Grappa 2
I-20124 Milano
Italy
Tel: (39) 2 29 002 369
Fax: (39) 2 29 000 004

Japan:

Japan Refrigeration & Air Conditioning Industry Association
Kikai-Shinko Bldg.201
3-5-8 Shibakoen
Minato-ku
Tokyo
Japan
Tel: (81) 3 3432 1671
Fax: (81) 3 3438 0308

Japanese Association of Refrigeration
San-Ei Building, 4th Floor
No 8, San-El-Cho
Shinjuku-ku
Tokyo 160
Japan
Tel: (81) 3 3359 5231
Fax: (81) 3 3359 5233

Jordan:

Amman Chamber of Industry
PO Box 1800
Amman-Jordan
Tel: (962) 6 643 001
Fax: (962) 6 647 852

Republic of Korea:

Korea Refrigeration and Air Conditioning Industry Association
13-31 Yoido-Dong
Yongdeungpo-ku
Seoul 150-010
Republic of Korea

Malaysia:

Federation of Malaysian Manufacturers
17th Floor, Wisma Sime Darby
Jalan Raja Laut
50350 Kuala Lumpur
Malaysia
Tel: (60) 3 293 1244
Fax: (60) 3 293 2681

Morocco:

Association Nationale du Froid
BP 6433, Rabat-Instituts
Rabat
Marocco
Tel: (212) 7 61 045
Fax: (212) 7 761 557

Netherlands:

Nederlandse Vereniging voor Koude (NVvK)
PO Box 6442
7401 JK Deventer
Netherlands
Tel: (31) 5700 45 195
Fax: (31) 5566 4504

New Zealand:

N. Z. HEVAC Ltd.
Unit I
55 Druces Road
PO Box 97-453
Manukau City
Tel: (64) 9 262 1405
Fax: (64) 9 262 1407

Norway:

Norsk Kjøleteknisk Forening
PO Box 2312 - Solli
N-0201 Oslo
Norway
Tel: (47) 22 60 13 90

Philippines:

Philiphine Appliance Corporation
8377 DR.A. Santos Ave,
Paranaque
Metad
Manila
Philippines
Tel: (63) 2 828 5551 to 59
Fax: (63) 2 828 7309

Portugal:

Instituto Nacional do Frio, Instituto de Apolo a Transformacao e Comercializacao dos Produtos Agrarios e Alimentares
Rua Barata Salgueiro 37, 2°
1200 Lisboa
Portugal
Tel: (351) 1 54 30 25

Associacao Portuguesa da Industria de Refrigaracao e Ar Condicionado (APIRAC)
Rua do Alecrim 53-2°
1200 Lisboa
Portugal
Tel: (351) 1 347 4674/75
Fax: (351) 1 347 4576

South Africa:

The South African Institute of Refrigeration and Air Conditioning
PO Box 175
Isando 1600
South Africa
Tel: (27) 11 886 2555

Spain:

Istituto del Frio
CSIC
Cludad Universitaria
28040 Madrid
Spain
Tel: (34) 1 585 6726
Fax: (34) 1 549 3627

ATECYR Club del Frio
Apartado 34167
Barcelona
Spain

Sweden:

The Swedish Refrigeration Foundation (KYS)
PO Box 17537
118 91 Stockholm
Sweden
Tel: (46) 8 616 04 00
Fax: (46) 8 669 78 37

United Kingdom:

British Refrigeration Association
c/o R. C. Bradley
Sterling House
6 Furlong Road
Bourne End
Buckinghamshire SL8 6DG
United Kingdom
Tel: (44) 62 853 1186/7
Fax: (44) 62 881 0423

Refrigeration Industry Board/ Institute of Refrigeration
Kelvin House
76 Mill Lane
Carshalton Surrey SM5 2JR
United Kingdom
Tel: (44) 81 647 7033
Fax: (44) 81 773 0165

Uruguay:

Asociacion Uruguyana del Frio
Milan 4708
Sagayo
Montevideo
Uruguay

USA:

Air-Conditioning and Refrigeration Institute ARI
4301 North Fairfax Dr. Suite 425
Arlington VA 22203
USA
Tel: (1) 703 524 8800
Fax: (1) 703 528 3816

American Society of Heating, Refrigerating and Airconditioning Engineers - ASHRAE
1791 Tullie Circle, NE
Atlanta, GA 30329
USA
Tel: (1) 404 636 8400
Fax: (1) 404 321 5478

Chemical Manufacturers Association
2501 M Street, NW
Washington, DC 20037
USA
Tel: (1) 202 887 1100
Fax: (1) 202 887 1237

Industry Cooperative for Ozone Layer Protection
Suite 300
1440 New York Avenue NW
Washington, DC 20005
USA
Tel: (1) 202 737 1419
Fax: (1) 202 639 8685

Mobile Air Conditioning Society - MACS
PO Box 1307
Lansdale
PA 19446
USA
Tel: (1) 215 362 5800
Fax: (1) 215 855 7257

Motor Vehicle Manufacturers Association
Environmental Activities Staff
GM Technical Center
30400 Mound Road
Warren, MI 48090-9015
USA
Tel: (1) 313 872 4311
Fax: (1) 313 872 5400

Yugoslavia:

Air Conditioning, Heating and Refrigeration Engineer's Association (SMEITS)
Kneza Mlosa 7/11
11001 Beograd
Yugoslavia
Tel: (243) 11 330 041
Fax: (243) 11 331 372

RESEARCH AND DEVELOPMENT ORGANIZATIONS, TRAINING INSTITUTES, AND CONSULTANTS

Acurex Environmental Corporation
PO Box 13109
Research NC 27709
USA
Tel: (1) 919 541-0480
Fax: (1) 919 541-7885

ARTI
The Air-Conditioning and
Regrigeration Technology Institute
4301 North Fairfax Drive
Suite 425
Arlington VA 22203
USA
Tel: (1) 703 524-8800
Fax: (1) 703 528-3816
Telex: 892351

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APPENDIX AND ANNEXES

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APPENDIX

CATALOGUE OF CFC-FREE TECHNOLOGIES AND RETROFITS, UNDER DEVELOPMENT

The following methods, technologies, and retrofits are under development, and are likely to be available on the market within a few years.

Retrofitting from CFC-12 to Propane (HC-290)

Because of the flammability propane should only be retrofitted into systems with low refrigerant charge, i.e. domestic and commercial refrigerators with hermetic systems. A small refrigerant charge reduces the flammability hazard significantly. Propane should never be retrofitted into refrigeration plants with electrical equipment that may cause ignition, without taking precautions to avoid accidents. It is important to ensure the necessary safety precautions, and system design and refrigerant charge should always meet local codes and regulations. For further details see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

The volumetric refrigerating capacity is 35-50% higher for propane than for CFC-12, depending on the operating conditions. Even without changes in system design or system optimization, a refrigerator where CFC-12 is substituted with propane is theoretically capable of similar performance with lower charge. This is not surprising considering the much lower liquid density of propane. However, compressor/motor modifications are required in order for the compressor to operate properly and to maintain the same heating capacity.

Because of *higher condensing pressure* of propane compared to CFC-12, the maximum available condensing temperature are 68°C, compared to 83°C for CFC-12.

Refrigeration systems using propane as refrigerant can be lubricated with polyalkylene glycols. (PAG lubricants). It is also reported that both alkylbenzenes and mineral oils are suitable.

The retrofit procedure from CFC-12 to propane is technically possible regarding thermodynamic and physical properties of the refrigerants, but it is still on the planning/bench test state /Boldrin, 1991/.

SYSTEM MODIFICATION :
For small domestic and retail refrigerators with refrigerant charges up to 300 g, only minor change to the system is necessary when retrofitting from CFC-12 to propane.

- Adjustment or change of expansion device
- Change of desiccant filter
- If necessary, change of lubricant

Fuel grade propane contains mercaptan (traces gas) which may be aggressive to certain materials. Hence, compatibility with all the materials in the system should be checked.

RETROFIT PROCEDURE :

1) Run the compressor and pump the charge to an external gas cylinder

2) Drain the original oil charge from the compressor. If an alkylbenzene lubricant is used, it is not necessary to change the lubricant.

3) Carry out the required equipment modifications, such as change of desiccant filter, adjustment or change of expansion device, etc.

4) Recharge the system with the new lubricant.

5) Evacuate the system.

6) Recharge the system with propane.

Retrofitting from R-502 to Propane (HC-290)

Due to the flammability, propane should only be retrofitted into systems with low refrigerant charge, e.g. domestic and commercial freezers with hermetically sealed systems. Small refrigerant charges makes the flammability hazard acceptably low. Propane should never be retrofitted into refrigeration plants with electrical equipment that may cause ignition, without taking precautions to avoid accidents. It is important to take the necessary safety precautions, and system design and refrigerant charge should always meet local codes and regulations. For further details see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*.

Practical tests have shown that propane is particularly well suited for domestic and small commercial freezers. Even without change of design or system optimization, a freezer in which propane has been substituted for R-502, is capable of similar performance.

Refrigeration systems using propane as refrigerant can be lubricated with polyalkylene glycol (PAG lubricants). It is also reported that alkylbenzenes and mineral oils are suitable lubricants.

The retrofit procedure from R-502 to propane is technically possible, regarding thermodynamic and physical properties of the refrigerants, but it is still on the planning/bench test state.

SYSTEM MODIFICATION:

For small domestic and commercial freezers with refrigerant charge up to 300 g, only minor changes in the system is required when retrofitting from R-502 to propane.

- Change of expansion device

- Change of desiccant filter
- If necessary, change of lubricant

RETROFIT PROCEDURE:

1) Use the compressor to pump the charge to an external gas cylinder.

2) Drain the original lubricant charge from the compressor. If an alkylbenzene lubricant is being used, it is not necessary to change lubricant.

3) Carry out the required equipment modifications.

4) Recharge the system with the new lubricant.

5) Evacuate the system, and recharge it with propane.

Domestic Refrigeration

Retrofitting from CFC-12 to Hydrocarbons

Experience has shown that, even without design changes or system optimization, a CFC-12 refrigerator retrofitted with propane is capable of similar performance with a lower refrigerant charge /James,1992/, /Haukås,1992a/, /Haukås,1992b/. No modification was done to the compressor. Hydrocarbons are flammable, but is still well suited as refrigerants for freezers and refrigerators, due to small refrigerant charges. The system design and refrigerant charge must always meet local laws and regulations in order to ensure safety during operation and service. For more detailed procedure, see chapter 4.2.8 *"Retrofitting from CFC-12 to Propane, HC-290"*.

New equipment with HFC-152a

HFC-152a has shown the best result with regard to energy consumption /Fischer,1991/. Flammability is of great concern in many countries, but in small refrigeration and freezer units with charges of a few hundred grams, the safety risk is quite small. System design and refrigerant charge must always meet local laws and regulations in order to ensure safety during operation and service. HFC-152a has been used in a limited number of refrigerators in China. For more information, see chapter *3.2.2. "HFC Refrigerants"*, and chapter *4.3.3. "HFC-152a"*.

Commercial Refrigeration

Retrofitting from CFC-12 to Blends

The most promising blends for retrofitting CFC-12 equipment are ternary blends containing HCFC-22, HCFC-124 and HFC-152a (commercially available today). Binary blends containing HCFC-22 and HCFC-142a are also being evaluated. For further information on refrigerant blends, see chapter 3.2.4, *"Mixtures/blends"*. For details on the retrofitting procedure, see chapter 4.2.5, *"Retrofitting from CFC-12 to Blends"*.

Retrofitting from CFC-12 to HFC-152a or Hydrocarbons

Flammable refrigerants as HFC-152a and the hydrocarbons (e.g. propane) should only be used in *smaller systems with low refrigerant charge* to keep the flammability hazard acceptably low. System design and refrigerant charge should always meet local laws and regulations, and necessary safety precautions should be taken to ensure safety during operation and service.

For further details regarding commercial refrigerating equipment with flammable refrigerants, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*. For details on the retrofitting procedures, see chapter 4.2.7, *"Retrofitting from CFC-12 to HFC-152a"* and chapter 4.2.8, *"Retrofitting from CFC-12 to Propane"*.

Retrofitting from R-502 to Hydrocarbons

Flammable refrigerants as the hydrocarbons (e.g. propane) should only be used in *smaller R-502 systems with low refrigerant charge* to keep the flammability hazard acceptably low. System design and refrigerant charge should always meet local laws and regulations, and necessary safety precautions should be taken to ensure safety during operation and service.

For further details regarding commercial refrigerating equipment with flammable refrigerants, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*. For details on the propane retrofitting procedure, see chapter 4.2.11, *"Retrofitting from R-502 to Propane"*.

New Equipment with Flammables - Hydrocarbons and HFC-152a

Flammable refrigerants as the hydrocarbons (propane) and HFC-152a should only be used in smaller systems with low refrigerant charge. System design and refrigerant charge should always meet local laws and regulations, and necessary safety precautions should be taken to ensure safety during operation and service.

Within commercial refrigeration indirect systems (brine systems) are preferable, since the refrigerant charge then will be minimized. Increased energy consumption due to pumping of the secondary refrigerant and the use of two step system (extra temperature difference) must always be taken into consideration. Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"* provides more detailed information on the hydrocarbons, for instance examples of different safeguards to ensure system safety.

Cold Storage

Retrofitting from CFC-12 to Hydrocarbons

Flammable refrigerants as the hydrocarbons (eg propane) should only be used in *smaller systems with low refrigerant charge* to keep the flammability hazard acceptably low. System design and refrigerant charge should always meet local laws and regulations, and necessary safety precautions should be taken to ensure safety during operation and service.

For further details regarding commercial refrigerating equipment with flammable refrigerants, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*. For details on the retrofitting procedures, see chapter 4.2.8, *"Retrofitting from CFC-12 to Propane"*.

Retrofitting from R-502 to Hydrocarbons

Flammable refrigerants as the hydrocarbons (eg propane) should only be used in *smaller R-502 systems with low refrigerant charge* to keep the flammability hazard acceptably low. System design and refrigerant charge should always meet local laws and regulations, and necessary safety precautions should be taken to ensure safety during operation and service.

For further details regarding commercial refrigerating equipment with flammable refrigerants, see chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"*. For details on the propane retrofitting procedure, see chapter 4.2.11, *"Retrofitting from R-502 to Propane"*.

Industrial Refrigeration

Retrofitting from CFC-12 and R-502 to Ammonia

Ammonia replacing the CFCs in existing equipment is normally not considered to be appropriate, mainly due to the material compatibility problems (for example copper). However, for industrial applications, steel is used in most cases, independent of the choice of refrigerant. Therefore, retrofit to ammonia is possible.

A change from CFCs to ammonia may imply improved system efficiency, due to better compressor efficiency, reduced temperature span (more efficient heat exchangers), reduced pressure drops and less pump work in systems with pump circulation.

Retrofitting may involve rebuilding or installation of new compressors, change of oil return system, change of all copper fittings and valves, change of refrigerant pumps and in some cases change of refrigerant lines.

For more details on the use of ammonia as refrigerant, see chapter 3.2.3, *"Natural refrigerants"* and chapter 4.3.5, *"Ammonia (NH_3)"*.

Air Conditioning and Heat Pumps

New Equipment with HFC-32, HFC-152a and Hydrocarbons

Other potential refrigerants exists, such as HFC-32, HFC-152a and hydrocarbons (for example propane), but little verified data exists on their performance and reliability within the actual air conditioning systems /UNEP,1991/.

Flammable refrigerants should generally be used in equipment with low refrigerant charge to keep the flammability hazard acceptably low. It is important to take the necessary safety precautions, and system design should always meet local laws and regulations. See chapter 3 *"CFC and Non-CFC Refrigerants and Technologies"* for further details on HFC-152a, HFC-32 and hydrocarbons.

Transport Refrigeration and Air Conditioning

Retrofitting from R-502 to Propane

For the lower temperature range in smaller units in road transport propane are suitable retrofit refrigerants for R-502 /Boldrin,1991/. For details on the retrofit procedure, see chapter *4.2.11 Retrofitting from R-502 to propane.*

New Equipment with Hydrocarbons

Flammable refrigerants as the hydrocarbons (propane) should only be used in smaller systems with low refrigerant charge. System design and refrigerant charge should always meet local laws and regulations, and necessary safety precautions should be taken to ensure safety during operation and service. Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"* provides more detailed information on the hydrocarbons, for instance examples of different safeguards to ensure system safety.

New Equipment with Air Cycle

Air cycles are under development as alternatives for transport refrigeration. Chapter 3, *"CFC and Non-CFC Refrigerants and Technologies"* provides more information on air cycle.

Vehicle Air Conditioning

New Equipment

An intermediate transition to HFC-134a in vehicle air-conditioning is necessary in order to cope with the short-term national and international CFC phase-out dates. But, owing to the relatively high global warming potential of this compound, there is already considerable skepticism towards permanent use, particularly in motorcar air conditioning where direct effects from refrigerant emission plays a significant role /AFEAS,1991/. HFC-134a emission may increase the lifetime global warming impact from a car by as much as 15-20%, a quite significant effect considering the large and rapidly increasing number of vehicle air-conditioning systems.

Furthermore, even the most comprehensive testing and evaluation program cannot remove all uncertainties or exclude possible unknown environmental effects from new chemical compounds such as HFC-134a. In order to eliminate all doubt with respect to future environmental effects, substances that are present naturally in the biosphere, and for which the effects are long established, must be generally preferred.

As a consequence of this, a number of new concepts for vehicle air conditioning are under development or investigation, for instance based on air cycles, water/zeolite adsorption, stirling cycles, metal hydride cooling, and trans-critical CO_2 vapor compression. The latter concept has attracted considerable interest due to its unique combination of environmental and practical advantages /Pettersen,1993/.

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ANNEX A

THE UNEP IE OZONACTION PROGRAMME UNDER THE MULTILATERAL OZONE FUND

The Montreal Protocol

Mounting scientific research has implicated chlorofluorocarbons (CFCs), halons, carbon tetrachloride, 1,1,1-trichloroethane, methyl bromide, and hydrochlorofluorocarbons (HCFCs) in the depletion of the stratospheric ozone layer, that segment of the earth's atmosphere which protects animal and plant life from the damaging effects of ultraviolet radiation. In September 1987, nations concerned about this crisis signed the Montreal Protocol, a landmark agreement that identified the major ozone depleting substances (ODSs) and established a timetable for their eventual phase-out. Under the Montreal Protocol, ODS production and consumption of the controlled substances are to be reduced and eliminated through the development of chemical substitutes and alternative manufacturing processes.

The Multilateral Fund and the UNEP OzonAction Programme

Under the London and Copenhagen amendments to the Protocol, the Multilateral Fund (MF) was established to provide financial and technical assistance to developing countries that are Parties to the Montreal Protocol. The United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the World Bank and the United Nations Industrial Development Organization (UNIDO) were chosen to be the Fund's implementing agencies, with UNEP being assigned the responsibility of conducting research, data gathering, and providing a clearinghouse function to:

(i) Assist Parties operating under paragraph 1 of Article 5, through country specific studies and other technical co-operation, to identify their needs for co-operation;

(ii) Facilitate technical co-operation to meet these identified needs;

(iii) Distribute, as provided for in Article 9, information and relevant materials, and hold workshops, training sessions, and other related activities, for the benefit of Parties that are developing countries; and

(iv) Facilitate and monitor other multilateral, regional and bilateral co-operation available to Parties that are developing countries.

UNEP IE's OzonAction Programme is the result of that mandate. It consists of several major elements: information exchange, training, networking, country programmes, institutional strengthening, and international halon bank management..

Information Exchange

The information exchange element of the OzonAction Programme aims to transfer information concerning policy and technical options for the phase-out of the controlled ODSs to developing countries.

OzonAction Information Clearinghouse (OAIC):
The OAIC is an integrated information exchange service designed to meet the needs of developing countries through various communication media. The OAIC provides technical, policy and scientific information on a range of ODS phase-out issues including:

- descriptions of alternative technologies and product listings for each industrial use sector;
- an international directory of experts and consultants;
- technical literature abstracts, and information for ordering documents;
- descriptions of national and corporate strategies, policies, legislation, and programmes to phase out ODS;
- listings of workshops, conferences, and meetings concerning ozone depletion issues;
- bulletins containing news on phase-out initiatives.

There is no charge for using the OAIC query response service -- simply phone, fax or write us with your question. Anyone with a personal computer can use the diskette version, and with the addition of a modem and communication software, the on-line system.

OzonAction Newsletter:
This quarterly newsletter reports on the initiatives undertaken by countries and organizations that are implementing the Montreal Protocol. The OzonAction newsletter contains the latest news from governments and industry regarding the phase-out of the controlled ODSs, as well as science and technology updates.

Other ODS-Reduction Documents:
OzonAction will publish specific technical and policy documents and brochures in response to specific information needs within industry and government.

Training

Regional Workshops:
A series of regional workshops is designed to provide government and industry decision-makers with basic information on ODS control policies and strategies. Additionally, these workshops provide participants with the latest information about replacement technologies and products relating to the controlled substances.

Regional Training Courses:
Based on a "train the trainer" approach, these sectorial courses impart the latest technical information and skills required to phase out ODSs (for example, service and maintenance practices, and recovery/recycling for the refrigeration sector).

National Activities:
The OzonAction Programme will sponsor information campaigns at the national level to help raise the consciousness of the general public about the threat posed by the controlled ODSs. OzonAction will also be cooperating with UNDP to address specific technological issues within specific countries.

Documentation/Training Manuals:
The OzonAction Programme will additionally publish technical papers, workshop proceedings, and training manuals/guidelines/handbooks.

Networking

The OzonAction Programme facilitates regional networking activities, which enable government officers in charge of their countries' National Ozone Units to interact and share information on strategies and policies to phase out ODS. Such information sharing and regional co-operation is hoped to expedite the phase-out. Presently, two ODS Officers Networks (ODSONETs) in South East Asia & Pacific and Latin America are in operation, and a third in Africa is being launched.

Country Programmes

The OzonAction Programme is conducting a series of country programmes for developing nations that have low rates of consumption for the controlled substances. The purpose of these programmes is to establish a baseline survey on the use of the controlled substances in these countries and to draw up policy strategies for their replacement and control. The data developed under this effort will establish a basis for other phase-out projects.

Institutional Strengthening

The OzonAction Programme assists the development of projects to establish National Ozone Units responsible for the implementation of the ODS phase-out in developing countries.

International Halon Bank Management

In accordance with Decision IV/26 of the Copenhagen Amendment to the Montreal Protocol, UNEP IE has established an International Halon Bank Management Information Clearinghouse which maintains a contact list for national halon banks, collects information about availability of recycled halons to the national halon banks, answers queries concerning alternative technologies or practices that substitute for halons, and develops halon banking-related documents.

For More Information About These Services

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UNEP's Industry and Environment (IE), formerly the Industry and Environment Office, was established in Paris in 1975 to bring industry, government, and nongovernmental organizations together to work towards environmentally sound forms of industrial development. To this end, the UNEP IE concentrates on formulating and promoting appropriate policies and strategies. More specifically, it seeks to:

- Define and encourage the incorporation of environmental criteria in industrial development;
- formulate and facilitate the implementation of principles and procedures to protect the environment;
- promote the use of safe, low and non-waste technologies (LNWT); and
- stimulate the exchange of information and experience on environmentally sound forms of industrial development throughout the world.

UNEP IE's work programme follows four principal areas: the publication of technical guides; technical cooperation; training; and information transfer. It has also developed two priority programmes: "Awareness and Preparedness for Emergencies at the Local Level" (APELL) to prevent and respond to technological accidents, and Cleaner Production.

ANNEX B

Glossary of Significant Terms

The following terms are explained:

ODS 15-13
ODP 15-13
GWP 15-13
Greenhouse effect (global warming effect) 15-13
TEWI 15-13
Article 5 Countries 15-14
The Multilateral Fund 15-14
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ODS

Ozone depleting substances (ODS), e.g. the CFCs, HCFCs and halons, have an ozone depletion property due to their content of chlorine (Cl) and/or bromine (Br) and their chemical stability. (see *ODP*.) In this catalogue, ODS refers to the substances controlled under the Montreal Protocol and its amendments.

ODP

The stratospheric ozone layer (O_3) protects life on earth against harmful ultraviolet radiation from the sun. The ozone depletion potential (ODP) is the relative ability or potential of certain substances, e.g. the CFCs, HCFCs and halons, to deplete stratospheric ozone when they are released to the atmosphere by direct emission, leakage from refrigerating plants etc. The ODP value is normally related to CFC-11 (ODP=1.0).

The ODP is strongly related to the content of chlorine (Cl) and/or bromine (Br) and the chemical stability of the substance, i.e. atmospheric lifetime. (see also Halocarbons and CFC/HCFC/HFC Refrigerants.)

The CFCs, HCFCs and halons have been the subject of worldwide attention due to the stratospheric ozone issue and the related international agreement on control measures for ozone protection known as *the Montreal Protocol*. Review provisions of this Protocol have established the phaseout deadline for the controlled CFCs and halons by the year 2000 and the HCFCs by the year 2030, except for a delay of 10 years for developing countries.

GWP

The global warming potential (GWP) is the relative contribution of certain substances (greenhouse gases), e.g. carbon dioxide, methane, CFCs, HCFCs and halons, to the global warming effect when the substances are released to the atmosphere by combustion of oil, gas and coal (CO_2), direct emission, leakage from refrigerating plants etc.

The GWPs used throughout this manual are relative to carbon dioxide (ODP=1.0), which is consistent with the Intergovernmental Panel on Climate Change (IPCC) indexing approach.

The GWP can be given with 20, 100 or 500 years integration time horizon. Unfortunately there is not a complete agreement within the scientific community on what is the proper time horizon, but 100 years is most commonly used.

Greenhouse effect (global warming effect)

Some substances in the atmosphere are absorbing infrared emission from the earth, causing the average global temperature to increase. See *GWP*, global warming potential.

TEWI

The total equivalent warming impact (TEWI), combines the global warming effect associated with energy consumption, i.e. emission of CO_2 in power generation (indirect GWP) and the greenhouse effect due to the refrigerant emission (direct GWP). TEWI is useful as an indicator for the relative contributions to future global warming. The TEWI depends on how the power is generated, system design, lifetime of the system, refrigerant leakages etc., hence it is not possible to list the TEWI for each refrigerant.

Improved energy efficiency for a system has a great influence on the TEWI, compared to the new refrigerants with limited direct GWP and less leakage. The indirect GWP has a great impact for units with long lifetime, but is less important for units with short lifetime and higher leakage.

Article 5 Countries

Article 5 countries are developing countries which are Party to the Montreal Protocol with a annual calculated level of consumption less than 0.3 kg per capita of the controlled substances in Annex A, and less than 0.2 kg per capita of the controlled substances in Annex B, on the date of the entry into force of the Montreal Protocol, or any time thereafter. These countries are permitted a ten years grace period compared to the phaseout schedule in the Montreal Protocol for Developed Countries.

The Multilateral Fund

The Multilateral Fund for Implementation of the Montreal Protocol has been set up by the Parties to the Montreal Protocol to provide financial support and technology transfer to developing countries. (Article-5 countries.)

Halocarbons

Halocarbons are compounds (in this case, refrigerants) derivated from methane (CH_4) and ethane (C_2H_6), where one or several of the hydrogen atoms are substituted with chlorine (Cl), fluorine (F), and/or bromine (Br). These compounds are so called *partly halogenated halocarbons*. When all the hydrogen atoms are substituted the compound is said to be *fully halogenated*.

The ability of halocarbons depleting ozone in the stratosphere (see chapter 2, "Environmental aspects") is due to their content of chlorine and/or bromine and their chemical stability. Fully halogenated halocarbons have much higher chemical stability (atmospheric lifetime typically 100-500 years) than partly halogenated halocarbons (atmospheric lifetime typically 1-20 years).

CFC Refrigerants

CFC indicates a molecule composed of chlorine (Cl), fluorine (F), and carbon (C). The CFC refrigerants are fully halogenated halocarbons, and have generally a high ODP. Examples of CFC refrigerants are CFC-11 (CCl_3F), CFC-12 (CCl_2F_2) and CFC-114 ($CClF_2$-$CClF_2$).

HCFC Refrigerants

HCFC indicates a molecule composed of hydrogen (H), chlorine (Cl), fluorine (F) and carbon (C). The HCFC refrigerants are partly halogenated and have much lower ozone depletion potential (ODP) than the CFCs. Examples of HCFC refrigerants are HCFC-22 ($CHClF_2$) and HCFC-123 ($CHCl_2CF_3$).

HFC Refrigerants

HFC indicates a molecule composed of hydrogen (H), fluorine (F) and carbon (C). The HFC refrigerants are chlorine free and an *ODP of zero*. Examples of HFC refrigerants are HFC-134a (CF_3CH_2F) and HFC-152a (CHF_2CH_3).

HC Refrigerants (Hydrocarbons)

HC indicates a molecule composed of hydrogen (H) and carbon (C). Another name for these refrigerants is hydrocarbons. The hydrocarbons have an *ODP of zero*. Examples of hydrocarbons are propane (C_3H_8, HC-290), propylene (C_3H_6, HC-1270) and butane (C_4H_{10}, HC-600).

Natural Refrigerants

Natural refrigerants are naturally existing substances which are harmless to the nature and already circulating in the biosphere. These refrigerants have therefore no negative global environmental impact (ODP and GWP of zero). Examples of natural refrigerants are ammonia (NH_3), hydrocarbons (eg propane), carbon dioxide (CO_2), air and water.

Synthetic Refrigerants

Synthetic refrigerants are chemically manufactured substances. This group includes the CFCs, HCFCs and HFCs (halocarbons), which are considered harmful to the global environment (ODP and GWP), and are now regulated by the Montreal Protocol.

Blends/mixtures

A blend is a mixture of two or more pure fluids. A ternary blend contains three fluids. Given the right composition, blends can achieve properties to fit almost any refrigeration purpose. Eg. a mixture of flammable and non-flammable components can result in a non-flammable blend. Blends can be divided into three categories: azeotropic, non-azeotropic and near-azeotropic blends.

Azeotropic blends

Azeotropic blends has almost the same properties as pure fluids, eg. constant condensing- and evaporating temperature under constant pressure, due to isothermal phase change. Azeotropic blends can be used in existing refrigeration equipment without any modifications.

Near-azeotropic blends

Near-azeotropic blends/mixtures (NEARB/NEARM) have properties very similar to azeotropic blends, and can be used as refrigerants in existing refrigeration equipment without any modification.

Non-azeotropic blends

In non-azeotropic (zeotropic) blends/mixtures (NEARB/NEARM), the compositions of coexisting liquid and vapor differ, and condensation and evaporation occur over a range of temperatures. This effect can in some applications give improved performance in plants with heating/cooling demand with gliding temperatures. Heating of hot tap water is one example. The equipment has to be modified, when using a non-azeotropic blend.

Transitional Substances

Transitional substances are regulated by the Montreal Protocol, Annex C. Transitional substances can be used for servicing existing equipment even after the phaseout date for production, in order to encourage the phaseout of CFCs. So far the list of transitional substances only includes HCFCs, but it may be extended in the future.

Drop-in replacement

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

Retrofitting

Retrofitting means the procedure and necessary modifications needed when replacing CFC refrigerants with non-CFC refrigerants in existing refrigerating, air conditioning and heat pump plants. The degree of modification will depend upon system design, size and age, choice of alternative refrigerant etc.

Recovery

Recovery means collection and storage of controlled substances from machinery, equipment, containment vessels, etc., during servicing or prior to disposal.

Recycling

Recycling is re-use of a recovered controlled substance following a basic cleaning process such as filtering and drying. For refrigerants, recycling normally involves recharge back into equipment, and it often occurs "on-site".

Reclamation

Reclamation is re-processing and upgrading of a recovered controlled substance through such mechanisms as filtering, drying, distillation and chemical treatment in order to restore the substance to a specified standard of performance. It often involves processing "off-site" at a central facility.

Toxicity - TLV

Toxicity is characterized in terms of Threshold Limit Values (TLVs) which *"represents conditions under which it is believed that nearly all workers can be repeatedly exposed day after day without adverse effects"* /ACG90/. For volatile substances, such as refrigerants, TLVs are expressed as parts per million volume concentrations in air (ppm). The term TLV is a trademark of the American Conference of Governmental Industrial Hygienists (ACGIH) and properly refers to exposure limits fixed by the group.

Flammability - LFL and ΔH_{comb}

The lower flammability limit (LFL) is defined by the ASTM Standard E 681-85 as *"the minimum concentration of a combustible substance that is capable of propagating a flame through a homogeneous mixture of the combustible and gaseous oxidizer under the specified conditions of test"* /AST85/. The conditions of test usually reported for refrigerants are in dry air in ambient temperature and pressure.

The heat of combustion (ΔH_{comb}, MJ/kg) is calculated assuming CO_2, HF (or F_2 if insufficient H), Cl_2 and H_2O (if excess H) as products. Negative and small positive values indicate that the reaction with oxygen is not energetically favorable.

Energy Efficiency - COP

The energy efficiency or Coefficient of Performance (COP) of a refrigerating system is defined as the ratio between the refrigerating capacity of the plant, Q_0 (cooling/freezing capacity, kW) and the power/electricity consumption, P (kW) of the compressors and pumps. The COP is primarily depending on the working cycle and the temperature levels (evaporating/condensing temperature) but also the properties of the refrigerant and system design and size.

$$COP = (Q_0/P)$$

Volumetric Refrigerating Capacity

The volumetric refrigerating capacity $\mathbf{q_{vol}}$ (kJ/m^3) is defined as the ratio between the specific enthalpy of evaporation, q_o (kJ/kg), and the specific saturated vapor volume of the refrigerant, v (m^3/kg). The potential cooling/freezing capacity (kW) of a refrigerating plant per unit volume suction gas (m^3) at the compressor inlet for given evaporation temperature and pressure:

$$q_{vol} = q_0/v$$

If a refrigerant have a large volumetric refrigerating capacity (as HCFC-22) a smaller compressor volume/capacity is needed to provide a certain amount of cooling/freezing (kW). If the same amount of cooling/freezing is to be delivered by a refrigerating system with eg CFC-12 as refrigerant, the compressor capacity (and compressor costs) will increase about 40%.

Normal Boiling Point

Normal boiling point (NBP) is the boiling point of a compound (here refrigerant) *at atmospheric pressure* (1.013 bara). E.g. NBP for ammonia is -33.3°C.

Compressor Discharge Temperature

The compressor discharge temperature is the gas temperature at the high pressure outlet from the compressor (superheated gas). The gas temperature is typically 30-40°C higher than the condensing temperature at saturation pressure, mainly depending on the evaporating/condensing temperature, refrigerant properties and compressor energy efficiency.

ANNEX C

Codes of Practice and Standards for the Refrigeration, Air Conditioning and Heat Pump Sector

All document in this list are in English. To obtain a copy of a document, please contact the organization that developed the code standard. All organizations are listed in *ANNEX D, Contacts for additional information.* UNEP IE's Information Paper on *Standards and Codes of Practices* is a reference document to get additional information.

AUSTRALIA

Code of practice: design and service of domestic refrigerator units. Environment Protection Authority - Victoria, 1993

Code of Practice: design and service of industrial and commercial air conditioning and refrigeration units. Environment Protection Authority - Victoria, 1993

Code of good practice for the reduction of emissions of ozone depleting refrigerants in refrigeration and air conditioning applications (February 1992 Draft). AFCAM (Australia. Association of Fluorocarbon Consumers and Manufacturers), 1992

CANADA

Code of practice for the reduction of chlorofluorocarbon emissions from refrigeration and air conditioning systems (EPS 1/RA/1). Environment Canada, March 1991

EUROPEAN COMMUNITY

Code of good practice for the reduction of emissions of chlorofluorocarbons (CFCs) R-11 and R-12 in refrigeration and air conditioning applications (Report EUR 9509 EN). Refrigeration Service Engineers Society for Commission of the European Community, 1984.

NEW ZEALAND

Automotive air conditioning code of practice: for the control of chlorofluorocarbons emission during the fitting, servicing, repair or de-commissioning of motor vehicle air conditioning. MTA (Motor Trade Association Inc.), 1991.

Code of practice for the reduction of emissions of chlorofluorocarbons (CFCs) in refrigeration and air conditioning applications (Code Number OLPACOP1:1991). IRHACE (Institute of Refrigeration, Heating and Air Conditioning Engineers of New Zealand Inc. and Refrigeration Air Conditioning Companies Association), 1991.

Code of Practice of Refrigeration Air Conditioning Companies Association. IRHACE, Undated.

SWEDEN

Swedish Refrigeration Code: mobile refrigeration systems: Refrigeration systems for climate comfort in motor vehicles and working vehicles. Kylbranschens Samarbetsstiftelse (Swedish Refrigeration Foundation), September 1992.

Swedish Refrigeration Code: safety standards for the design, execution, installation, operation and maintenance, etc, of refrigerating and heat pump plants. Kylbranschens Samarbetsstiftelse (Swedish Refrigeration Foundation), August 1988.

UNITED STATES

1988 standard for specifications for fluorocarbon refrigerants: ARI Standard 700-88. ARI (Air Conditioning and Refrigeration Institute), 1988.

1990 guideline for containers for recovered fluorocarbon refrigerants: ARI Guidelinne K-1990. ARI, 1990.

1991 standard for performance of refrigerant recovery, recycling and/or reclaim equipment (ARI Standard 740-91). ARI, 1991.

1990-91 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists, Cincinnati. 1990.

ASHRAE Standard 34-1989, Number Designation and Safety Classification of Refrigerants. ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers), Atlanta. 1989.

ASTM Standard Test Method E 681-85, Concentration Limits of Flammability of Chemicals. American Society for Testing and Materials, Philadelphia, 1985.

ASHRAE Handbook: - FUNDAMENTALS. ASHRAE, Atlanta, USA 1985. ISSN 82-643223.

ASHRAE Handbook - REFRIGERATION, Systems and Applications. ASHRAE, Atlanta, USA 1987. ISBN 0-910110-70-0. ISSN 1041-2344.

ASHRAE Handbook - HVAC Systems and Applications. ASHRAE, Atlanta, USA 1987. ISBN 0- 910110-50-6.

ASHRAE Handbook - EQUIPMENT. ASHRAE, Atlanta, USA 1983. ISSN 0737-0687.

American Standard for Equipment, Design and Installation of Ammonia Mechanical Refrigeration Systems. 13. ANSI (The American National Standards Institute)/IIAR (International Institute of Ammonia Refrigeration) -2-1984. Approved by ANSI July 24, 1985.

UNITED KINGDOM

BS 4434 1989, Specifications for Safety Aspects in the Design, Construction and Installation of Refrigerating Appliances and Systems. British Standard Institute, 1989.

ANNEX D

Contacts for Additional Information

AFCAM Association of Fluorocarbon Consumers and Manufacturers
P.O.Box 3076
Manuka ACT 2603
Australia
Tel: (61) 6 273 1592
Fax: (61) 6 273 4990

AFEAS Alternative Fluorocarbon Environmental Acceptability Study
The West Tower Suite 400
1333 H Street NW
Washington, DC 20005
USA
Tel: (1) 202 898 0906
Fax: (1) 202 789 1206

ANSI The American National Standards Institute
11 West 42 Nd Street
New York 136
USA

ARI Air Conditioning and Refrigeration Institute
PO BOX 12014
Arlington
Virginia 222 19-2014
USA
Tel: (1) 703 524 8800
Fax: (1) 703 528 3816

ARTI Air-Conditioning and Refrigeration Technology Institute
PO BOX 12014
Arlington
Virginia 222 19-2014
USA
Tel: (1) 703 524 8800
Fax: (1) 703 528 3816

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers,Inc.
1791 Tullie Circle, N.E.
Atlanta, GA 30329
USA
Tel: (1) 404 636 8400
Fax: (1) 404 321 5478

ASTM American Society for Testing and Materials
1916 Race Street, Philadelphia, PA 19103
USA
Tel: (1) 215 299 5400
Fax: (1) 215 977 9679

British Standard Institute
2 Park Street
W1 London
Great Britain
Tel: (44) 71 629 9000

Environment Canada
1179 Bleury Street
Montreal
Canada
Tel: (1) 514 283 4670

Environment Protection Authority
477 Collins
3000 Melbourne City
Victoria
Australia
Tel: (61) 3 628 5111

IIAR International Institute of Ammonia Refrigeration
1101 Connecticut Ave. NW
Washington DC 20036
USA
Tel: (1) 202 857 1110
Fax: (1) 202 223 4579

IIR The International Institute of Refrigeration
177, Boulevard Malesherbes F-75017, Paris
France
Tel: (33) 1 42 273 235
Fax: (33) 1 47 631 798

PAFT Programme for Alternative Fluorocarbon Toxicity Testing
c/o ICI Klea
PO Box 13, The Heath
Runcore, Cheshire WA7 4QF,
United Kingdom
Tel: (44) 928 513 213
Fax: (44) 928 511 418

SINTEF Refrigerating Engineering
7034 Trondheim
Norway
Tel: (47) 73 59 39 00
Fax: (47) 73 59 39 26

United Nations Development Programme (UNDP)
Attn: Frank Pinto
1 United Nations Plaza
New York
NY 10017 USA
Tel: (1) 212 906 5042
Fax:(1) 212 906 6947

United Nations Environment Programme Industry and Environment (UNEP IE)
Attn: Rajendra M. Shende
Tour Mirabeau
39-43, quai André Citroén
75739 Paris Cedex 15
France
Tel: (33) 1 44 37 14 50
Fax:(33) 1 44 37 14 74

United Nations Industrial Development Organization (UNIDO)
Attn: Mrs. A. Tcheknavorian
PO Box 300
A-1400 Vienna
Austria
Tel: (43) 1 211 310
Fax:(43) 1 2307 449

United States Environmental Protection Agency (US EPA)
Office of Atmosperic and Indoor Air Programs,
Global Change Division
401 M. St. S.W., Washington DC
20460 USA
Tel: (1) 202 477 1234
Fax:(1) 202 676 0483

World Bank
Attn: Mr. Ken Newcombe
1818 H. Street NW,
Washington, DC 20433
USA
Tel: (1) 202 477 1234
Fax: (1) 202 676 0483

ANNEX E

Data Collection Method and Survey Used to Develop the Suppliers List

THE DATA COLLECTION METHOD

In order to make this catalogue, information had to be gathered from around the world. In this section we will present the method used in this information gathering, and also some of the weakness in the methodology that can be pointed out.

Problem definition

First of all we had to define what kind of information we wanted. "What do we need to know?"

The information was supposed to be used to make a catalogue that could help developing countries in their work to meet the CFC challenge. These countries need to know what kind of alternatives that exist, and what is coming up in the future. They also need information on whom to contact when they have questions and difficulties.

The problem can be described as:
Collect information and data on CFC-free technology for refrigeration, air conditioning and heat pumps. What is commercially available, and what is under development? Locate companies and organizations that work with this kind of technology. Present the information in a form that can be used to help developing countries to meet the CFC-challenge.

Method - how to collect information

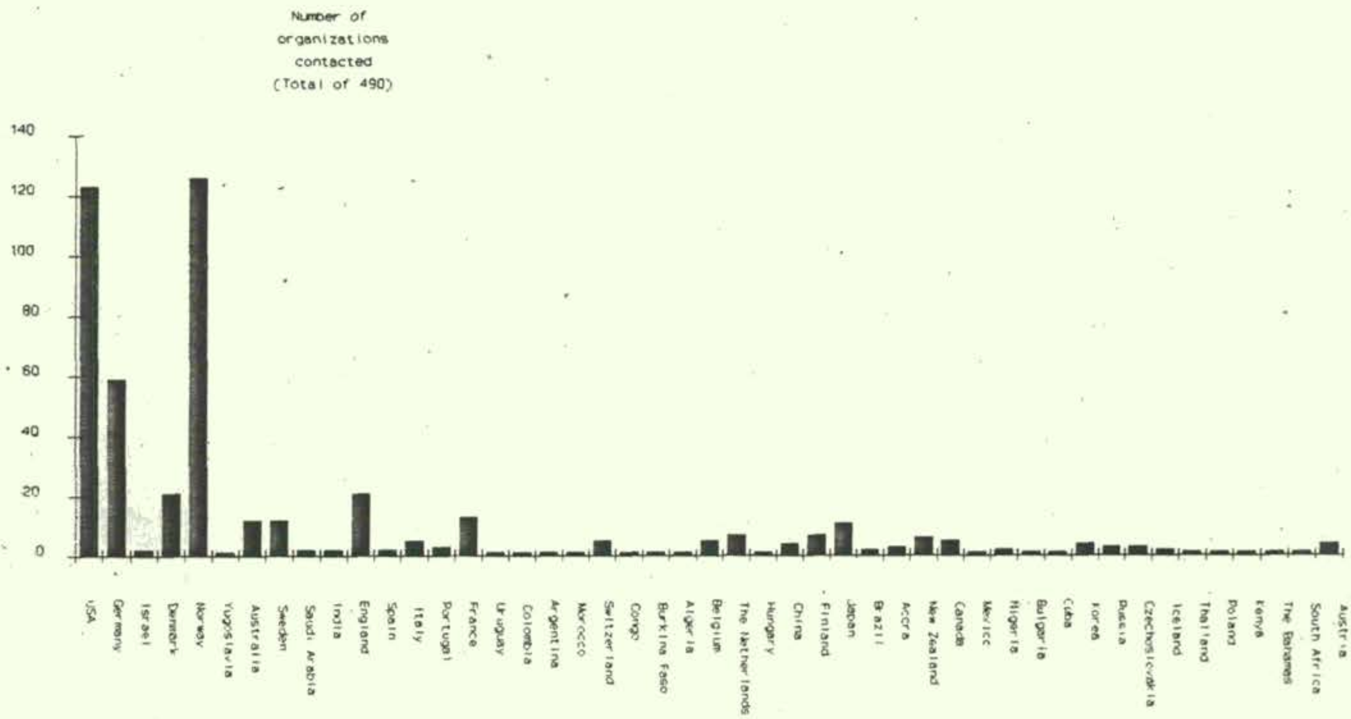
Having the problem stated, the next step was to develop a method on how to get the information we needed. We could use secondary data - collect information from conference-proceedings and other publications or we could use primary data - collected specifically for our use. The final solution was to use both methods. Some information was gathered from secondary sources, and the rest was collected using a survey/questionnaire developed especially for the purpose of this data gathering.

The survey/questionnaire was sent, together with a letter explaining the purpose, to organizations all over the world.

Respondents - who was contacted?

To find out who to contact under the data collection, we started with the personal network that people working at SINTEF Refrigeration Engineering possessed around the world. We gathered information from different sources and organizations that might have the kind of information we were seeking. Some of the organizations we contacted during this period, was IIR (International institute of refrigeration), UNEP (United Nations Environmental Programme), International Heat Pump Centre of Japan, among others. Out of this information a list of possible contacts was made.

Organizations in 47 different countries were contacted. As a start 320 questionnaires were sent out. Later, after gathering information from the organizations that had received the questionnaire, another 170 questionnaires were sent. As the figure below shows, most of the organizations were sited in USA, Germany and Norway. Other countries represented with several organizations are Denmark, Sweden, Australia, England, France and Japan.



The large amount of norwegian organizations is a result of the fact that we used the list of members in one of the largest Refrigeration-Entrepreneur-Associations i Norway as a basis when the list of possible contacts was made.

Possible sources of error

The fact that most of the organizations represented in this catalogue come from only a few countries, may give a unsatisfactory picture of the situation. It is also a fact that many of the organizations are universities, associations or non-profit-organizations. These may be able to give information, but perhaps not on the latest commercial and mature technology and equipment.

In a future revision of the catalogue it might be necessary to improve this, especially by contacting several more organizations from other regions than USA and Europe.

Many of the organizations contacted, have not given any reply. A reason for this may be that SINTEF Refrigeration Engineering is not a world known institute. The organizations that have given information tend to come from countries that are rather closely related to Norway. This may have influenced on the result of the data collection.

THE SURVEY

During the information gathering a survey/questionnaire was sent to the organizations we wanted information from. This survey was developed specially for this purpose, and poirited out what kind of information we seeked from the respondents. The survey is presented on the next two pages.

Please, fill in as much as possible (some questions may not be pertient to all products/technologies).

1. The product or technology name (refrigerant, compressor, chiller, heat exchanger, process, etc):

____

____

2. Application area:

- Domestic refrigeration ☐
- Retail refrigeration ☐
- Transport refrigeration ☐
- Cold storage and food refrigeration ☐
- Industrial refrigeration ☐
- Comfort air conditioning ☐
- Mobile air conditioning ☐
- Heat pumps ☐

3. Please describe briefly the products/technologies CFC reduction method (check and use few words):

- Process change ☐
- Alternative process equipment ☐
- Product redesign/substitute product ☐
- Engineering controls ☐
- Improved operating practices ☐
- Substitute chemical (transitional) - drop in ☐
- Substitute chemical (transitional) - modifications needed ☐
- Substitute chemical (replacement) - drop in ☐
- Substitute chemical (replacement) - modifications needed ☐
- Recovery/recycling ☐
- ODS bank ☐
- Alternative use pattern (e.g. elimination of "nonessential" products or ODS application) ☐
- Purification/treatment ☐
- Destruction ☐
- Other (specify) ☐

____

____

____

4. Please give the most important technical data (capacity, output, constraints, etc):

____

____

____

5. Safety drawbacks (flammable/explosive etc):

____

____

____

6. Other drawbacks (increased energy consumption, weight, volume):

____

7. Please describe the use of the product/technology:

Stage of development
- Planning ☐
- Bench test ☐
- Pilot stage ☐
- Fully implemented ☐

Level of use:

Scarely | —— | —— | —— | —— | —— | —— | —— | —— | —— | Widely

8. If the CFC-free technology is a refrigerant, please fill in:

Refrigerant:... used as substitute for: ....

Experience (drawbacks): ....

Component change necessary ? ....

9. Please give the approximate investment costs $: ....

10. Please summarize changes in operational and maintenance cost (per month or year) and changes in personnel or hours requirement:

____

____

11. What channels of distribution are applied (sold where)?:

____

____

12. This information is provided by:

Contact person: ....

Organization ....

Address ....

Telephone ....

Fax number ....

Telex address ....

13. If you know other manufacturers, research, scientific, or academic organizations where additional information or documentation can be obtained, please write them down. For each organization, please include name, address, telephone and fax number.

14. Any other information pertinent to this matter:

THANK YOU FOR YOUR COOPERATION!

ANNEX F

Request for Information

This catalogue is a "living" document that will be updated on a regular basis to reflect technological advancement, new products, and changing control measures. Information is welcome both on alternatives to uses covered in the catalogue as well as on alternatives not discussed. UNEP request that companies or individuals with such information use the form in next page to supply this information to:

UNEP IE OzonAction Programme
Ref.: Refrig Catalogue Update
Tour Mirabeau
39-43, Quai André Citroën
75739 Paris Cedex 15
France
Tel: (33) 1 44 37 14 50
Fax: (33) 1 44 37 14 74

REFRIGERATION, AIR CONDITIONING AND HEAT PUMP USES DATA FORM

Name: ______________________________

Title: ______________________________

Company: ______________________________

Address: ______________________________

Telephone: ________________ **Fax:** ________________

Use Description

Name of Use: ______________________________

Brief Description of Use:

ODS Used (e.g., CFC-12): ______________________________

Industry Sectors Using ODS-based Product (e.g. domestic, commercial, water chillers):

Non-ODS Alternatives Commercially Available (if necessary, please use a separate sheet for each alternative):

Name of Alternative: ______________________________

Supplier(s) Contact Phone/Fax Numbers