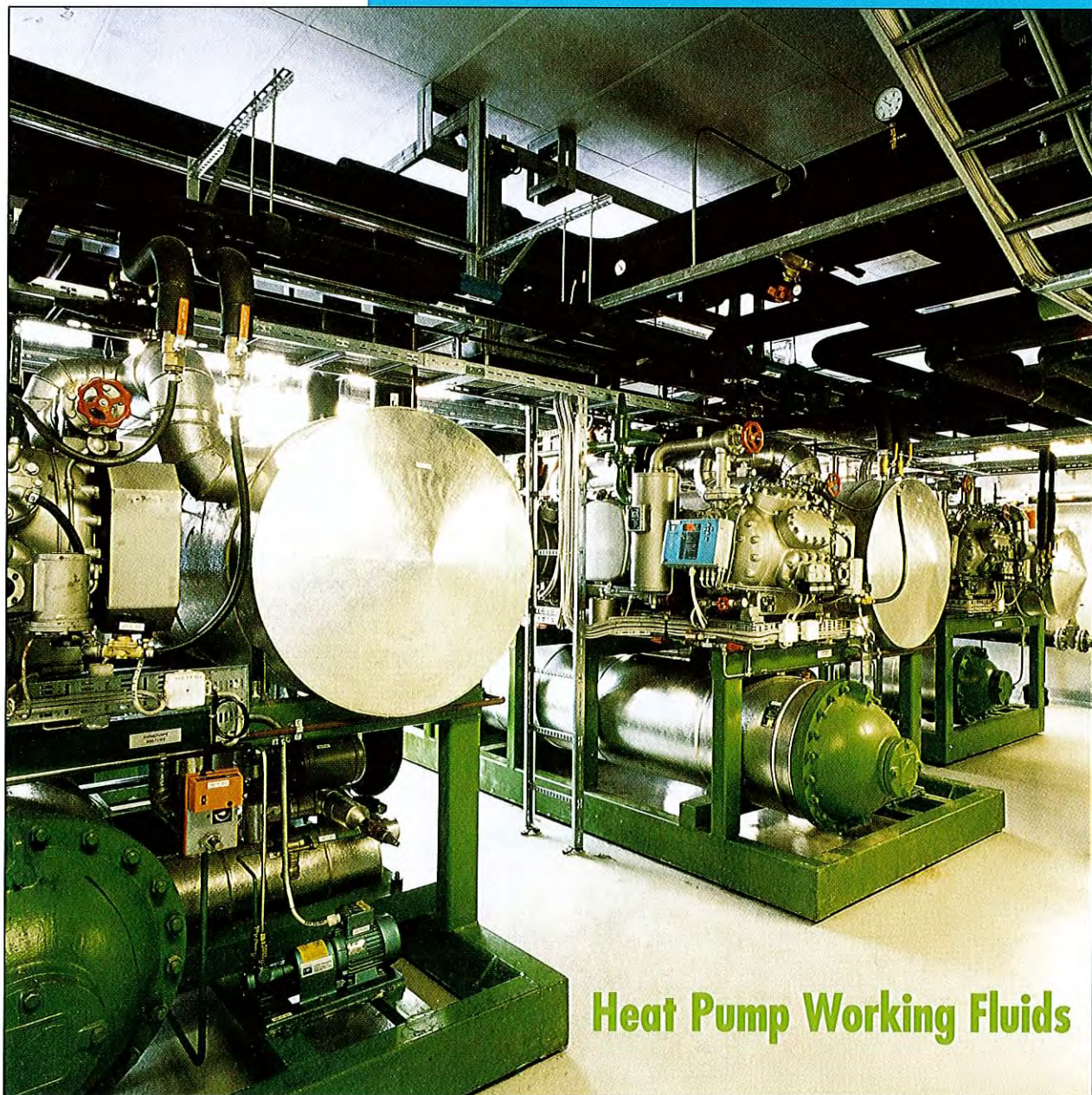


IEA Heat Pump Centre

NEWSLETTER



Heat Pump Working Fluids



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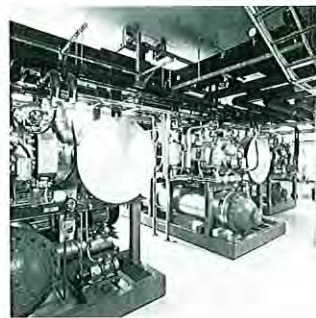
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Front Cover: In Norway more and more large heat pumps are using ammonia as a working fluid. These two vapour compression heat pumps (450 kW each) heat an office building using sea water as the heat source. More details are given on page 8.

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an International Energy Programme.

A basic aim of the IEA is to foster cooperation among the 23 IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology, and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration currently within the framework of 35 Implementing Agreements, containing a total of more than 60 separate collaboration projects.

IEA Heat Pump Centre

The eight member countries of the IEA Heat Pump Centre (HPC) form a network for exchanging information on heat pump technology. By increasing awareness and understanding worldwide, the HPC aims to accelerate the implementation of heat pump technology as a means to reduce energy consumption and thereby to limit harmful environmental effects. This publication is one element of the HPC activities.

Any part of this publication may be reproduced, with acknowledgement to the IEA Heat Pump Centre, Sittard, the Netherlands.

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Gold Medal for Norway



During a harsh winter the canals and lakes in the Netherlands freeze over and many Dutch people take to the ice. When in the grip of a big freeze, a stillness envelops the land. The virgin ice can be as smooth as glass and when you skate across it the ice vibrates with a high-pitched singing sound. Following the frozen waterways is the perfect way of travelling through the winter landscape. I am drawn to the ice every time and each winter I hope that it will be cold enough to hold the Eleven Cities Marathon in the northern province of Friesland. Along with about 1600 fellow skaters, I have twice skated the 200 km route along the canals that link eleven towns.

Unfortunately, the Netherlands had another disappointing winter this year which did not deserve the name; it was mild and for skating on natural ice, the only ice that really counts, the Dutch had to visit frozen lakes in Finland or Austria.

On two blades the Dutch are hard to beat. Norwegians and Swedes know all about it. As soon as they can walk, Dutch kids learn how to skate. With little blades on a wooden base strapped to their boots, they scrape along the ponds and canals. It's the stuff that breeds champions. Hopefully, the Dutch skaters will have demonstrated the benefits of their early introduction to ice at the recently held 1994 Winter Olympics in Lillehammer, Norway. However, the Norwegians have their own approach to skating which earns them their fair share of medals.

My attention was drawn to the Winter Olympics not only by the skating, but also by the knowledge that many of the facilities there contain heat pumps with ammonia as the working fluid. A great deal of energy was needed to provide the right space conditions for participants and spectators. However, as can be expected from environmentally conscious Norway, energy efficiency was the starting point in designing and building the various Olympic sporting facilities.

An example of the growing number of heat pump installations using ammonia in not only Lillehammer but other parts of Norway can be seen on the front cover. The installation shown uses heat from the environment.

I believe the Norwegians deserve an extra international medal for their outstanding work in hosting an environmentally-friendly Winter Olympics. For the time being the Norwegians are unbeatable in this field.

A stylized blue ink signature of Jos W. J. Bouma.

Jos W. J. Bouma
General Manager, IEA Heat Pump Centre.

News & Views

Heat pumps star in Winter Olympics

Norway - Heat pump technology has helped make the XVII Winter Olympic Games held in Lillehammer in February the most environmentally friendly in modern times. The specially built Olympic halls and arenas have been designed to use 30% less energy than any similar facilities around the world and many of them employ heat pumps.

The Winter Olympics provide the perfect opportunity to promote the benefits of heat pumps to a wide audience. Furthermore, most of the heat pumps are using ammonia as the working fluid, which demon-

strates that this potentially hazardous but environmentally friendly refrigerant can be used with safety in public buildings.

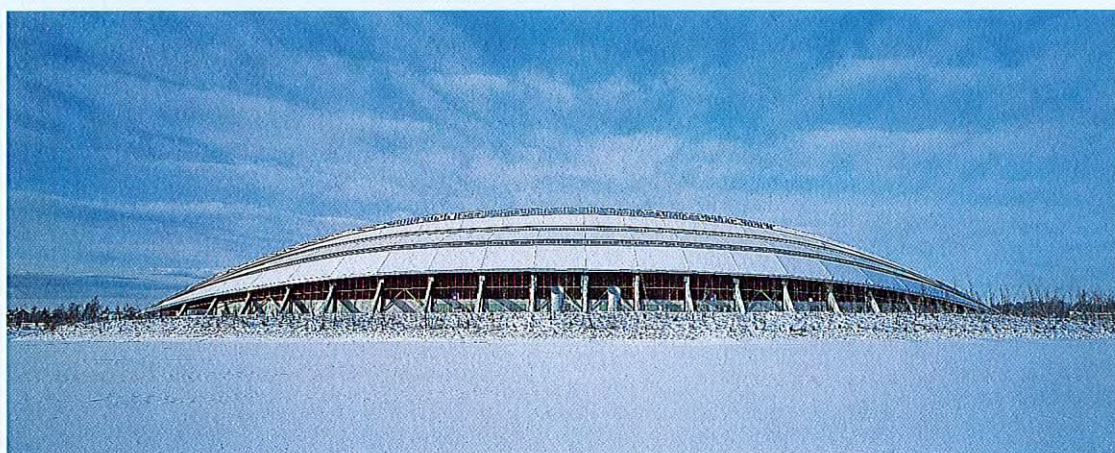
The "Olympic" heat pumps are used for ice production and most of them recover the heat for use in low-temperature hydronic heating systems. Only the bobsleigh and luge track facilities could not employ heat-recovery heat pumps as the adjacent buildings were not close enough.

Electric vapour compression heat pumps served the following Olympic events:

- speed skating at the Hamar Olympic Hall (see photo);
- figure skating and short track speed skating at the Hamar Olympic Amphitheatre;
- ice hockey at the Håkon Hall and the Gjøvik Olympic Cavern.

Not only do the heat pumps offer high energy efficiency, they also produce ice of "record breaking" quality.

(Source: Dr Ulf Rivenæs, Norwegian National Team)



The Hamar Olympic Hall equipped with large heat pumps with ammonia as working fluid. Photograph: Jarle Kjetil Rolseth.

HCFC phase-out brought forward

Europe - The European Union (EU) (previously known as the European Community) has agreed new phase-out dates for HCFCs in advance of the dates agreed under the Copenhagen Amendment to the Montreal Protocol. Table 1 compares the new EU phase-out dates with the Montreal Protocol dates (the reduction percentages are based on 1989 consumption levels). In

addition, the use of HCFC-22 in "open" cooling equipment, such as is used in cars, will be banned from 1 January 1996. The regulations were agreed upon at a conference of environmental ministers on 2-3 December 1993, but must still be ratified by the European Parliament.

(Source: CCI, Germany, 1/94)

Table 1: HCFC phase-out schedules.

Date	Reduction (%)	
	Montreal Protocol	European Union
2004	35	35
2007		60
2010	65	80
2013		95
2015	90	100
2020	99.5	
2030	100	

Government cuts heat pump support

Norway - Government support for heat pump technology has been reduced from US\$ 1 million in 1993 to US\$ 0.4 million in 1994. But compared with many other energy efficiency programmes, the cuts in the Norwegian Heat Pump Programme are minimal. Total spending on energy efficiency has been drastically cut from US\$ 75 million in 1993 to just US\$ 7.5 million in 1994 - a figure that has recently been revised upwards from just US\$ 5 million. Most of the cut-back is accounted for by the removal of the 20% cash incentive for installing energy-efficient equipment, such as heat pumps. The government felt that this policy attracted too many "free-riders".

Norway's cooperation with the IEA, including the Heat Pump Centre has not been affected. Additional money is also available to heat pump manufacturers through other budgets which pay 50% of development costs.

Heat pump technology still remains a priority item in Norway's energy policy, being the only technology to have a separate budget. Under the continued leadership of manager Dr Ulf Rivenæs, the Norwegian Heat Pump Programme will focus on education and the CFC issue in 1994.

(Source: Dr Ulf Rivenæs, Norwegian National Team)

Survey shows user satisfaction

Germany - A recent survey of about 7000 users showed that 35% have had no problems since installing a heat pump, and that less than 50% have needed servicing in the last five years. Conducted by six energy offices in the Bavarian region, the survey showed that 75% of heat pumps are used in new buildings, and that 81% supply underfloor heating. Ground water is the heat source for 58%, while 25% are air-source. The share of ground-source heat pumps has risen rapidly to 11%. Most users (82%) indicated that they installed a heat pump primarily because of its environmental benefit.

(Source: Wärmepumpe from IZW, Germany, December 1993)

Leading producer opts for propane

Germany - Germany's largest heat pump manufacturer, Kulmbacher Klimagerätewerke (KKW), has announced that all its heat pumps will be propane-filled by the end of this year. Speaking at a seminar on heat pumps in Würzburg on 3 November 1993, Managing Director Gerd-Dietmar Kohlrusch stated that no difficulties were expected in the use of propane-filled heat pumps in Germany. Furthermore, he claims that the introduction of variable-speed technology, together with the improved performance from using propane, will significantly reduce energy consumption. KKW sold around 1000 heat pumps in Germany in 1993.

The seminar entitled "Electric Heat Pumps - the Environment's Friend" attracted some 200 participants, reflecting the rising interest for heat

pumps in Germany. Currently, out of around 10 million heating systems in Germany, some 40,000 of them have heat pumps.

To promote more interest in heat pump installations, electric utility RWE Energie AG is offering a special low tariff for heat pump equipment and an extended guarantee of four to five years. Furthermore the company offers technical support and will lend money for the purchase of heat pump equipment with a favourable interest rate of 3%. RWE makes the proviso that building heat requirements must be limited to 65 W/m², and the heat pump must achieve an SPF (heating) of at least three.

(Source: CCI, Germany, 14/1993 and Wärmepumpe from IZW, Germany, December 1993)

ASHRAE approves new blends

USA - At its winter meeting in January, ASHRAE (the American Society of Heating, Refrigeration and Air-Conditioning Engineers) approved safety regulations for two new blends designated as R-403. R-403 refrigerants are blends of HCFC-22, R-218 (a fully-fluorinated fluorocarbon) and propane. These R-502 replacements are now incorporated in ASHRAE Standard 34-92 "Number Designation and Safety Classification of Refrigerants." ASHRAE classifications for toxicity and flammability determine a refrigerant's ratings and the corresponding safety procedures required to assure the safety of building occupants in case of refrigerant leakage.

(Source: ASHRAE, USA)

Technology & Applications

Absorption conference challenges researchers

Prof. Alefeld: "We are not good enough at absorption."

USA - If sorption systems are to compete with electric compression heat pumps, they must become more energy efficient.

Speaking at the International Absorption Heat Pump Conference, Prof. Georg Alefeld of the Technical University of Munich, Germany, concluded that: "We are not good enough at absorption." According to Alefeld, the overall efficiency of a heat pump driven by electricity from a modern gas-fired power station is higher than can be achieved with a single-stage absorption heat pump.

To make absorption heat pumps more attractive, multi-effect systems with high efficiency should be developed. Further improvements in efficiency can be made through developing working fluids with "tailor-made" properties as well as using appropriate additives for enhancing heat and mass transfer.

The conference was held in conjunction with the 1994 ASHRAE winter meeting in New Orleans on 19-20 January, and attracted participants from all over the world. It focused on research and included

presentations on several "new" cycles. In particular, solid-vapour cycles, which date back to the 1930s when they were used for refrigeration before compression systems took over, are undergoing a revival. A paper on the Dutch Salt Water Energy Accumulation and Transformation (SWEAT) system showed how such systems are efficient, easy to control and can be built relatively cheaply.

A history of the development of absorption heat pumps for residential space conditioning in the US was presented by Mr Ben Phillips of Phillips Engineering. Mr Phillips noted that more research is still needed and should not be restricted to the cycle itself but should include heat transfer and distribution components such as the house coil, circulation pump and blower. The US Department of Energy has supported the development of an advanced 10 kW cooling capacity air-to-air absorption heat pump which has achieved COPs measured at 1.6 for heating and 0.7 for cooling. United Technologies Carrier will develop this machine further as an advanced product for the residential market requiring minimal service.

The conference revealed that, despite the ongoing development work, absorption technology faces an uphill struggle for success. The challenge for researchers is to improve efficiency while keeping equipment costs at an affordable level.

The conference proceedings are available from ASME/United Engineering Center, 345 East 47th Street, New York, NY 10017. (ISBN No. 0-7918-06987-7)

(Source: Mr Jos Bouma, IEA Heat Pump Centre)

Superior heat pumps

Japan - The Heat Pump Technology Center of Japan has awarded "Superior Heat Pump Status" to eight heat pump systems from 1993. Table 2 shows the systems selected by neutral members from universities and national laboratories as being "worthy to diffuse into society."

(Source: Japanese National Team)

Table 2: 1993 winners of Japan's superior heat pump status award.

Applicant(s)	Application	Main Feature
TEPCO, Shimizu, Ebara Corp.	District heating	Use of sewage heat
Yomiuri Shinbunsha, Shimizu	Machine cooling, space conditioning and hot water	Vertical closed steel plate storage tank
Shimizu, Kansai Electric Power, Tokyo	Space conditioning	Ice storage
Toho Gas, Azusa Sekkei, Asahi Kiki	Swimming pool, hot water, space conditioning	Gas-engine heat pump
Okumuragumi, Kansai Electric Power, Kuiken	Hot water, space conditioning	Hot water storage
Takenaka, Sunnwel, Japan	Space conditioning	Ice and hot water storage
Taisei Corporation	Space conditioning	Ice and hot water storage
Hitachi, Enndou Tao Kennchiku Sekkei, Sougousetsubi, Hitachi Reinets	Space conditioning	Multi-unit system

The secret life of a refrigerant

Switzerland - A test facility at the Laboratoire d'Energetique Industrielle in Lausanne allows researchers to see and to video the evaporation and condensing phenomena of working fluids. A 3 m long glass tube allows refrigerant flow patterns to be examined as the refrigerant is heated or cooled by water flowing through a concentric pipe (see photo). The tube has three measurement subsections and provides realistic simulation of both in-tube and outer-tube evaporation and condensation. In-

tube evaporation can be observed through transparent tubes at the end of each subsection. A pivoting central support allows any tube angle adjustment from horizontal to vertical.

Heat transfer and pressure drop measurements have been made on both traditional and replacement refrigerants, including HCFC-123, HFC-134a, HP62, HP80, R-402a and R-404a. Tests have been made over a broad range of quality ratios (vapour

mass: total mass) valid for both heat pump and organic Rankine cycles (ORC) conditions. Both plain tubes and enhanced heat-transfer surfaces, such as microfin tubes, have been tested.

The work is improving the understanding of the way flow patterns lead to differences between predicted and actual evaporation and condensation behaviour. Current work is focused on the dry-out region of in-tube evaporation for various refrigerant-lubricant combinations. Sponsored by ASHRAE (the American Society for Heating Refrigerating and Air-Conditioning Engineers), this work is important for the understanding of expansion valve control in direct-expansion heat pumps.

(Source: Mr Nakhle Kattan, Swiss Federal Institute of Technology, Lausanne, Switzerland. Tel: +41-21-693-3549; Fax: +41-21-693-3502)

Evaporation of HCFC-123 under different flow regimes.



Refrigerant study chooses HP62

Switzerland - A practical study to compare R-502 replacement refrigerants has found the azeotropic mixture HP62 to be the best choice as far as thermodynamic performance is concerned.

Conducted by Scheco AG, Winterthur, for the Swiss Federal Office of Energy, the study compared the refrigerants HP81, HP80 (R-402) and HP62 in practical tests in conventional heat pump equipment. HP62 is a mixture of HFC-125 (44%), HFC-134a (4%) and HFC-143a (52%). The result is of particular importance with R-502 now forbidden in new equipment in Switzerland.

(Source: Mr Martin Zogg, Switzerland. Tel/Fax: +41-34-220785)

Ammonia heat pumps use sea water and sewage

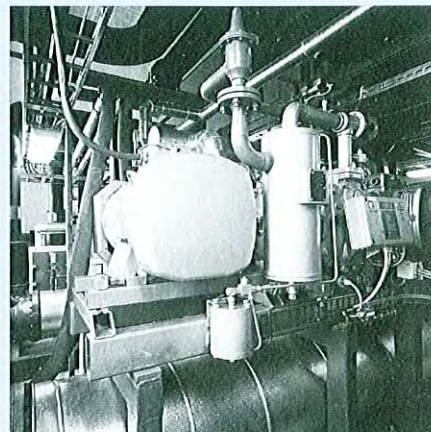
Norway - Ammonia is the chosen working fluid for two new compression heat pump systems, both built by Sabroe Refrigeration. In October 1993, a 675 kW two-stage system using treated sewage as its heat source was installed in a small district heating system at Stjørdal. Despite high supply/return temperatures of 80/60°C, the heat pump is able to boast a COP of 3.1. Condensation temperatures of up to 77°C are met by 40 bar second-stage compressors.

In order to avoid sedimentation of mud, the system uses a one-pass shell-and-tube evaporator. An automatic washing system featuring circulating washing balls cleans the tubes regularly. With a total ammonia charge of 600 kg, the heat pump features several safety measures: gas alarms in the engine room, an automatic compressor shut-down system, an emergency

ventilation system and a sprinkler system.

Another ammonia heat pump system was installed in September 1993. Two 450 kW compression heat pumps serve Statoil's new office in Trondheim utilizing sea water as a heat source (see photograph on the front cover). With a hydronic heat distribution system dimensioned at 60/40°C supply/return temperatures, the system uses standard 25 bar compressors. The COP at the dimensioning point is 4.0.

At outside temperatures below -5°C, a propane-fired boiler supplies back-up heating. Year-round space cooling is provided directly by sea-water with a 200 kW ammonia chiller available to cover peak loads in summer. The heat pumps use plate heat exchangers in both evaporators and condensers and an ammonia charge of just 0.22 kg per kW.



Close-up of the sea water heat pump at Trondheim.

Nonetheless, the system is fitted with gas alarms, a shut-down system and an emergency ventilation system.

(Source: Mr Jørn Stene, SINTEF Refrigeration Engineering, Trondheim, Norway. Tel: +47-7359-1642)

Markets

Shipments return to 1990 levels

Japan - Heat pump sales underwent continued decline in recession-hit Japan in 1993. Shipment figures for room and packaged heat pumps showed falls of 14.9% and 13.6% respectively for the year ending in October 1993. This second year of declining shipments brings annual sales down below the levels of 1990. Table 3 plots the sales trend. It also shows a consistent rise in the percentage share of heat pumps in the total sales of room and packaged air conditioners including cooling-only systems.

Predictions for 1994 are optimistic. From a survey of its members, the Japan Refrigeration & Air Condition-

ing Industry Association (JRAIA) predicts a rise of 10% in sales of room heat pumps. This is based on increased house building and renovation, and on a prediction that the cool summer of 1993 will not be repeated. The relatively warm winter is also expected to favour heat pump sales since their heating capacity is generally regarded as being insufficient on very cold days.

The slump in heat pump sales has slowed down the introduction of new models as manufacturers accumulate large inventories. However, the trend in new equipment has shifted away from making equipment more compact, towards

reducing energy consumption. In response to consumer demand, the latest models claim to reduce annual power costs by as much as 50%.

The main competitor to the heat pump in Japan is the oil heater. Demand for the current heating year is predicted as follows:

Oil fan heaters up 2% to 3,400,000 units; Forced draft flue oil space heaters up 1% to 310,000 units and oil heaters remaining level at 2,200,000 units

(Source: JARN, 25 November & 25 December, 1993)

Year Ending	Room Heat Pumps		Packaged Shipments	Share
	Shipments	Share		
Oct '90	4,242,929	72%	725,129	78%
Oct '91	5,342,855	75%	859,176	80%
Oct '92	4,911,610	79%	747,239	81%
Oct '93	4,180,101	83%	645,260	82%

Table 3: Japanese domestic heat pump shipments. Share indicates the proportion of heat pumps to total air conditioning equipment.

Shipments up 8%

USA - Air-Conditioning and Refrigeration Institute statistics on US shipments of heat pumps show a rise of 8% in the year ending in November 1993 with January-October sales totalling 809,518 units.

(Source: Koldfax from the ARI, January 1994)

IEA Heat Pump Programme

Following guidelines agreed under the IEA Heat Pump Programme's "Strategy Plan," information on some recently completed Annexes will become more widely available this year. In cooperation with the respective Operating Agents, the HPC will produce reports on Annexes such as Annex 17 "Experiences with New Refrigerants in Evaporators" and Annex 20 "Working Fluid Safety."

IEA Heat Pump Programme activities continue through Annexes 16, 18 and 21 as shown in Table 4. A full progress report on Annex 18 is given in the article on page 28. Annex 21 is continuing with the assessment of industrial heat pump potential in its member countries.

Meanwhile, new subjects for IEA Heat Pump Programme Annexes are

being considered. In particular, the proposal for an Annex on natural refrigerants is taking shape. The proposed Annex will concern the design and application of vapour compression systems with ecologically-safe working fluids such as ammonia, propane, butane, water, air and carbon dioxide.

With Norwegian company SINTEF Refrigeration Engineering a potential Operating Agent, the Norwegian National Team is now working on attracting interest from organizations worldwide. The feedback so far suggests that the new Annex should have a practical orientation and should attract direct involvement from industry. Companies with an interest in developing environmentally-friendly heat pump and refrigeration products are encouraged to find out

whether this Annex could be of interest to them. More information can be obtained from your country's delegate to the Executive Committee, your National Team Leader or from the address below. A discussion meeting will be held in the spring and will be open to all interested parties.

The working fluid issue will also be the focus of one HPC workshop this year. Despite its recent withdrawal from the HPC, Sweden will host this workshop which will focus on the practical issues relating to the replacement of CFCs in heat pumps.

(Source: IEA Heat Pump Centre and Mr Rune Aarli, SINTEF Refrigeration Engineering, N7034, Trondheim, Norway. Tel: +47-73-593-929; Fax: +47-73-593-926)

Table 4: Summary of the Annexes.

No.	Annex	Operating Agent	Participants	Start Date	Completion
16	Heat Pump Centre	NL	AT, CA, IT, JP, NL, NO, CH, US	Jan 1990	
18	Thermophysical properties of environmentally acceptable refrigerants	US	AT ¹ , CA, DE, JP ² , NO, SE, UK, US	Dec 1989 Jan 1993	Dec 1992 Dec 1996
21	Global environmental benefits of industrial HPs	US	CA, FR, JP, NL, NO, SE, UK, US	Jan 1992	Dec 1994

Participating countries: Austria (AT), Belgium (BE), Canada (CA), Denmark (DK), France (FR), Germany (DE), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), Spain (SP), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US).

¹Phase one only. ²Japan is the Cooperating Agent of phase 2.

Feedback

The editorial staff of the IEA Heat Pump Centre invites readers who wish to express their views on articles printed in this Newsletter or on heat pump issues in general, to send in letters. Letters which are considered to be of interest to readers will be printed, either in full or in shortened form.

An article by Mr James M. Calm on the global warming impact of chillers in the September issue of the IEA Heat Pump Centre Newsletter provoked a response from Mr Richard S. Sweetser of the American Gas Cooling Center. He emphasizes the danger of comparing gas and electric equipment without a very detailed examination of the resource energy and associated emissions of both electric and gas delivery systems from the mine or well-head to the end-use electrical or gas connection. The main passages from Mr Sweetser's letter are printed below.

Making a fair comparison

End-use efficiency comparison of HVAC unit and system performance needs to be critically analyzed. The energy and HVAC industry is fraught with incomplete, incorrect and advocacy analysis of unit and building performance. Data available to the Cooling Center from US HVAC manufacturers yields end-use efficiency data which differs significantly from that espoused in James Calm's article.

Furthermore, the efficiency and emissions of the electric power system in converting resource energy into end-user electricity impacts a variety of energy use decisions, especially policies concerning the selection of gas-fired versus electrically-powered technologies. Therefore, it is imperative one scrutinizes any attempt at declaring the facts of the matter. It is common to use overall average efficiencies or arbitrary regional averages when calculating the resource energy consumption and resulting emissions for electrically powered equipment.

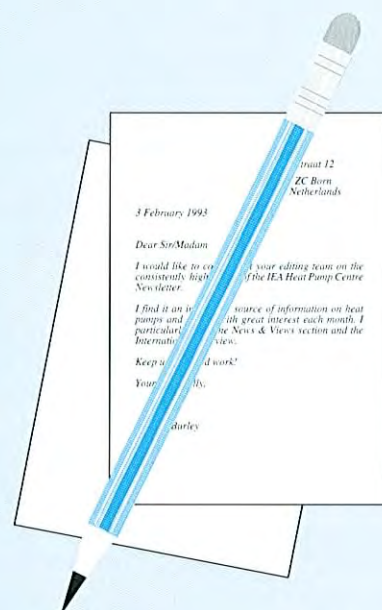
This will lead to incorrect conclusions, especially in the case of highly seasonal loads such as space conditioning. For example, most space cooling energy is consumed when the electric power system is running at high part-load in hot weather. Space heating energy is consumed during cold weather at high or low system part-load,

depending on the geographic region. The overall electric power system efficiencies may be substantially different for these two cases, yet annual average efficiencies are typically used to calculate resource energy consumption. In this time of fierce competition between the electric and gas industries, it is critical that the efficiency of the electric power system be thoroughly understood.

The efficiency of electric power generation, transmission and distribution is impacted by many factors including: type of power plant; system part load; weather conditions; demand; dispatch sequence; standby losses, and type of equipment installed for power plants (e.g. transformers and power lines, both utility and end-user owned and operated).

While some factors are fixed, such as the type of equipment, other factors are dependent on load and weather conditions. For example, gas turbine systems are very sensitive to ambient air temperature. Power line and transformer losses are dependent on the square of the current. These dependencies are lost when overall average efficiencies are used.

Using *specific* power system efficiencies instead of national annual averages will give more accurate results when comparing the resource energy use and emissions of



electric and gas technologies. We anticipate that efficiencies during peak summer generating periods will be well below annual or regional average. If so, this will help support the case for gas cooling, both to end users and to policy makers.

The American Gas Cooling Center is embarking on such a study with the hopes of providing engineers and policy makers who are interested in viewing the cooling portion of energy consumption in isolation from the heating portion. Of course, analyzing the cooling system provides only a portion of the space conditioning profile.

Mr Richard S. Sweetser
American Gas Cooling Center
1515 Wilson Boulevard, Arlington
VA 22209, USA

Heat Pump Working Fluids

An International Overview

Bert Stuij, IEA Heat Pump Centre

One can imagine that CFCs (chloro-fluoro-carbons) were welcomed with delight when they entered the refrigeration market in the 1930s. While refrigerants had previously often been toxic, flammable or both, the CFC 'safety refrigerants' coupled appropriate thermodynamic properties with unprecedented user friendliness. However, the perception of CFCs as benign compounds shifted dramatically in the 1980s, when it became apparent that they damage the stratospheric ozone layer and aggravate the greenhouse effect.

A worldwide quest commenced to find appropriate alternatives for CFCs that would allow continued safe and efficient operation of refrigeration and heat pumping equipment, but would have negligible environmental drawbacks. This article discusses some of the highlights and arguments of this quest. Details on research, regulations and working fluid application trends in individual countries are provided, as well as a general discussion of ozone depletion, global warming and safety, and how these issues have affected the selection of alternatives.

* * *

The ideal heat pump working fluid has to balance challenging demands - it must allow excellent efficiency while posing no risk to either the local or global environment. This means that it should be non-flammable, non-toxic and have a zero ozone depletion potential (ODP) and zero global warming potential (GWP). In addition, the ideal fluid must be cost effective. This is a complex demand indeed, affected by such diverse factors as the price of the fluid, the efficiency it allows, and the required equipment and lubricants.

It is unlikely that the 'ideal fluid' exists. And although research in most countries addresses all demands, there is a notable variation in emphasis from country to country and continent to continent. In North America and Japan, for instance, there is strong emphasis on the immediate safety of refrigerants in the massively applied space conditioning heat pumps. As a consequence there is hesitation to accept some 'natural' fluids such as toxic ammonia or flammable hydrocarbons as replacements. In Europe, on the other hand, where the domestic space-conditioning

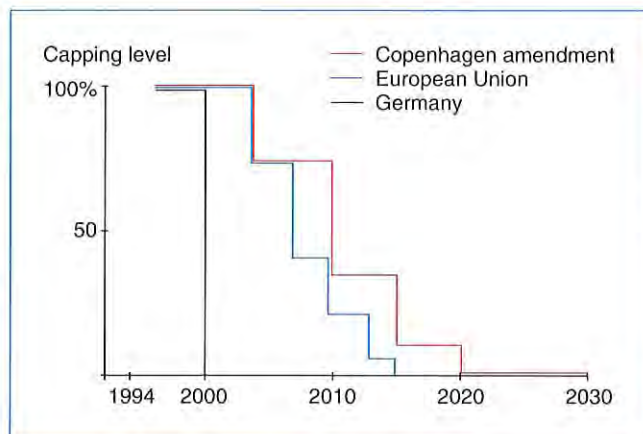


Figure 1: HCFC phase-out regulations.

market is smaller, there is pressure to accelerate the application of natural fluids, because they have no environmental drawbacks. Here it is believed that the safety implication of hazardous refrigerants can be controlled by proper design and use. In developing countries, in this survey exemplified by India and China, the emphasis is different again, as concerns are expressed about the price and availability of suggested alternatives such as HFC-134a, in particular as they have to be combined with expensive and relatively scarce lubricants.

Ozone Depletion

The role of refrigerants in ozone depletion is now an accepted fact. As a consequence, the 1992 Copenhagen Amendments to the Montreal Protocol have stipulated that CFC-12 will no longer be available from the end of 1995, and that HCFCs must be phased out (see Figure 1).

Some countries have decided to impose tighter restrictions on the use of HCFCs. In Germany HCFCs will have to be phased out by the year 2000, in Switzerland by 2005. The environmental ministers of the European Union agreed in December 1993 to recommend an accelerated phase-out schedule to the European parliament, as shown in Figure 1, and there is a distinct possibility that even tighter regulations will follow in Europe, possibly in line with Germany. In the USA, selected HCFCs face early phase-out, notably HCFC-141b. It is possible that the Copenhagen restrictions will be tightened in the future.

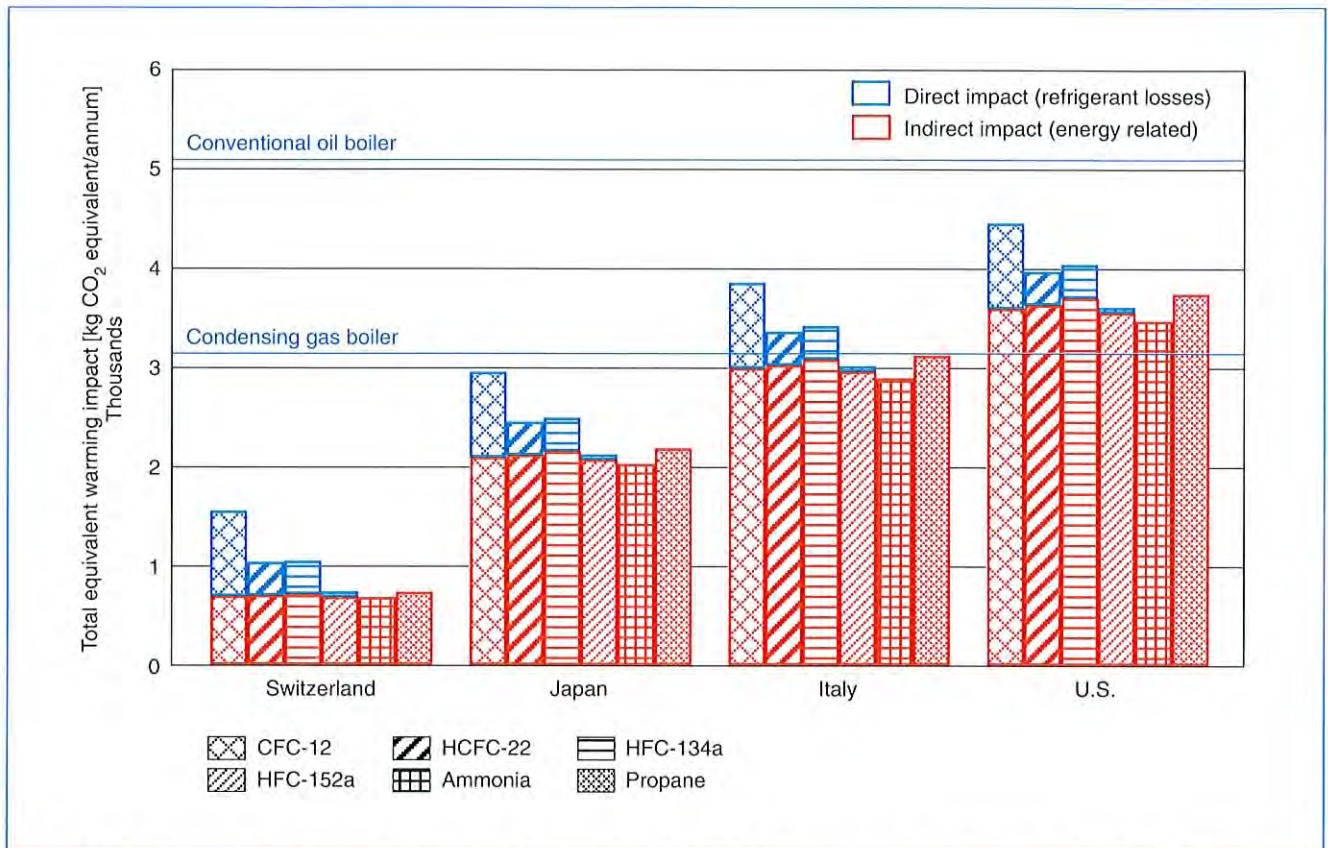


Figure 2: Total equivalent warming impact (TEWI) of a 10 kW heat pump with various working fluids. For comparison the CO₂ emissions from a gas boiler and oil boiler, meeting the same heat demand, are shown.

The strict regulation of HCFCs adds urgency to the search for solutions, since the possibility to use them as 'transition working fluids' diminishes. In any case, developing countries have remarked that the introduction of equipment using HCFCs may be a bad solution for them, because the refrigerants may not be available throughout the long lifetime of the equipment.

Global Warming

The second environmental issue in which working fluids are implicated is global warming. While the use of heat pumps can reduce fuel consumption and the associated CO₂ emissions, many working fluids are effective greenhouse gasses. The loss of working fluids with a GWP during, or at the end of, a heat pump's life compromises its contribution to the mitigation of the greenhouse effect. To allow a balanced assessment the TEWI (total equivalent warming impact) concept was developed. The TEWI is the addition of the direct impact of released working fluids, to the indirect impact associated with the drive energy for the equipment.

Unlike ODP or GWP, TEWI is not a true 'refrigerant property'. Although affected to some extent by working fluid characteristics, it also depends on factors such as equipment design and longevity, leakage prevention, lifetime and, for an electric heat pump

most profoundly, how electricity is generated (coal, oil, nuclear, hydro). By way of illustration Figure 2 shows calculated TEWIs of some refrigerants in a specific type of heat pump operated in different countries. For this figure an integration time horizon of 20 years was used. Assumptions are summarized in Table 1. The efficiencies achievable with working fluids are based on ideal cycle efficiencies (see also *IEA HPC Newsletter*, Vol. 11, No. 2, pp. 24), although this can be misleading. Propane, for instance, has a lower theoretical cycle efficiency than HCFC-22, but generally performs better in real cycles, as its near ideal molar mass allows better compressor performance. For comparison, the graph also shows the warming impact associated with the CO₂ emissions from directly fuelled heaters.

Figure 2 illustrates the obvious notion that the relative importance for global warming of the refrigerant losses reduces as the energy system becomes more fossil based. In Switzerland, for instance, the use of propane instead of HFC-134a reduces the TEWI of the given system by one third. In the USA, the indirect impact dominates, and the difference between HFC-134a and propane is minor. As seen here the total warming impact is dominated by the energy related component. However, depending on the assumed leakage rate, the GWP can remain the single most significant distinguishing factor between the various refrigerants.

USA

Virtually all unitary residential and commercial heat pumps use HCFC-22. Indeed, the USA is the predominant user of this refrigerant (see Figure 3). The most visible research efforts to find a suitable HCFC-22 alternative are performed under the Alternative Refrigerants Evaluation Programme (AREP), coordinated by the Air Conditioning and Refrigeration Institute (ARI). Concerns about the acceptability of flammable refrigerants remain, and although propane is explicitly included in the evaluations, most attention is given to HFC blends. A large number of blends has been reviewed, but research efforts focus on an azeotrope, HFC-32/125 (mass ratios 50/50 and 60/40), and two zeotropes, HFC-32/134a (30/70 and 25/75) and HFC-32/125/134a (30/10/60 and 23/25/52). Most of the alternatives allow efficiencies within 10% of that achieved with HCFC-22. Equipment modifications will be required to make optimum use of zeotropic blends.

University research supported by the Electric Power Research Institute (EPRI) and the Environmental Protection Agency (EPA) has synthesized a number of partially fluorinated propanes plus two- and three-carbon ethers. Eleven of these compounds show potential as substitutes, and their properties suggest that as pure synthesized fluids or blends they could be used for most refrigeration and heat pump applications. The compounds continue to undergo modelling, flammability and toxicity tests.

Increased attention to global environmental issues has raised concern that refrigerants will eventually be regulated by their global warming potential (GWP). The Alternative Fluorocarbon Environmental Acceptability Study (AFEAS), supported by an international consortium of chemical manufacturers, the Department of Energy and the Oak Ridge National Laboratories, put the GWP of refrigerants in context by introducing the total equivalent warming impact (TEWI) concept. The study emphasized that the energy-related emissions of CO₂ are in most cases far more significant than the warming impact of released refrigerants.

Since July 1992 it has been illegal to vent CFCs or HCFCs, which must be recovered or recycled. A number of practical issues still need to be resolved to optimize recovery and recycling in the field. High temperature incineration is the preferred disposal method for chlorine-containing refrigerants that cannot be recycled.

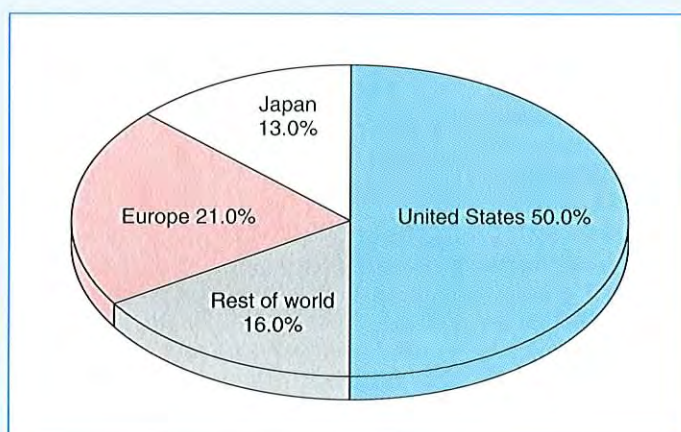


Figure 3: World use of HCFC-22.

Canada

The vast majority of space conditioning heat pumps in Canada use HCFC-22, and that will remain the case for some time. Industrial heat pumps typically used CFC-12, and will use HFC-134a in the future. For the few high temperature CFC-114 heat pumps HCFC-123 may be a medium term replacement.

The National Research Council (NRC) of Canada is involved in a number of working fluid research projects. NRC research has confirmed HCFC-123 as a good candidate for high temperature industrial applications, at least in the medium term. The introduction of HFC-134a is supported by testing programmes and market/feasibility studies, for both domestic and industrial applications, especially drying. R&D projects are evaluating HCFC-22 replacements, including blends containing HFC-32, HFC-143a, HFC-134a or HFC-125.

The University of Moncton is also active in evaluating CFC and HCFC replacements. The Energy Diversification Research Laboratory of Varennes, Quebec, recently initiated a R&D programme to evaluate different working pairs for absorption systems. Venting of refrigerants is prohibited. The Canadian Heating, Refrigeration and Air Conditioning Institute is doing most of the training of HVAC technicians on refrigerant handling in Canada.

The fact that the TEWI is only to a limited extent determined by refrigerant characteristics has made it difficult for policy makers to consider it when making refrigerant regulations. Indeed in some European countries, where concern about the warming impact of some HFCs may result in early curtailment, regulations will be based on GWPs, and not on TEWIs. In Norway and to a lesser extent Germany, HFCs are already viewed as transitional rather than final replacements because of their GWP.

Safety

The introduction of CFCs and HCFCs as non-flammable and non-toxic working fluids has been instrumental in the rapid spread of domestic refrigeration and space conditioning. Especially in North America and Japan it is strongly felt that the refrigerant safety which is now taken for granted should not be given up lightly. Consequently there is a reluctance to propose ammonia and propane as refrigerants, except for those applications where they have traditionally been used - e.g. in industrial cooling or petrochemical process industries. Clearly non-toxicity and non-flammability is in general a requirement for drop-in replacements for equipment designed for non-hazardous refrigerants.

In Europe, most notably perhaps in Norway and Germany, there is a strong feeling that proper engineering can ensure safety, even with a hazardous refrigerant in the system. Risks can be reduced by the design of hermetic minimum-charge equipment, fail-safe venting systems and indirect heat distribution systems (although an efficiency penalty may have to be paid).

Worldwide Search

An enormous effort is underway to find appropriate replacements for CFCs and HCFCs within the time frame imposed by the Montreal Protocol, or by even stricter national regulations. Research institutes, chemical companies and equipment manufacturers have often joined forces to suggest and evaluate cost effective, safe and environmentally acceptable working fluids.

A notable joint effort is the Alternative Refrigerants Evaluation Programme (AREP), in which 37 equipment manufacturing companies from North America, Japan and Europe collaborate to evaluate alternatives for the massively applied HCFC-22, and the common chiller refrigerant R-502. The programme is coordinated by the American Air Conditioning and Refrigeration Institute (ARI), and its results will be universally accessible. Both drop-in replacements and longer term alternatives are scrutinized. Ammonia and propane are included, but toxicity and flammability concerns have focused the attention on HFC blends.

The European Union has initiated a number of research and evaluation programmes in which

Annual heat demand [kWh]:			15000	
Installed heat pump capacity [kW _{heating}]:			10	
Refrigerant leakage [%/Year]:			4	
Refrigerant Properties:				
	Global Warming Potential*		Refrigerant charge [kg/kW _{heating}]	SPF**
	20 yr	100 yr		
CFC-12	7100	7300	.30	3.00
HCFC-22	4100	1500	.20	2.97
HFC-134a	3200	1200	.25	2.91
HFC-152a	510	140	.22	3.03
Ammonia	0	0	.10	3.12
Propane	3	3	.12	2.89

*An integration time horizon of twenty years has been assumed for the calculations for Figure 2.

**SPF: Seasonal Performance Factor, based on ideal cycle efficiencies

Emissions from electricity generation:	
	[kg CO ₂ /kWh]
Switzerland	0.14
Japan	0.42
Italy	0.60
USA	0.72

Gas boiler emissions: 0.21 kg CO₂/kWh

Oil boiler emissions: 0.34 kg CO₂/kWh

Table 1: Refrigerant and system assumptions for TEWI calculations.

research institutes and market parties collaborate. One, 'Replacements for R-12 in Refrigeration Systems' was finalized in May 1993. Another, 'Replacement of CFC's in Refrigeration Equipment by Environmentally Benign Alternatives' is currently ongoing. It includes an in-depth assessment of the applicability of flammable refrigerants.

Within the IEA Heat Pump Programme the behaviour of many new refrigerants has been researched in Annexes 13, 17, and 18. Annex 20 addressed working fluid safety, concluding that 'the risks assigned to working fluids such as ammonia and propane are, in general, grossly exaggerated' (IEA HPC Newsletter, Vol. 11, No. 3, pp. 4). A new Annex on so-called 'natural working fluids' (CO₂, air, water, ammonia, hydrocarbons) was recently proposed by Norway.

The International Institute of Refrigeration (IIR) plays a

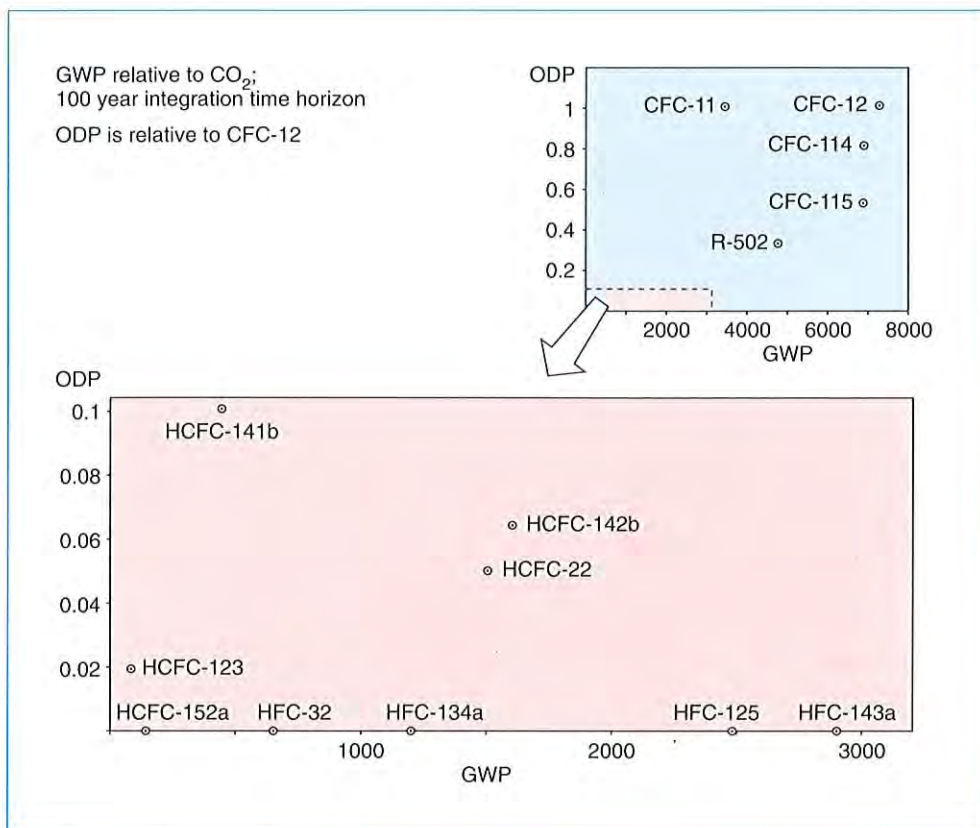


Figure 4: Ozone depletion potential (relative to CFC-11) and global warming potential (relative to CO₂ - 100 year integration time horizon) of refrigerants.

pivotal role in the distribution of results from working fluid research. Through conferences, workshops and publications, the Institute ensures that the most up-to-date information is available to a wide audience.

The parties to the Montreal protocol have set up a multilateral fund to transfer refrigerant technology to developing countries. Projects supported by the fund have included training, and conversion of the domestic appliance sector from CFC-12 to HFC-134a.

Alternatives

HFCs are widely regarded as perhaps the most promising replacement candidates, in particular when refrigerants need to be non-toxic and non-flammable. The GWP of many HFCs under consideration are shown in Figure 4. HFC-blends can be designed to be used in a wide range of applications. Less desirable properties, such as flammability or high GWP can be compensated. HFC-134a is already widely available, and seen as the most appropriate alternative for CFC-12. It is a near certainty that the use of HFC-134a will dramatically increase in the coming years. HFC-152a has a lower GWP, and probably allows a higher equipment efficiency. However, it is moderately flammable and concerns remain about its stability and high temperature behaviour. It will most likely be included in blends, as will HFC-32 which is also flammable. AREP identified several promising blends to replace HCFC-22, notably two zeotropes (HFC-32/

134a and HFC-32/125/134a), and one azeotrope (HFC-32/125).

Two HFCs with a high boiling temperature, HFC-245ca and HFC-356, have been considered as possible long term replacements for CFC-11 in chillers, and CFC-114 in high temperature heat pumps. Very little about their stability, toxicity and GWP is known at this stage. Long term tests at NRC, Canada, have confirmed HCFC-123 as a suitable medium term replacement in these applications.

In the USA, 11 compounds have been synthesized in EPRI-supported university research, mainly in the three-carbon HFC range. Their properties suggest that the pure fluids or their blends can cover a wide range of heat pumping and refrigeration applications. However, the research is at an early stage, and these can only be long term alternatives.

Ammonia is a natural refrigerant with excellent thermodynamic, environmental and economic performance. It is cheap, has a zero GWP and zero ODP, and typically yields a 5 to 10% higher COP than a comparable heat pump with CFCs, HCFCs or HFCs. However, it is moderately flammable, toxic, incompatible with copper, and requires a relatively high pressure for many heat pump applications. (40 bar at 78°C condensing temperature). Ammonia has been used successfully for over a century in many industrial and commercial cooling applications. Recently it has

Japan

International coordination and cooperation in the phase-out of CFCs and HCFCs is viewed as a necessity. Japan has therefore joined a number of international initiatives, such as AREP, the AFEAS, and the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

In Japan itself, 13 equipment manufacturers have initiated the Japanese Alternative Refrigerants Evaluation Programme (JAREP). As with AREP, the aim is to test alternatives for HCFC-22 and CFC/HCFC-502. Efforts are focusing on HFC-134a and HFC blends. Test results will be open to the public. Today, the use of HFC-134a in heat pumps and refrigerators is already accelerating. It is expected, however, that the azeotrope HFC-32/HFC-125 and/or the zeotrope HFC-32/125/134a will be preferred in the future.

In 1990 the New Energy and Industrial Development Organization (NEDO) launched a five-year programme to find a completely new refrigerant for high temperature compression heat pumps, principally as a replacement for CFC-114. The new compound must be non-hazardous, and at least match the performance characteristics of CFC-114. Issues of compatibility with lubricants and materials are being addressed.

China

Domestic working fluid production facilities are available for the production of HFC-134a and HFC-152a. The widespread introduction of HFC-134a is expected to be delayed by the expensive lubricants required. Various HFC and HCFC mixtures are being evaluated. For industrial heat pumps with CFC-12, a mixture of HCFC-22 with HFC-152a is now being considered, since system pressures are often too high with pure HCFC-22. Other CFC replacements (still based on HCFCs) under scrutiny are HCFC-22/142b and HCFC-22/HCFC-142b/HFC-152a. The HFC blends which receive most attention are HFC-32/152a/134a, and HFC-152a/134a. Laboratory tests are being performed on the working pair HCFC-22/DME for hybrid absorption/compression heat pumps.

China receives support through the multi-lateral fund set up by the parties to the Montreal Protocol. Activities to recover used refrigerants are on the increase.

India

Compression heat pumps are reportedly rare. The ones manufactured predominantly use CFC-12. India will endeavour to adhere to the internationally agreed phase-out schedules.

Research on working fluids is performed in the National Chemical Laboratory (NCL), Pune, the Indian Institute of Technology (IIT), Madras, and the Indian Institute of Science (IISc), Bangalore. At NCL mainly theoretical assessments have been made of alternatives for CFC-12 and CFC-114. HFC-134a is recognized as the most developed alternative, but HFC-152a also receives attention because of its superior thermodynamic performance. HCFC-123 was reviewed as a CFC-11 alternative. NCL recently reviewed a large number of HFCs and fluorinated ethers, and recommended the following fluids for further evaluation as CFC-114 alternatives: HFC-143, HFC-236ca, HFC-236cb, HFC-236ea, HFC-236fa, HFC-254cb, and HFE-134. All these fluids promise better COPs than CFC-114. Some new research initiatives are a result of Indo-German collaboration.

been applied in a number of medium to large capacity heat pumps, most notably in Norway, Sweden and Germany. Safe use requires sound engineering, and safety design measures can include enclosure of the heat pump, application of low charge systems, indirect distribution systems, and fail-safe ventilation systems. Environmental pressures are likely to be a strong stimulus for accelerated penetration of ammonia heat pumps.

Hydrocarbons are natural refrigerants that have been used as working fluids for many years, most notably in the petrochemical industry. Propane and propane/(iso)butane mixtures are now emerging as a serious option, in particular for small charge systems, e.g. domestic refrigerators and residential space conditioning heat pumps. In Europe, propane filled refrigerators are rapidly penetrating the market, and German heat pump manufacturers are now selling propane filled

residential units. Propane, a real drop in for HCFC-22, is environmentally benign, and in spite of a lower theoretical cycle efficiency it achieves a slightly higher COP in real systems. Of course it is highly flammable. Proper design measures will have to ensure safety, which can include the application of hermetic low charge systems and the safe location of the propane filled unit.

Environmental pressures will make hydrocarbons serious competitors for HFCs and HFC blends, but regulations and concerns about safety and product liability will slow down or prevent their penetration in many areas.

Other naturals such as CO₂, water and air are also receiving attention. Theoretical studies and prototype tests have shown that the use of CO₂ can be highly beneficial in applications where heat is absorbed at a

Austria

CFCs have been prohibited in new equipment since January 1992. CFC-12 and CFC/HCFC-502 have mainly been replaced by HCFC-22, and to some extent by HFC-134a. Very limited work on the HFC blends offered by the chemical industry is carried out in Austria at this moment. Manufacturers are hesitant because of the variety of mixtures proposed, the lack of information on composition, and the uncertainty about material and lubricant compatibility. In view of these uncertainties, the 'old' natural refrigerants receive renewed attention. In medium-sized and large-scale applications, ammonia is gaining an increasing share of the market. Propane is being studied as a refrigerant for small domestic heat pumps. There is confidence that the safety aspects in small systems can be handled, and regulations preventing more widespread application are being reviewed. Tests on direct expansion ground coupled systems using propane give promising results.

Germany

To find a replacement for HCFC-22 is a matter of tremendous urgency in Germany, since the use of this refrigerant will be prohibited from 1 January 2000. The search for alternatives is complicated by the fact that German concern about the global warming impact of some HFCs is rapidly growing. Many of the HFC blends proposed are therefore viewed with reservation. Yet HFC-134a will be an important refrigerant in many applications in Germany for the foreseeable future. Appropriate lubricants have been developed, and issues such as material compatibility have been solved. Intensive research is ongoing to find non-hazardous, low GWP HFC blends to replace HCFC-22 and R-502.

At the same time, interest in hydrocarbons and ammonia is growing. It is believed that the safety implications of these working fluids can in general be controlled by proper use and careful engineering. Refrigerators with a propane/iso-butane mixture, the development of which was initiated by Greenpeace, are now sold by all leading German manufacturers. Small domestic space conditioning heat pumps with propane as working fluid are on the market. A 100 kW heat pump in a swimming pool was recently converted to propane, with a charge of some 20 kg.

The long term trend is towards natural refrigerants, primarily ammonia and hydrocarbons, and for specific situations CO₂ and water. HFCs will play an essential role for some time to come, but are in Germany already viewed as a transitional rather than long term solution for many applications.

Greece

Computer simulation programs for new refrigerants such as HFC-134a, -152a and -125 are being developed at the University of Athens. Support in the transition to alternatives is provided by ELKEPA, the Greek productivity centre. Training courses, and items such as recovery units, HFC-134 charge cylinders and leak detectors are available. The heat pump manufacturer Interklima SA is collaborating with the University of Athens to develop small space-conditioning heat pumps with HFC-134a. Greece is expected to support European Union phase-out regulations.

constant temperature, and released with a temperature glide. Examples are district heating heat pumps and water heating heat pumps. Water is a good refrigerant for high temperature applications (evaporation above 90°C). An air cycle heat pump is currently being developed with European Union support. A significant amount of development work is still required to reach an acceptable COP with the system. In general it can be said that environmental pressures and safety concerns favour these alternatives. However, none of them is near maturity at this stage, and they should be viewed as medium to long term alternatives.

Better Placed

Regulations imposed through the Montreal Protocol have led to an impressive worldwide drive to find suitable replacements for CFCs and HCFCs. HFCs are widely viewed as promising alternatives. Non-toxic and non-flammable pure HFCs and blends which are now available allow continued use of conventional vapour compression technology. In some areas,

notably in Europe, it is felt that the global warming potential of most HFCs compromises their quality as long-term alternatives. Here, the interest in the so called 'natural refrigerants' is growing.

The argument that substances such as ammonia and propane cannot pose an environmental threat because they occur in nature sets them apart from all synthetic alternatives. And experience shows that the performance of heat pumps using such refrigerants is at least adequate. Environmental concerns are therefore certain to favour their application, but the question is whether the toxicity and flammability risks can be contained and accepted.

It is not surprising that this continuing debate and the ensuing uncertainty is reported to have hampered the penetration of heat pumps as an environmentally benign technology to some extent. However, the enormous amount of working fluid research will almost certainly result in heat pumps that are better placed to take on the environmental challenges of the 21st century.

Italy

Extensive research is ongoing on new working fluids and unconventional working pairs for absorption equipment. In the field of compression systems, ENEA (Agency for New Technology and the Environment) is evaluating the performance of new compressors operating with HFC-134a, in collaboration with a heat pump manufacturer. Italian manufacturers are preparing to switch away from HCFC-22. HFC-134a is considered the most important alternative. ENEA has been cooperating with an Italian company to realize effective recovery and regeneration systems

Norway

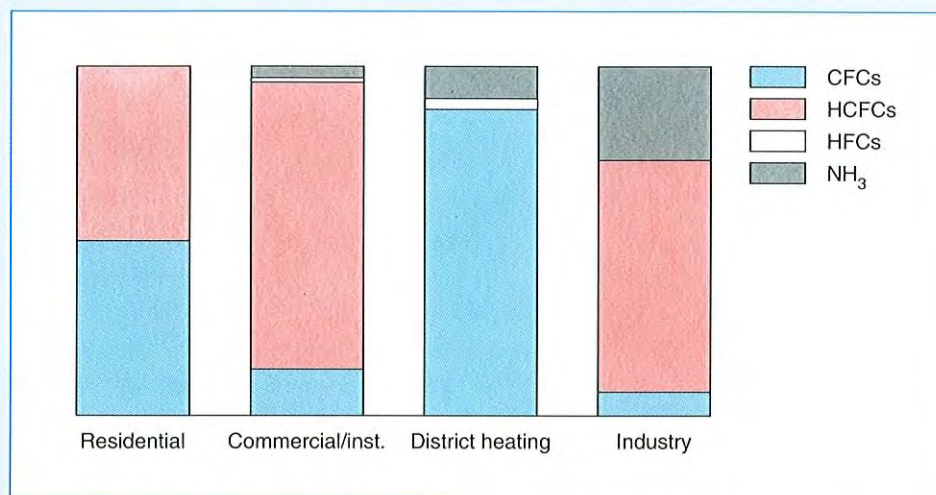


Figure 5: Working fluids used in installed heat pumps in various market sectors in Norway (percentage in each market sector).

An indication of the current use of working fluids in the various market sectors is provided in Table 2 and Figure 5. In new heat pump installations, HCFC-22 and HFC-134a dominate the residential and commercial/institutional sector, while ammonia is used in large heat pump installations. Blends are mainly applied when retrofitting existing heat pump and refrigeration plants using CFC-12 or R-502.

For the future the focus is on the utilization of natural substances as working fluids, mainly ammonia, flammables (eg propane) and carbon dioxide (CO₂). Research and development activity is currently concentrating on low-charge ammonia heat pump systems and compact heat pumps with propane as working fluid. Design rules for heat pumps using ammonia or flammables are being worked out. A high-efficient air-conditioning system for automobiles using carbon dioxide as working fluid has been developed. Carbon dioxide is also considered as a very promising working fluid in various refrigeration systems and larger heat pump installations. Eight heat pump installations using ammonia, propane, HFC-134a and HFC-152a are currently being monitored. The heat pumps are installed in commercial/institutional buildings, district heating systems, ice rinks and industry, and their thermal output range from about 30 kW to 2,500 kW.

January 1991 CFC-regulations ban the sale or installation of any heat pump with CFCs. From 1 January 1995 it will be impossible to buy any "new" CFC in Norway, but small amounts of recovered/recycled CFC will be on the market during a transition period. It is already mandatory to return CFCs from scrapped or retrofitted heat pumps and refrigeration installations. In 1992, the total CFC consumption for recharging refrigeration plants and heat pumps was about 200 tonnes. Up to spring 1993, 20 tonnes of CFC was collected, of which about 50% was destroyed. It is expected that tighter regulations regarding HCFC-22 will be imposed, probably including the prohibition of its use in new heat pump and refrigeration installations.

Market Sector	CFCs (tonnes)	HCFCs (tonnes)	HFCs (tonnes)	NH ₃ (tonnes)
Residential	5	5	0	0
Commercial/institutional	25	150	0.1	2
District Heating	20	0	0.2	2
Industrial	5	50	0	20
Total	55 (20%)	205 (72%)	0.3 (0.1%)	24 (8%)

Table 2: Working fluids used in installed heat pumps in various market sectors in Norway (tonnes).

Netherlands

The Netherlands is participating in a number of international working fluid research projects. Reflecting the small compression heat pump market, most of the research is refrigeration- oriented. The Dutch Organization for Applied Scientific Research, TNO, and the chemical company, AKZO, took part in the European project 'Replacement of CFC-12 in Refrigeration Systems', in which extensive tests were performed on HCFCs, HFCs, propane and CO₂. As elsewhere, HFC-134a is recognized as a good replacement candidate for CFC-12, and TNO has initiated a programme for optimizing it's use in a number of practical refrigeration applications. HFC-blends are being researched as HCFC-22 alternatives, and ammonia cooling installations for supermarkets will be developed and tested in 1994. TNO participates in the recently launched European research programme 'Replacement of CFC's in Refrigeration Equipment by Environmentally Benign Alternatives', and specifically addresses the implications of the use of flammable refrigerants in this context. An air cycle heat pump is under development, and extensive attention is given to sorption systems. Water/Na₂S absorption equipment is undergoing field tests, and advanced ammonia/water absorption heat pumps are now commercially available.

Switzerland

Most domestic heat pumps are installed with HCFC-22, but some already use HFC-134a. Hydrocarbons are increasingly viewed as attractive alternatives, although still mainly in the research and test phase. German split heat pumps with propane in the outdoor unit will be put on the market in 1994. Large-scale industrial heat pumps now generally use HFC-134a. Figures 6 to 8 show trends for the use of CFC-12, R-502 and HCFC-22.

Research efforts in Switzerland address a relatively wide range of alternatives, including HFC-134a, HFC blends, as well as ammonia and hydrocarbons. In the Laboratoire d'Energetique Industrielle, Lausanne, for instance, heat transfer characteristics of HFC-134a, HCFC-123 and some HFC blends are being researched. At the same time a 3.5 MW ammonia heat pump is being analyzed, and air-to-water heat pumps with propane and HFC-134a are being tested. At INFEL, Zürich, a bivalent heating system has been developed with a propane air to water heat pump and a wood furnace.

With CFCs phased out in Switzerland from 1 January 1994, urgent research for a replacement of R-502 has been taking place at Scheco AG, Winterthur. HP-62, a blend of HFCs 134a, 125 and 143a has been confirmed as the most suitable replacement. HCFCs may no longer be applied from 1 January 1996 where suitable alternatives are available. The latest phase-out date for HCFCs is currently 1 January 2005.

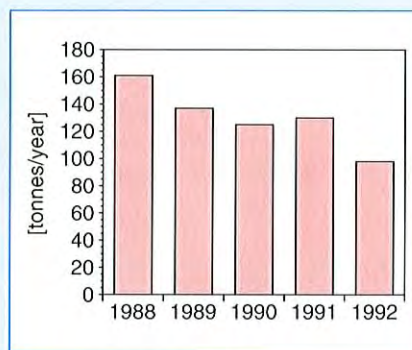


Figure 6: Use of CFC-12, Switzerland.

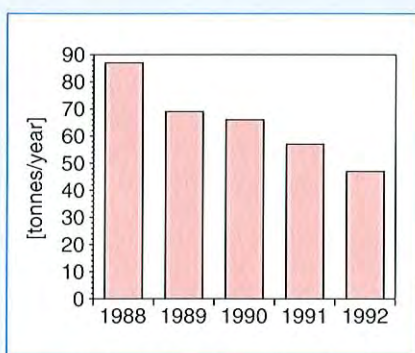


Figure 7: Use of R-502, Switzerland.

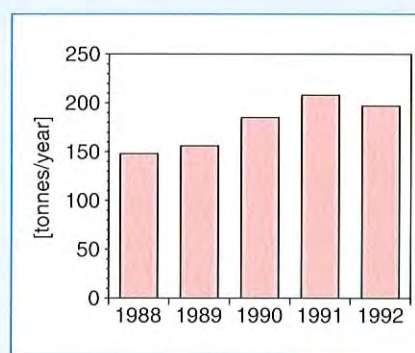


Figure 8: Use of HCFC-22, Switzerland.

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AREP's Compressor Calorimeter and System Drop-In Tests

David S. Godwin, USA

The phase-out of the production of HCFC-22 scheduled for the year 2020 will require manufacturers of heat pump equipment to find suitable alternatives for this widely-used refrigerant. In fact, HCFC-22 is the most widely used refrigerant in the US. The R-22 Alternative Refrigerants Evaluation Program (AREP) was established by the Air-Conditioning and Refrigeration Institute (ARI) to assist manufacturers in obtaining performance data on a multitude of HCFC-22 and R-502 alternatives.

Two steps in AREP are the testing of compressors and unmodified systems with the alternative refrigerants. Results from some of these compressor calorimeter and system "drop-in" tests conducted as part of AREP are summarized and evaluated in this article. Capacities and efficiencies achieved with the alternative heat pump working fluids are examined as a ratio to those achieved with the baseline refrigerant (HCFC-22 or R-502).

Several alternatives are found to perform almost as well as, and sometimes better than, the baseline refrigerant, in compressors and/or systems not optimized for the alternative. No single alternative appears as a universal replacement for either HCFC-22 or R-502.

* * *

Heat pump equipment manufacturers from around the world are currently working cooperatively to assess the performance of several non-ozone depleting refrigerants as potential replacements for HCFC-22 and R-502 (a blend of CFC-115 and HCFC-22), as part of the R-22 Alternative Refrigerants Evaluation Program (AREP). The purpose, organization and test plan established under AREP were explained in IEA Heat Pump Centre Newsletter Vol.10, No. 3 [1].

Manufacturers participating in AREP have voluntarily tested several refrigerants (see Table 1) in equipment designed for HCFC-22 or R-502. Results from compressor calorimeter and system drop-in tests of some of these refrigerants are summarized below. The discussion presented is not meant to provide a comprehensive analysis of all the results received; rather, it is a brief summary of results from some of the more

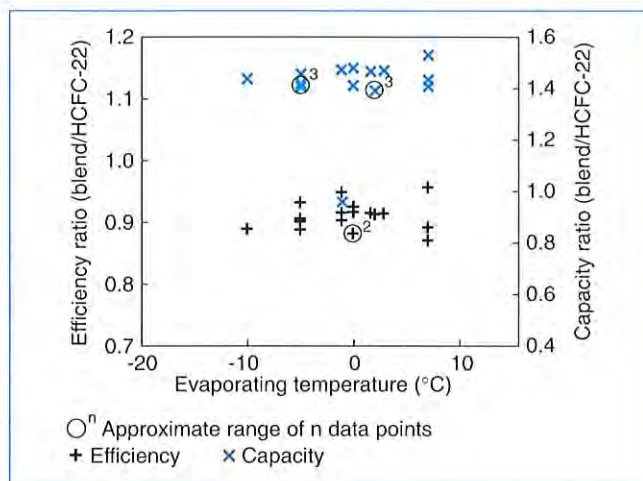


Figure 1: Compressor Calorimeter Results of R-32/125 (60/40).

widely-tested working fluids suggested to replace HCFC-22. A review of compressor calorimeter and system drop-in results of all the refrigerants tested under AREP can be found elsewhere [2,3]. Also, a set of all approved AREP compressor calorimeter and system drop-in reports, is available to the public [4].

Compressor Calorimeter Results

R-32/125 (60/40)

Figure 1 shows the capacity and efficiency achieved with various HCFC-22 compressors using this HFC blend, over a range of evaporating temperatures and at condensing temperatures of either 130°F (54.4°C) or 55°C (131°F). Both performance parameters are normalized by taking a ratio of the performance achieved with the blend, divided by that achieved with the baseline refrigerant, HCFC-22.

It can be seen that capacities with this blend are approximately 40 to 50% higher than HCFC-22 at the condensing temperatures shown. Efficiencies are about 5-10% below those achieved with HCFC-22.

These data come from several different manufacturers testing different sizes and types of compressors. The normalized results show good agreement. There are, however, two outlying points worth noting. Two capacity ratios are below 1.0, far below the general trend. This occurred because the compressors used to obtain these data points were altered - the displace-

HCFC-22 replacements		R-502 replacements
HFC-134a	R-32/134a [40/60]	R-125/143a [45/55]
propane (R-290)	R-125/143a [45/55]	R-125/143a [50/50]
ammonia (R-717)	R-32/125/134a [10/70/20]	R-32/125/134a [10/70/20]
R-32/125 [50/50]	R-32/125/134a [23/25/52]	R-32/125/134a [20/40/40]
R-32/125 [60/40]	R-32/125/134a [24/16/60]	R-32/125/143a [10/45/45]
R-32/134a [20/80]	R-32/125/134a [25/20/55]	R-125/143a/134a [44/52/4]
R-32/134a [25/75]	R-32/125/134a [30/10/60]	
R-32/134a [30/70]	R-32/125/290/134a [20/55/5/20]	

Notes:

- Refrigerants are not listed in any particular ranking order
- Compositions are nominal and do not include deviations of charged or circulating compositions from nominal.
- All compositions are HFCs apart from R-290 and R-717

Table 1: Alternative refrigerants tested as part of AREP. Percentage composition by weight is shown in [].

ment was intentionally reduced, by about a third compared to HCFC-22. As expected, this brought capacities down to about par with the baseline.

R-32/125/134a (30/10/60)

This HFC blend shows quite similar performance to HCFC-22. Figure 2 shows results from reciprocating, rotary, and scroll compressors of various sizes. Although capacity ratios seem to drop off at lower evaporating temperatures, they still remain very close to unity. Efficiency ratios are also close to 1.0 at the US 7.2°C/54.4°C (45°F/130°F) rating point. More scatter is seen at lower evaporating temperatures, but efficiencies still remain close to HCFC-22.

R-32/134a (30/70) & (25/75)

In general, both the efficiency and the capacity of the 30/70 HFC mixture are slightly lower than HCFC-22. For instance, at the US 7.2°C/54.4°C (45°F/130°F) rating point, the efficiency ratios tend to be slightly below unity, and the capacities are about 2 to 8%

worse than HCFC-22. Both capacity and efficiency ratios tend to suffer at lower evaporating temperatures.

In general, data for this blend from Japanese manufacturers seem to show slightly lower performance than comparable data from US manufacturers. This is not necessarily due to the equipment tested, but may be because the US and Japanese companies used differing sets of basic thermophysical data to calculate performance.

Concern over flammability led some companies to test a 25/75 mixture of this blend. Efficiencies with the less flammable composition were similar to the 30/70 mixture. Capacities, on the other hand, were somewhat lower than the 30/70 mixture.

System Drop-In Results

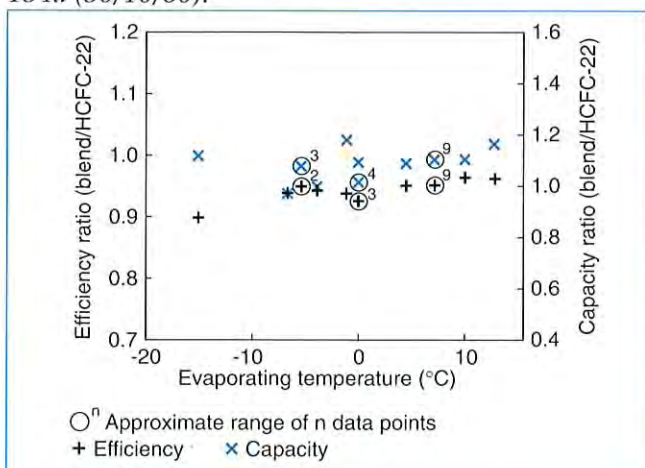
R-32/125 (60/40)

Figure 3 shows the results achieved with this HFC mixture in several different HCFC-22 systems, tested in the cooling and/or heating mode. There is a large amount of data showing system capacities with this blend to be about the same as with HCFC-22, in both the cooling and heating modes. These data come from tests where the compressor motor speed was altered (i.e. reduced) in an attempt to match capacity to that of HCFC-22. Higher capacities were seen in tests of systems without the motor speed modified.

Efficiencies in the heating mode were similar to those of HCFC-22. In the cooling mode, efficiencies are typically 10 to 20% below HCFC-22, although there were four tests which showed improved efficiency ratios. A cooling-only window unit, however, performed significantly worse in terms of efficiency.

Figure 3 indicates that efficiency decreases as capacity increases in both the heating and cooling modes, near capacity ratios of 1.0 (i.e., with modified compressor

Figure 2: Compressor Calorimeter Results of R-32/125/134a (30/10/60).



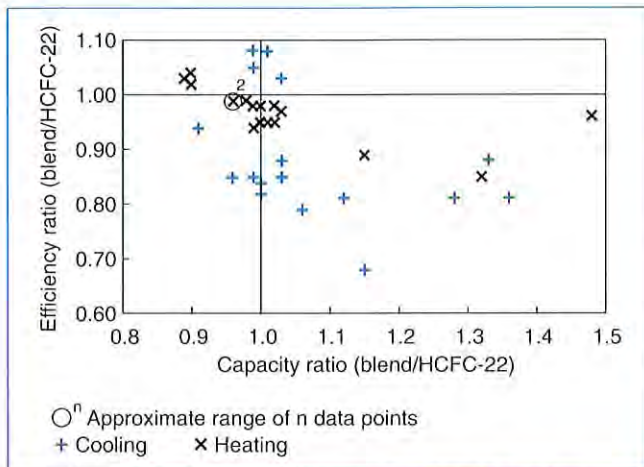


Figure 3: System drop-in tests of R-32/125 (60/40).

motor speeds). Although only limited data is available, this trend does not seem to hold true in the range of higher capacity ratios (although the efficiency ratios are somewhat lower than those achieved with the modified systems). This may be an indication that capacity and efficiency ratios in these tests are largely dependent on the system tested.

R-32/125/134a (30/10/60)

The majority of the data shows cooling capacities with this HFC mixture within $\pm 4\%$ of HCFC-22, and heating capacities between 2% below and 3% above the baseline (see Figure 4). This is similar to the AREP compressor calorimeter results, which also showed capacity ratios of approximately 1.0. Drop-in tests of a cooling-only window unit, however, showed capacity drops of 5 to 10%.

Efficiencies in both the cooling and heating modes were generally below the HCFC-22 baseline. A 5 ton (17.6 kW) ducted split-system heat pump fared slightly better than the other equipment, with efficiencies greater than HCFC-22 in the cooling mode, and only 3% below HCFC-22 in the heating mode. This and the window-unit tests suggest that performance results may be highly dependent on the type of equipment tested, in addition to the testing conditions.

Another outlying data point on Figure 4 comes from a test of a one horsepower (746 W) rotary-driven split-system heat pump. This unit required defrosting during the heating mode. With this defrosting cycle considered in the calculations, the capacity and efficiency ratios were only 0.87 and 0.84, respectively. Not including the defrosting cycle in the calculations, however, raised the capacity ratio to 1.01 and the efficiency ratio to 0.94.

R-32/134a (30/70) and (25/75)

In the heating mode, capacities with the 30/70 HFC blend ranged from 9% below, to 3% above the

baseline, and efficiencies were between 11% below, and 2% above HCFC-22. Capacity ratios for equipment using the 30/70 HFC mixture in the cooling mode were usually slightly below the baseline (ranging from 0.92 to 1.01). Cooling efficiencies were generally below the baseline also, in the range of 0.88 to 1.03.

Two tests with the 30/70 blend, however, showed worse performance in the cooling mode. One comes from the only drop-in chiller test with this blend. This chiller achieved a cooling capacity and efficiency (compared to HCFC-22) of only 86% and 79%, respectively. The other outlying point comes from a test of a water-source heat pump, whose capacity and efficiency ratios were 0.86 and 0.82, respectively. However, changing the amount of charge used increased these performance values to 0.95 and 0.98.

Capacity ratios with the 25/75 mixture in both the heating and cooling modes were somewhat lower than those of the other mixture. Efficiencies, on the other hand, improved slightly compared to the 30/70 mixture.

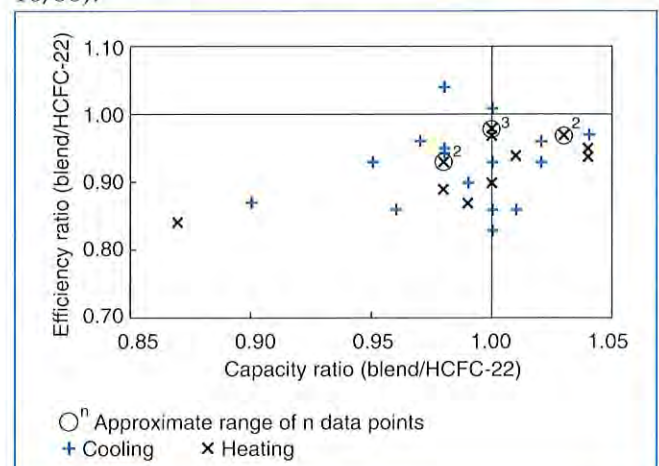
HFC-134a

In addition to being tested as a component of several blends, HFC-134a as a pure refrigerant has been proposed as an alternative to HCFC-22, primarily for use in chillers. Data were received from test reports covering several types of chillers and also some split-system heat pumps. Results are shown on Figure 5.

Data from the chiller drop-in tests showed fairly consistent results. In cooling, efficiencies were close to the baseline, ranging from 92 to 102% of HCFC-22, but capacities fell far short, reaching only 63 to 70% of the capacity achieved with HCFC-22. The chillers were not tested for heating performance.

Data from the split-system heat pumps were far more scattered. When run at the same motor speed,

Figure 4: System drop-in tests of R-32/125/134a (30/10/60).



efficiencies were higher than HCFC-22, by as much as 20%. These tests, however, showed capacities 20 to 30% below HCFC-22. Capacities were improved by increasing the motor speed with HFC-134a, but these increases in capacity were accompanied by losses in efficiency, in both cooling and heating.

Findings

The results above show that there are several non-ozone depleting working fluids whose performance approaches that of HCFC-22. Some of the refrigerants shown in Table 1 can equal or better the capacity and/or efficiency of HCFC-22 in the same compressor and/or system.

There may also be other viable candidates that were not looked at by AREP. In no way should the list of AREP refrigerants be considered a definitive list of all the possible HCFC-22 and R-502 replacements.

No Obvious Choice

Based on this work, there is no obvious choice of one refrigerant to replace HCFC-22 or R-502. In fact, it is likely that marketplace forces will support different refrigerants for various applications.

There is good agreement in the compressor calorimeter data, between different manufacturers, test locations, and types of equipment. Although we do see some scatter, there are only a few instances where the differences are extreme, and those instances can be explained. Of course, presenting results normalized to baseline refrigerants eliminated some of the variability between tests. But the consistency in the compressor results is also due to the efforts of the AREP participants in conducting their tests under standardized conditions.

In many cases the system drop-in results show good agreement, despite the fact that different types and sizes of equipment were tested by different manufacturers using different testing facilities. However, there is a significant amount of scatter in much of the data, indicating that the results from drop-in tests, even when normalized to baseline performance, are often dependent on the piece of equipment tested and the conditions at which the tests were performed.

The results reviewed above were measured in non-optimized HCFC-22 compressors and systems; therefore, even better performance is expected in actual equipment designed to use those alternative refrigerants. Participating companies will design and build systems "soft-optimized" for a particular refrigerant as part of AREP, but full optimization will be left to individual companies.

Much Needed Data Through Cooperation

The AREP effort so far has been a success. The program has provided much-needed data on several HCFC-22

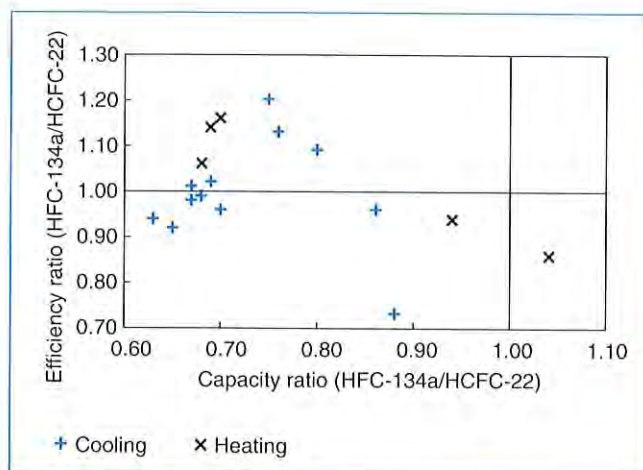


Figure 5: System drop-in tests of HFC-134a.

and R-502 alternatives in an efficient manner. This data will be useful to manufacturers in supplementing other available data on the performance of alternative working fluids, as well as confirming the results of their own tests. In addition, these performance results, along with future performance results and information on a host of other issues such as flammability, toxicity, availability, etc., will assist manufacturers in deciding which refrigerant(s) to pursue for use in their equipment.

But perhaps the most significant accomplishment of AREP has been the recognition by the international heat pump industry that, even in a very competitive environment, there are often advantages in cooperation.

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Japanese Programmes Examine Existing and New Compounds

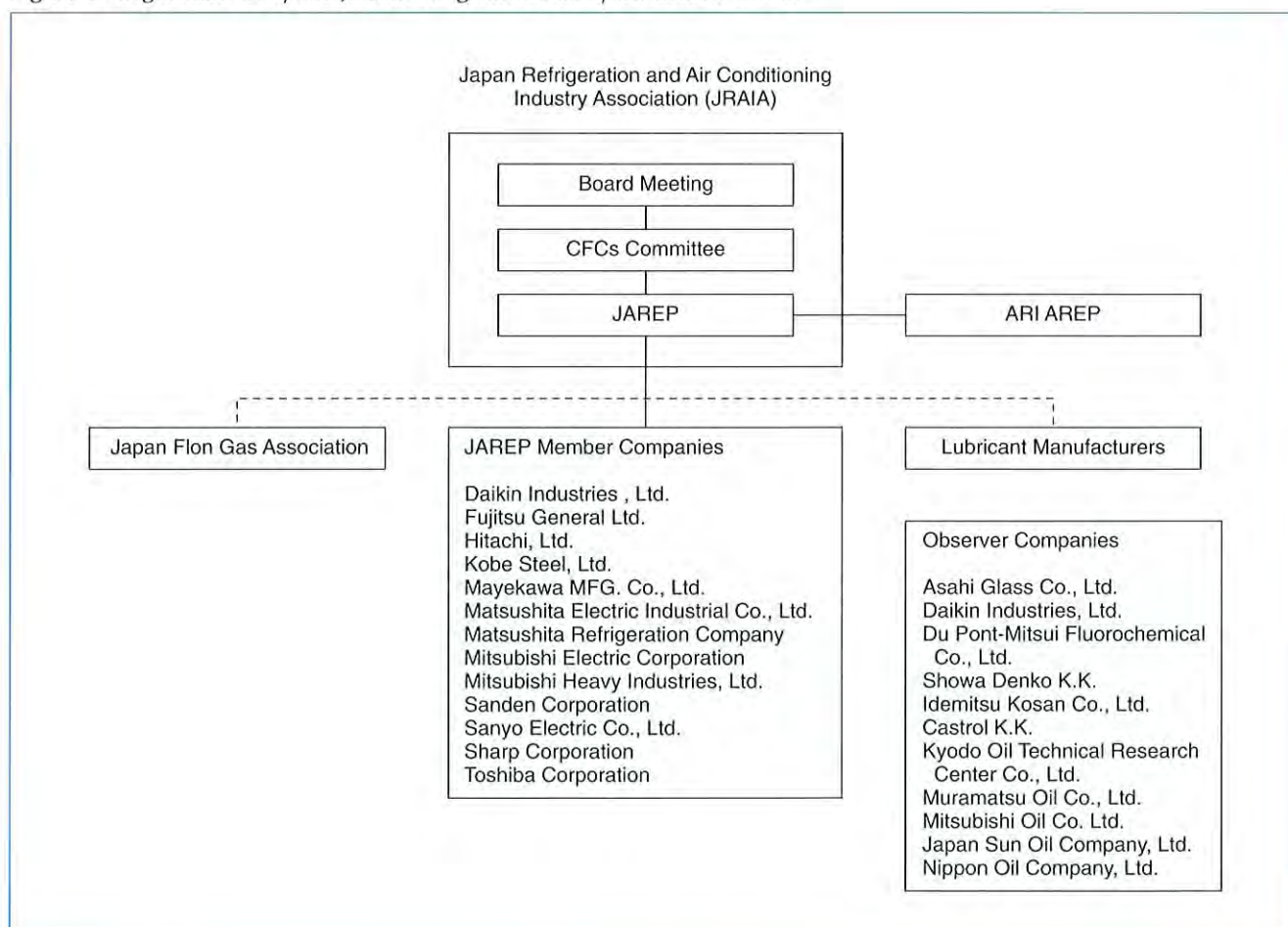
Elisa Boelman, Japan

This article looks at two ongoing R&D programmes in Japan, which aim to find alternative refrigerants to CFCs and HCFCs. One programme is looking at blends of existing refrigerants while the other is intent on developing a completely new refrigerant. Tests on blends using existing heat pump equipment have not yet indicated a high performance refrigerant, and flammability questions remain unanswered. In the quest for a new refrigerant, computer design tools have streamlined the evaluation process which now focuses on about 70 synthetic compounds.

JAREP

The Japan Alternative Refrigerants Evaluation Programme (JAREP) was established in March 1992 by the Japan Refrigeration and Air Conditioning Industry Association (JRAIA). Thirteen member companies and 12 non-member observers are cooperating in the programme as shown in Figure 1 [1]. JAREP is coupled with a similar programme, AREP, organized by the American Air-Conditioning and Refrigeration Institute (ARI). Data from JAREP tests will be supplied to the Institute for inclusion in ARI's Refrigerant Database (ARTI). It is hoped by JRAIA that broad publication of the findings of JAREP will contribute to improved

Figure 1: Organization of the JAREP Programme as of 26 March 1993.



Baseline Refrigerant	Alternative Refrigerants	Composition (Weight %)	Compressor Tests	System Tests
HCFC-22	HFC-32/134a	30/70	3 HP rotary (1) 1 HP rotary (5) 3/4 HP rotary (1) 5 HP scroll (1) 3 HP scroll (1)	3 HP split heat pump (1) 1 HP split heat pump (6) (all above rotary) 5 HP split heat pump (1) 3 HP split heat pump (2) 40 HP chiller (2)
HCFC-22	HFC-32/134a	25/75	1 HP rotary (1) 3 HP scroll (1)	1 HP split heat pump (5) 3 HP split heat pump (1)
	HFC-32/134a	35/65		1 HP split heat pump (1)
HCFC-22	HFC-32/125	60/40	1 HP rotary (3) 3/4 HP rotary (1) 5 HP scroll (1)	1 HP split heat pump (6) 3 HP split heat pump (2) 40 HP screw chiller (1)
HCFC-22	HFC-32/125/134a	30/10/60	1 HP rotary (4) 5 HP scroll (3) 3 HP scroll (1) 1 HP scroll (1)	1 HP split heat pump (rotary) (9) 5 HP split heat pump (1) 3 HP split heat pump (2) 1 HP split heat pump (all above scroll) (1)
R-502	HFC-125/143a	45/55	5 HP scroll (1)	5 HP air-cooled cond. unit (1) 1 HP air-cooled cond. unit (1)
R-502	HFC-125/143a/134a	44/52/4	5 HP scroll (2)	3HP condensing unit (1) 5HP water-cooled cond. unit (2)
	HFC-32/125/134a	10/45/45		1 HP condensing unit (2)
HCFC-22, CFC-12	HFC-134a		1 HP rotary (2) 3 HP rotary (1) 1179 cc screw (1) 150 HP screw (1) 30 HP reciprocal (1)	1 HP split heat pump (3) 3 HP split heat pump (1) 40 HP screw chiller (4)
The numbers in brackets refer to the number of manufacturers who are testing each product. 1 HP (Horsepower) = 750 W				

Table 1: JAREP evaluation tests as of 11 May 1993. As shown, refrigerants are tested in different compressors and in various systems.

developments in alternative refrigerants and technologies. A brief review of the JAREP programme is presented in the following paragraphs.

Candidates

Since JAREP activities are scheduled for completion by the end of 1995, its members must evaluate as many refrigerants as possible over a very limited period. The alternative refrigerants now being tested by JAREP members are shown in Table 1 [2]. In order to facilitate an effective exchange of results with the American Air-Conditioning and Refrigeration Institute, most blends correspond to those being tested in the AREP programme. A few exceptions are HFC-143a (being tested by JAREP only), as well as propane, ammonia and HFC-32/227ea, which are excluded from the JAREP programme [3].

Tests

During the preliminary evaluation stage to be completed in February 1994, tests are being carried out on unmodified products from manufacturing lines. Manufactured compressors are thus undergoing compressor calorimeter tests, and refrigeration or air-conditioning systems are being used for system performance tests. In the second evaluation stage to be completed in December 1995, similar tests will be performed on "soft-optimized" compressors and systems. In order to make up for the differences of some alternative refrigerants to the baseline ones for which the equipment was originally designed, the test equipment is optimized by means of slight modifications. Due to time constraints, it was decided to do a "soft optimization" with currently available production-line components rather than carry out an ideal optimization. Compressor modifications involve

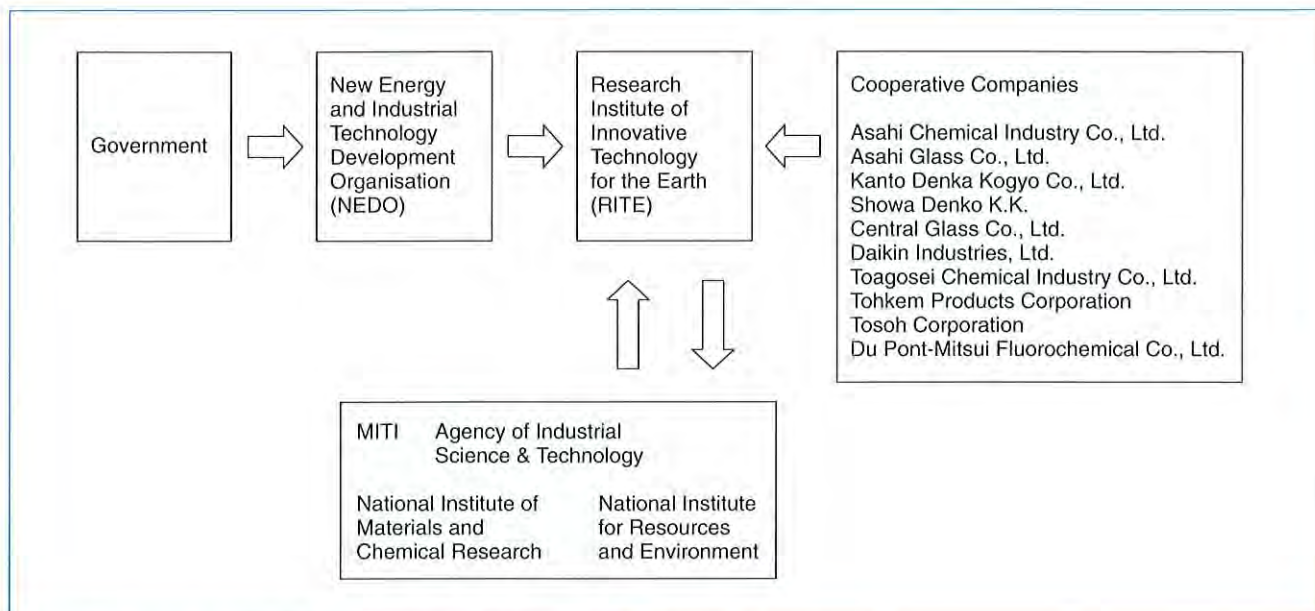


Figure 2: Organization of the Advanced Refrigerant Development Programme.

displacement changes and lubricant selection, and system modifications concern the compressor, flow control, heat exchanger, refrigerant charge, and injection of gas and liquid.

Achievements

A preliminary database of thermophysical properties for the blends being tested by JAREP has been tentatively made, but still has to be revised for better accuracy. Also, flammability testing procedures and definitions have yet to be settled. The experimental results obtained so far have not yet shown a high performance alternative refrigerant. For example, a zeotropic blend resulted in a COP and heating capacity above that of the HCFC-22 baseline, but a cooling capacity below the baseline. An azeotropic blend, HFC-32/HFC-125 (60/40 wt%), slightly exceeded the baseline cooling capacity and COP, but resulted in a discharge pressure increase of more than 1 MPa. Given these results, tests on ideally optimized products may still be required for a final evaluation.

New Refrigerants

In the latter half of 1990, the New Energy and Industrial Development Organization of Japan (NEDO), launched a programme aimed at developing a new compound [4-5], with a completely new molecular structure, as a CFC-114 replacement for compression type heat pumps. Figure 2 [6] illustrates the organizational structure of the five-year research programme. Performance requirements for the newly developed refrigerant include not only a low ODP and GWP, but also a boiling point appropriate for the utilization of industrial waste heat between 30°C and 60°C as an alternative energy source with compression heat pumps. The compound should also be stable in

the high-temperature range between 100°C and 150°C, with high thermal efficiency (comparable to or better than CFC-114), non-flammability and safety. A further requirement is the availability of lubricant oil with good mutual solubility, in particular at high temperatures. Since these requirements cannot be met by existing CFC substitutes, a completely new compound needs to be developed. The following paragraphs present a brief overview of the scope and main results achieved so far by the programme [7].

Molecular Design

The search for a new advanced refrigerant can be streamlined if the relationship between the properties and chemical structures of existing compounds is known. To this end, a database on fluorine compounds containing oxygen, nitrogen, sulphur and silicon was established, but hardly any information could be found on the prospective compounds searched for. Therefore, most of the database consists of test results (such as thermophysical properties, COP, toxicity, GWP etc.) obtained for synthesized compounds and organized for use in molecular design.

Other molecular design tools developed in the programme include numerical estimation methods of compound properties, so that time-consuming and expensive testing can be streamlined. As a result it became possible, for example, to estimate the infrared absorptivity of theoretical compounds from their structural formula. Given that low infrared absorptivity also means a low global warming potential (GWP), prospective refrigerants can be screened for their GWP without having to be synthesized for testing. Estimation methods have also been developed

for the lifespan of compounds in the atmosphere and for refrigerant thermodynamics (PTX and Mollier diagrams, cycle performance, thermophysical properties etc).

Synthesis and Testing

From the above-mentioned molecular design studies, about 300 types of ether, alcohol, nitrogen and silicon compounds were selected as candidates for synthesis. After consideration of equipment and processes requirements, about 70 types of compounds were synthesized. Measurements were then carried out to evaluate their basic thermophysical properties, such as boiling point, specific heat, viscosity, thermal and electric conductivity, flammability etc.

Safety and Environmental Impact

Newly developed compounds must meet safety and environmental impact requirements in order to qualify as suitable advanced refrigerants. Given the importance of toxicity requirements, preliminary tests were performed on the new compounds for skin irritation and propensity to accidents, as well as toxicity upon ingestion and aspiration. Since the new compounds are chlorine-free and thus have zero ozone depletion potential (ODP), the main concerns in terms of environmental impact are their GWP and atmospheric lifespan, which can be evaluated from the reaction rate of the compound with hydroxide radicals in the atmosphere.

Further Work

With eight patent applications filed from 1990 to 1992, the subsequent stage of the programme involves further narrowing down of the choice of compounds and evaluating their performance as refrigerants through test plant experiments.

Conclusion

Both programmes described in this article represent ongoing efforts to find and develop environmentally benign and technically viable alternative refrigerants. Despite the difficulties and uncertainties presently involved, it is hoped that a concerted effort will eventually lead to the determination of superior alternative refrigerants.

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Annex 18: An International Study of Refrigerant Properties

Mark McLinden, USA

Data on the thermophysical (thermodynamic and transport) properties of heat pump working fluids are essential to bring alternative refrigerants to commercial reality. This article highlights the activities of Annex 18 "Thermophysical Properties of the Environmentally Acceptable Refrigerants", which was established in 1990. The objectives of the Annex are to foster coordination and cooperation among researchers in this field and to determine thermophysical properties leading to internationally accepted formulations for the leading alternative refrigerants. Tasks in support of these goals have included surveys of research, compilations of data, evaluations of equations of state, and the preparation of properties bulletins for HFC-134a and HCFC-123. The Annex has recently entered its second phase with an emphasis on HCFC-22 alternatives.

* * *

Annex 18 of the IEA Heat Pump Programme was established to consider the thermophysical properties of the leading alternative refrigerants. The thermodynamic (or equilibrium) properties of the refrigerant largely determine the theoretical energy efficiency and heating or cooling capacity of the vapour compression cycle and are thus the key data needed in designing equipment and in comparing one working fluid with another. The transport properties have a major impact on equipment design (particularly of heat exchangers) and thus influence whether it is economically feasible to build a machine which can actually approach the theoretical efficiency of the thermodynamic cycle.

The objectives of the Annex are (a) to provide a forum for the exchange of information and data and for the coordination of activities on the thermophysical properties of environmentally acceptable refrigerants and (b) the determination (including experimental measurements, and the evaluation and correlation of data) of the thermophysical properties of these fluids leading to the publication of a comprehensive, internationally accepted properties bulletin. Tasks in support of these objectives are described in the next section and include surveys of current research and compilations and evaluations of available literature data and equations of state. Eight countries have participated in the activities of the Annex as indicated in Table 1; in addition to the official members,

observers from France and Russia have attended meetings. The National Institute of Standards and Technology (NIST) in the US acts as the Operating Agent.

The Annex had its genesis in a suggestion made at the "IEA Seminar on the CFC Problem," held in May 1988 in Rome, that it would be valuable to the refrigeration industry to have a project to collect and evaluate the property data on the "new" refrigerants that were just then becoming available. The US prepared proposals for a new Annex on this subject; these were submitted to the IEA Heat Pump Programme Executive Committee in October 1988 and June 1989. An informal meeting of several experts in thermophysical properties held in September 1989 at the ASHRAE CFC Technology Conference in Gaithersburg, Maryland, USA resulted in a third proposal for an Annex. The key change in the third proposal was a call for a task-sharing basis for the Annex; this proposal was given preliminary approval in December 1989 and final approval on 17 March 1990.

In addition to other IEA Annexes, there are ample precedents in the field of thermophysical properties which can serve as models for international cooperation. Perhaps the most relevant is the International Association for the Properties of Water and Steam (IAPWS), which regularly brings together property experts for the exchange of information; IAPWS also officially sanctions formulations for the properties of water and steam. Like IAPWS, the activities of Annex 18 are of interest primarily to properties specialists, but the ultimate outputs of both organizations (i.e., property formulations which are accepted as international standards) are intended to serve a very broad audience of practicing engineers. In contrast to many other Annexes, the task-sharing basis of Annex 18, as well as the rapidly changing field of the alternative refrigerants, means that the emphasis is on the reports and other contributions of

Table 1: Annex 18 member countries.

Austria ¹	Canada	Germany
Japan ⁴	Norway ²	Sweden
United Kingdom	United States ³	
¹ Member only of Phase I of the Annex		
² Joined Annex April, 1993		
³ Operating Agent		
⁴ Cooperating Agent Phase II		

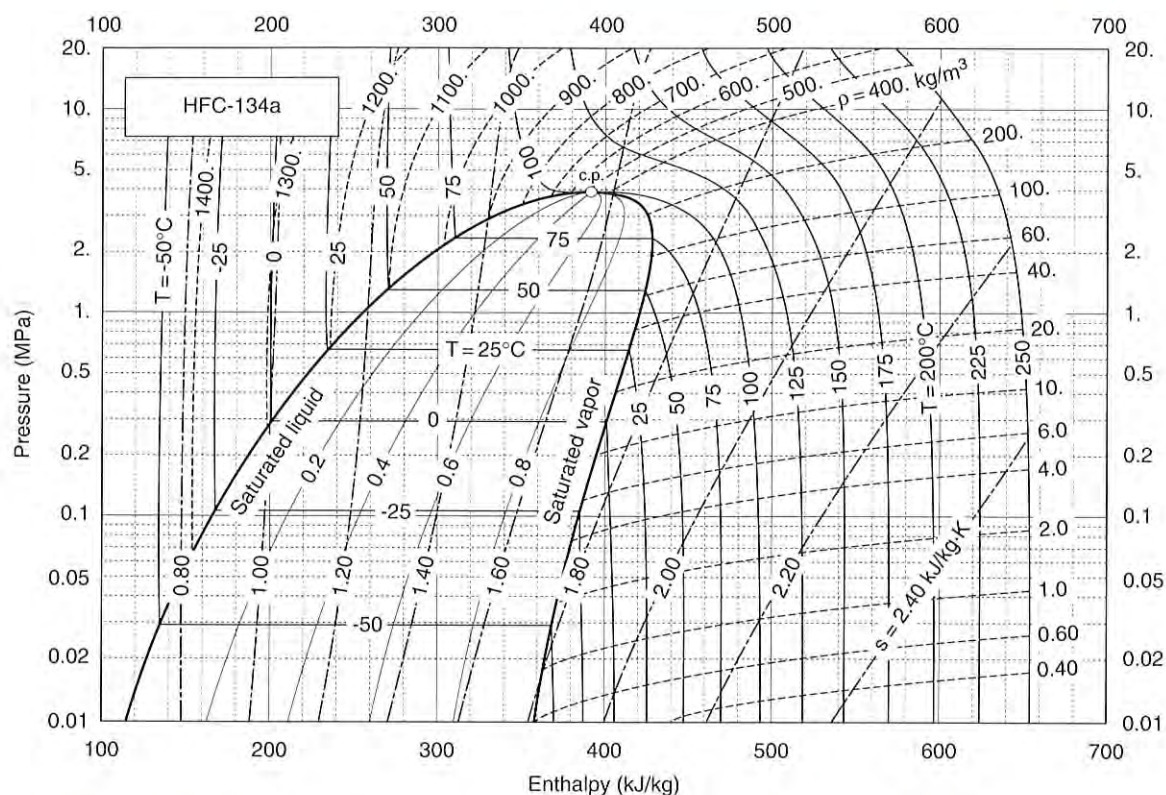


Figure 1: Pressure-enthalpy diagram of HFC-134a.

the individual participants rather than a single final report prepared by the Operating Agent.

The initial focus of the Annex involved the two leading alternative refrigerants, HFC-134a and HCFC-123. In October 1992 the Annex was extended for a second three year term. Alternatives to HCFC-22, and particularly refrigerant mixtures, will be the focus of this second phase. Japan has taken a lead role in organizing these tasks and serves as Co-operating Agent for Phase II of the Annex.

Technical Highlights

The ultimate goal of the Annex is the development of property formulations for the alternative refrigerants that would become international standards. The steps necessary to achieve this are: (1) collection of raw data; (2) evaluation of the quality of these data to arrive at an agreed-on data set for a given fluid; (3) selection of the property model which is best able to fit the data set; (4) publication of a properties bulletin. Tasks associated with these steps are described below. Further details were presented at the 4th IEA Heat Pump Conference by McLinden and Vamling [1].

Surveys of Research

Cooperation and coordination among the participants requires, first of all, knowledge of what others are doing. Towards this end, two surveys of current research on the measurement and modelling of refrigerant thermophysical properties have been carried out. The first survey was conducted in late 1990 with a report published in June 1991 [2]. Responses were received from 61 research groups in 15 countries and provided details for ongoing or planned work on the full range of thermodynamic and transport properties on more than a dozen pure refrigerants and two dozen mixtures. An update of this survey was undertaken in late 1992 with a report to be published in early 1994 [3]. For both surveys, Japan, the United Kingdom, and the United States conducted the survey, with the US acting as overall coordinator.

Compilations of Data

Complementing the surveys of current research are compilations of literature data. The data revealed in these compilations form the basis for modelling and correlation work and also feed into the database task described below. Japan, Sweden, and the United

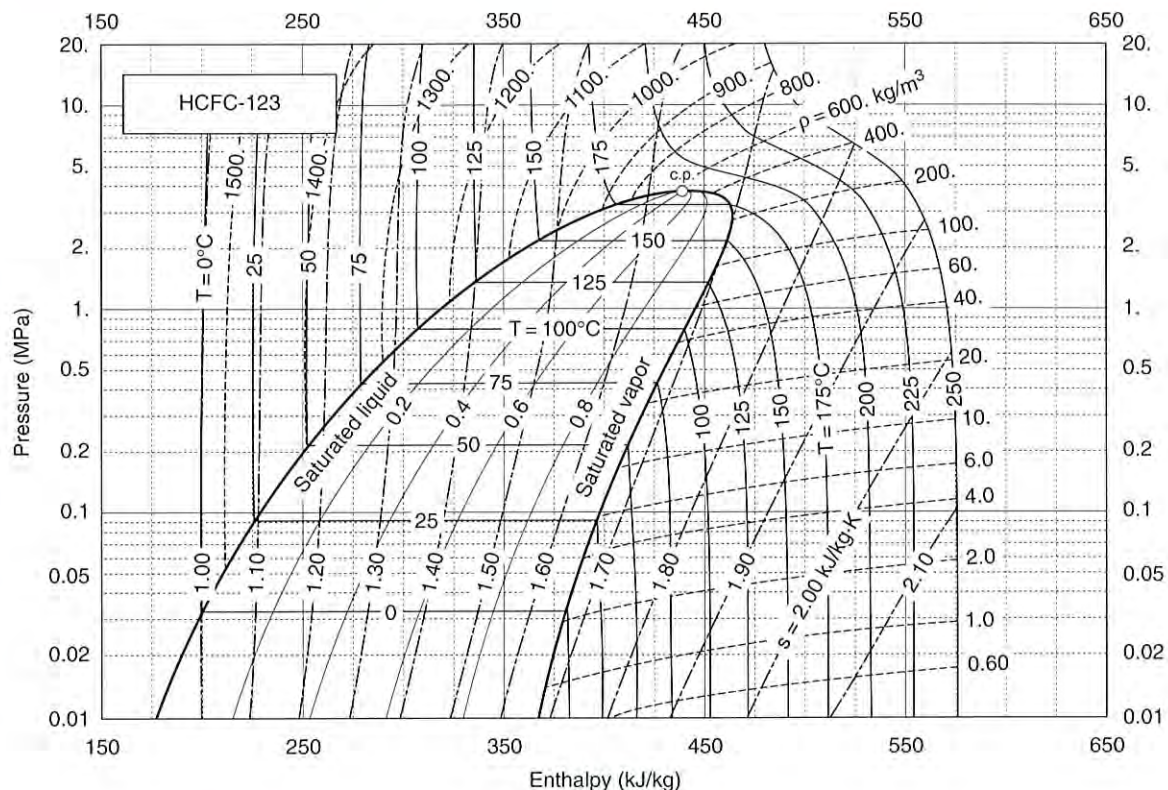


Figure 2: Pressure-enthalpy diagram of HCFC-123.

States are compiling thermodynamic data; Canada and Japan are responsible for the transport property data. This task has taken the form of periodic reports to the Annex. For the evaluation of HFC-134a and HCFC-123 data and equations of state (described below), computer diskettes containing all the experimental data points were distributed.

Database

A database has been established to support the other tasks in the Annex. The refrigerant database builds on a database of transport properties established 10 years ago at the University of Stuttgart. It uses a commercial database management system and runs on a work station. The database includes information on the experimental uncertainty as well as all experimental points and full bibliographic information. Data, both from the literature and received directly from other Annex participants in electronic form, is now being entered into the database. It currently includes over 1000 references. Annex participants can request specific information from the database; the results of the search (literature citations, data, etc.) are returned by E-mail or diskette.

Equation-of-State Evaluation

Given the importance of HCFC-123 and, especially, HFC-134a, it is not surprising that a tremendous quantity of property data has become available in a very short time. This abundance of data has, in turn, given rise to a number of equations-of-state for each of these two fluids. It was desirable to settle upon a standard formulation for use by the refrigeration industry, and the Annex participants decided to select an existing equation-of-state rather than attempting to develop yet another one. The comparison and evaluation of the available equations-of-state were assigned to two independent groups or "evaluators" in the US and the UK. The evaluators presented their preliminary evaluations at the July 1992 meeting of Annex 18. At that meeting, the Annex made recommendations for further comparisons and evaluations and also decided to allow revisions to the equations and additions to the data sets being reviewed, subject to a submission deadline of December 1992. Four of the equations were revised after the July meeting, at least in part in response to the preliminary comparisons; thus, this process has resulted in improved equations for these two leading alternative refrigerants. The final recommendations of the evaluators were presented at the April, 1993

meeting of the Annex. "Scientific papers" to be submitted to the *Journal of Chemical and Physical Reference Data* will detail the selected equations of state: that of Tillner-Roth and Baehr [4] for HFC-134a and the equation of Younglove and McLinden [5] for HCFC-123. These equations of state are to form the basis for international properties bulletins.

Properties Bulletins

The authors of the "winning" equations-of-state for HFC-134a and HCFC-123 will coordinate the preparation of the respective properties bulletins. These bulletins, which will be published by the International Institute of Refrigeration to provide the widest possible distribution, will consist of a brief synopsis of the experimental data and equations along with pressure-enthalpy and temperature-entropy charts and extensive tables. Figures 1 and 2 show pressure-enthalpy diagrams.

In addition to the thermodynamic properties calculated from the equation of state, the transport properties will also be included. The HFC-134a properties will be based on the work of Krauss et al. [6]; the HCFC-123 transport properties are still in preparation. A lack of comprehensive data for HCFC-123 and significant discrepancies between different data sets for HFC-134a preclude an "international standard formulation" designation for the transport properties, but the consensus of the Annex participants was to include the best available data in the bulletins with a "provisional" designation.

Phase II Tasks

The second phase of the Annex, which will conclude in March, 1996, will focus on HCFC-22 alternatives and, in particular, refrigerant mixtures which might serve as HCFC-22 replacements. Phase II tasks will include an investigation of mixing rules and the establishment of a reference mixture and agreed-upon data set for evaluating mixture equations-of-state. The multitude of (constantly changing) hydrofluorocarbon (HFC) mixtures currently proposed as HCFC-22 alternatives precludes the same sort of "Refrigerant Olympics" as was conducted for HFC-134a and HCFC-123, but the Annex does hope to make some definite, but general, recommendations on various mixture models. An assessment of the state of the art of pure HFC-32 and other HCFC-22 alternatives will also be prepared.

There is also considerable interest in ammonia and the other "natural refrigerants" (such as carbon dioxide and the simple hydrocarbons). The US is now conducting a comprehensive survey and assessment of the current data for ammonia; it will serve as the starting point for defining possible tasks on ammonia. Two of the Annex participants from Germany and the UK have developed correlations for ammonia transport properties in recent years and will look into the possibility of updating these works. Finally, the

newest Annex member, Norway, will likely contribute work on the hydrocarbons and/or carbon dioxide.

Spirit of Cooperation

Annex 18 has brought together experts in refrigerant thermophysical properties in the spirit of international cooperation. The Annex has conducted surveys of research and compilations of data which have surely hastened, and made more efficient, the determination of the properties of the alternative refrigerants. An impartial evaluation of equations of state for HFC-134a and HCFC-123 has resulted in the selection of formulations for these fluids which are expected to become internationally accepted standards.

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Testing the Available Alternatives

An Examination of HFC-134a, HFC-152a and Propane

Thomas Ebner and Hermann Halozan, Austria

The imminent ending of CFC production and the possibly quickening pace of the HCFC phase-out schedule has made the testing of the available alternative refrigerants for heat pumping equipment a priority item. At the Graz University of Technology a series of tests have compared the performance of CFC-12 and HCFC-22 with the available alternatives.

HFC-134a and HFC-152a were considered to be the main candidates as replacements for CFC-12, although it now emerges that HFC-152a will be withdrawn from the market for flammability reasons. For HCFC-22, only propane can be considered to be available, as the compositions of the mixtures provided by the chemical industry have yet to be finalized. The performance tests showed propane to be a real drop-in replacement for HCFC-22 and, despite its flammability, the prospects for future applications look promising.

* * *

Under the Copenhagen (1992) amendment to the Montreal Protocol, CFC production will terminate on January 1st 1995 and HCFC consumption will be capped from January 1st 1996, to a level set by the CFC and HCFC consumption in 1989. In Austria, this means that HCFC-22 consumption must now be reduced since the major contribution to the phasing out of CFCs was a change to HCFC-22. Consumption will then be further restricted under the phase-out schedule of the Montreal Protocol or by the accelerated schedule of the European Union (formerly the European Community). This scenario has made consideration of the available alternatives to CFC-12 and HCFC-22 an urgent priority.

CFC-12 Alternatives

CFC-12 was the main refrigerant for medium-temperature applications up to 80°C, including both large district heating systems and small equipment such as hot water heat pumps.

The alternative provided by the chemical industry is HFC-134a. HFC-134a is a hydrofluorocarbon, it is chlorine-free and has a zero, or near zero, ozone depletion potential (ODP). The global warming potential (GWP) is relatively high. New systems can be

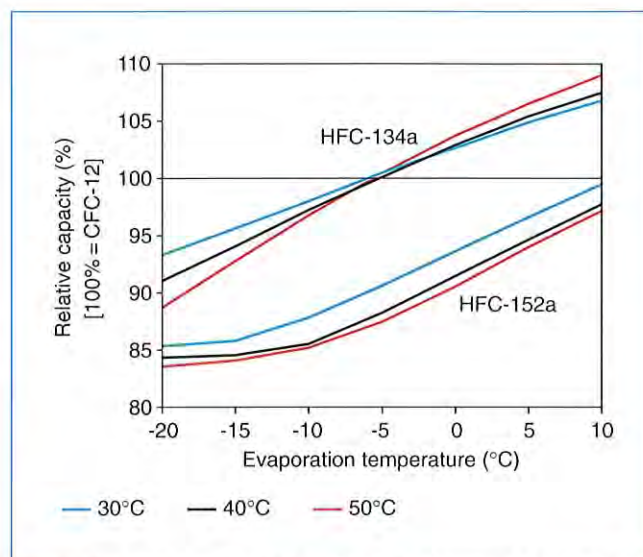


Figure 1: Cooling capacity of HFC-134a and HFC-152a relative to CFC-12.

equipped with HFC-134a, but retrofitting of existing systems still causes problems - systems with fully-hermetic compressors seem to be impossible.

One problem with HFC-134a is that it is incompatible with conventional mineral oils and requires a poly-alkylene glycol (PAG) or ester-based lubricant. These synthetic oils are much more expensive than the traditional lubricants and require careful handling to avoid water entering the system. PAG-lubricants are extremely hygroscopic and were not used in the tests described in this article after a compressor was damaged.

A second alternative for CFC-12 is HFC-152a, well known as one of the components of the azeotropic mixture R-500. HFC-152a is also chlorine free. It has a much lower GWP than HFC-134a and can be used with a conventional lubricant. Recently, however, it appears that HFC-152a will not be sold as a refrigerant, because it is flammable and does not match the requirements of a "safety" refrigerant.

HCFC-22 Alternatives

Finding an alternative to HCFC-22 is a real problem. The pure fluids developed by the chemical industry

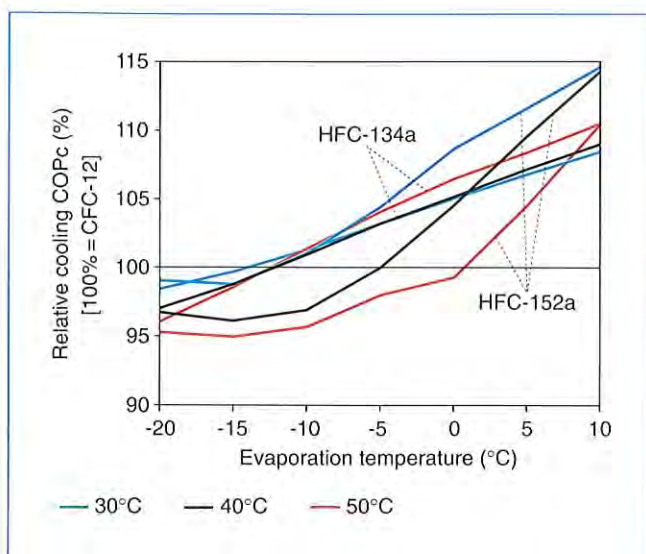


Figure 2: Cooling COP of HFC-134a and HFC-152a relative to CFC-12.

can be characterized as follows: If they are good refrigerants they are flammable, if not, they are safe.

This has meant that the chemical industry must offer mixtures, where flammability of one excellent component is suppressed by another component of worse performance. The majority of these mixtures comprise non-azeotropic blends of two to four components. The final composition of these mixtures will not be fixed until more is known about factors such as efficiency, lubricants, material compatibility and flammability. Possible decomposition due to leakages at different stages of the refrigerant cycle must also be studied. Equipment for these mixtures must be designed to accommodate temperature glide.

The other possibility is to change back to the old "natural" refrigerants like ammonia, propane, propane/butane blends or carbon dioxide (see the article on page 22). While the hydrocarbons are flammable and ammonia is toxic, these natural refrigerants have many advantages with respect to environmental protection: they have always played a role in our biosphere and they exhibit zero ODP and zero or negligible GWP.

Ammonia has an increasing share in new equipment, and developments are going on to reduce refrigerant charge. But ammonia requires a different technology using non-conventional hermetic compressors and no copper. For retro-fitting and the adaption of currently available technology, propane and mixtures of propane and butane are a good choice even if they are flammable (the flammability limit of propane is 0.043 kg per m³ air).

Test Programme

Since 1991, a test programme has been carried out at the Institute of Thermal Engineering in the Graz

University of Technology to compare CFC-12 with HFC-134a and HFC-152a, and HCFC-22 with propane. Prior to the tests, a database for determining the thermophysical properties was established and extensive computer modelling runs were carried out. The tests followed the rules of German standards DIN 8977, 8973 and 8928 and were carried out in the Institute's climate chamber.

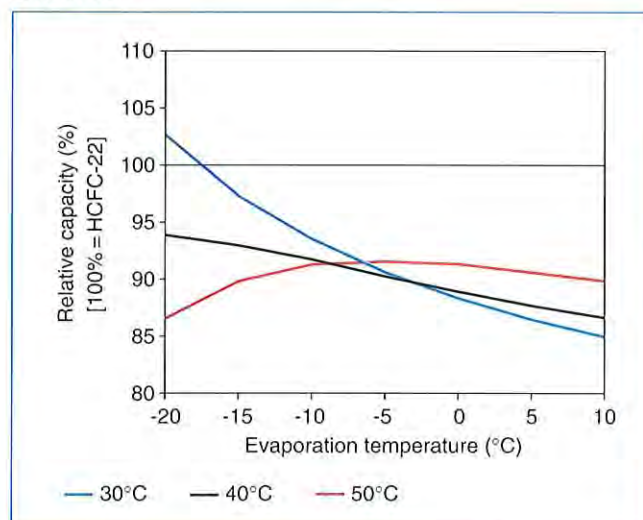
All test runs used the same compressor: a separated-hood hermetic compressor manufactured in Graz. A rigorous procedure was followed to avoid inaccuracies and to allow damage, such as to the copper plating, to be detected.

Between test runs with different refrigerants, the compressor was disassembled, cleaned and serviced in the factory. Furthermore, the test rig was cleaned to avoid the interaction of different refrigerants and lubricants. All temperature, pressure and mass-flow sensors were calibrated before measurement.

HFC-134a and HFC-152a

Cycle calculations showed that, comparing CFC-12 with these two alternatives, HFC-152a is the most efficient refrigerant; HFC-134a is in some applications as good as CFC-12, in the lower temperature region it is worse. The tests carried out gave similar results. As shown in Figure 1, the cooling capacity of HFC-152a is lower than that of CFC-12, while the cooling capacity of HFC-134a exceeds that of CFC-12, at evaporation temperatures above 5°C. Figure 2 shows that both refrigerants achieve a better COP than CFC-12 at higher evaporation temperatures. The high COP of HFC-134a is apparently due to the excellent lubricating properties of the ester-based oil (the tests with CFC-12 and HFC-152a were made with a conventional mineral-based oil).

Figure 3: Cooling capacity of propane relative to HCFC-22.



Propane

Looking only at the thermodynamic properties, cycle calculations identify HCFC-22 as a better refrigerant than propane. However, when transport properties are used in a compressor model, the situation changes, and propane performs better than HCFC-22. This is due to the smaller molar mass of propane which results in reduced pressure losses in the cycle.

Another advantage is that the discharge temperature is much lower with propane than with HCFC-22, so a one-stage system can cover a higher temperature lift. Furthermore, the refrigerant charge can be reduced by about 50% compared with HCFC-22. This is important with respect to flammability.

The same result was achieved by the test procedures. Figure 3 shows that the cooling capacity of propane is lower than that of HCFC-22. This reduction ranges from 0 to 15%, depending on the pressure ratio; the average is about 10%. This small reduction means that propane can be used for the majority of existing systems as a drop-in. For new systems, the investment costs for propane systems will not be higher than for HCFC-22 systems. Figure 4 shows that the cooling COP of propane is higher than for HCFC-22 (4% on average). By optimizing the circuit, this value can be increased further.

Discharge temperatures with propane are considerably lower than with HCFC-22, as shown in Figure 5. These temperatures were measured directly in the cylinder head of the compressor at the outlet valve and can be up to 40 K higher than the temperatures measured at the exhaust pipe, depending on the design of the compressor. Propane systems can thus operate under conditions for which an HCFC-22 system would risk compressor damage when using conventional mineral-based oils.

Figure 4: Cooling COP of propane relative to HCFC-22.

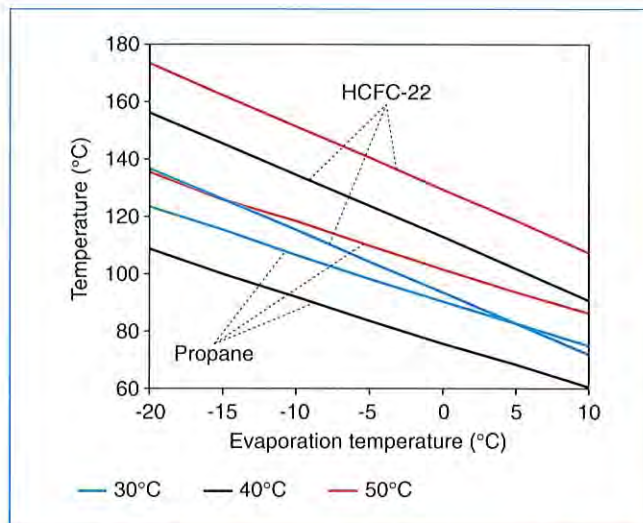
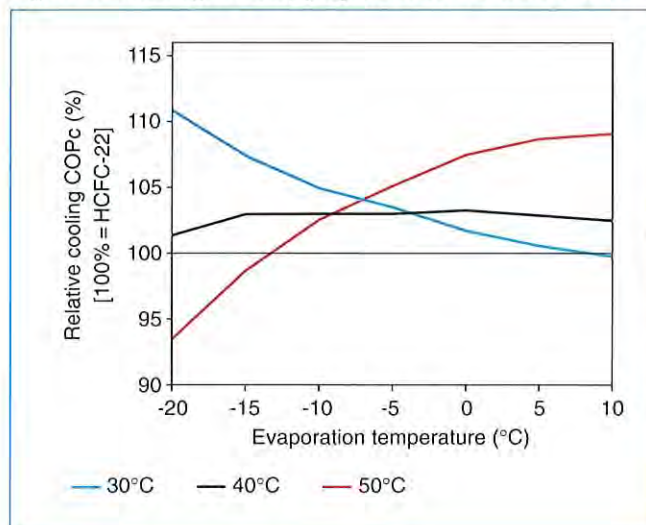


Figure 5: Discharge temperature of propane and HCFC-22.

Living with Flammability

The problem of the available alternative refrigerants is flammability. The question of non-flammable alternatives for HCFC-22 is fully open: mixtures suitable as a drop-in are not yet available, and for new systems, the alternatives have not yet been fully tested. Therefore, despite its flammability, propane as a drop-in for HCFC-22, is becoming more and more interesting. And in Europe, the safety aspects of using propane do not cause serious concern.

The tests made at the Graz University of Technology show that once the decision has been made to live with its flammability, propane is an extremely interesting replacement for HCFC-22. While capacity will be somewhat reduced, propane can improve COP or allow a higher temperature lift.

An alternative for CFC-12 is less problematic. HFC-134a has good performance characteristics, especially in the medium temperature range up to 80°C. However, in the low-temperature range, HFC-134a faces competition from propane/butane mixtures, such as are already in use in some European refrigerators.

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CO₂ Refrigerant in Large Heat Pumps

Transcritical Operation Leads to Superior Performance

Gustav Lorentzen, Norway

Carbon dioxide (CO₂) has been described as a near ideal refrigerant in every respect, provided that a suitable thermodynamic process can be designed to provide a competitively low power consumption. Such a process has been proposed for use in large heat pumps, such as for district heating systems, where the output has to be supplied to a gliding temperature sink. CO₂ also lends itself to the effective recovery of expansion work. Altogether it is well possible to improve the efficiency and COP of district heating systems by at least 20-25% over conventional technology.

* * *

Most heat pumps extract low-temperature heat from the immense reservoir of the environment (air, water, rock etc.) and a process with constant-temperature evaporation is therefore quite suitable for the purpose. They give off thermal energy at a higher temperature to a finite stream of air or water with limited heat capacity, resulting in a more or less gliding temperature. The amount of temperature change can range from a few degrees in a small direct condensation air heater, 15-20 K for normal "split units", up to 30-40 K in large district heating networks, and even more in some industrial applications and for direct tap water heating. This causes a very considerable excess power requirement in the normal type of cycle with condensation and heat rejection at essentially constant temperature (see Figure 1 (a)). What one should really have, is a cycle with a gliding temperature output as is indicated schematically in Figure 1(b).

Transcritical Cycle

Such a process can be approached by a transcritical cycle, using CO₂ as a working medium (Figure 2 (a)). In order to get a satisfactory fit to the near logarithmic temperature curve of the heat absorbing medium (water), the discharge pressure should be well above critical, in the order of 90-100 bar or higher. This means that when the evaporation temperature is for instance 0°C, the discharge temperature in single-stage compression with dry saturated suction will be about 70-80°C. This temperature can be adjusted in a certain range, up or down, by varying the discharge pressure and suction gas state, using a conventional suction gas heat exchanger or, possibly, some liquid injection (see Figure 2 (a)). The flexibility in the direction of a temperature reduction is rather limited,

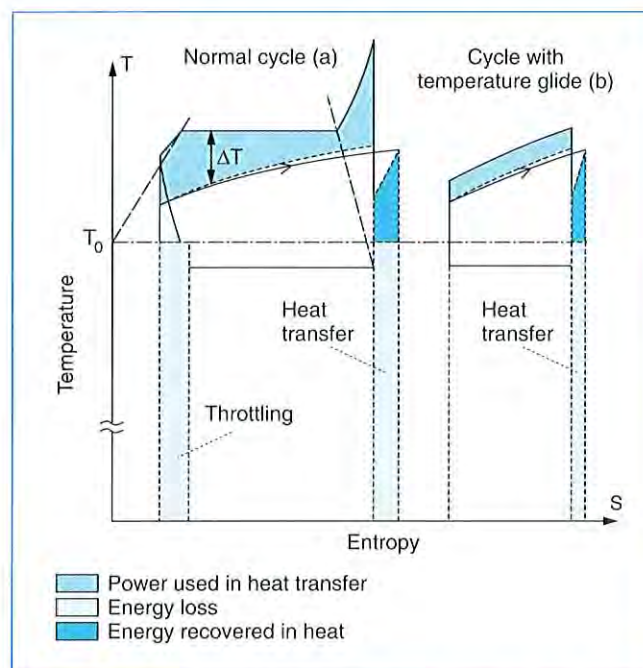


Figure 1: Exergy loss in heat rejection from a heat pump to a stream of fluid with finite capacity. (a) Conventional E-P process. (b) Gliding temperature ("Rhombic") process.

however. Lowering the pressure too much will deteriorate the temperature curve fit in heat exchange, while wet suction rapidly leads to poor compressor performance. The single-stage system shown is therefore most suitable when the required temperature glide is higher than 40-50 K, depending on the heat source temperature. In such cases it may easily reduce the specific power consumption by up to 40% compared to the conventional process, improving the COP correspondingly.

It should be noted that the simplified diagrams do not show the equipment required for the control of the compressor discharge pressure. This problem can be solved simply by means of a low-pressure side receiver [1 and 2].

Staged Compression

For most applications we need heat pumps with a smaller temperature glide. This problem is readily solved by a system of staged compression, to give a

discharge temperature close to the desired level. Figure 2 (b) gives an example of a two-stage arrangement, suitable for a modern low-temperature district heating application with a heating range of 35-60°C. The temperature-entropy chart compares the trans-critical CO_2 process with a conventional CFC-12 system for the same capacity and temperature requirement. The power saving achieved by the better temperature fit in heat transfer is a good 20%, but much of this is lost again in throttling from a relatively high temperature. On the other hand, the compressor efficiency will be much better for the CO_2 alternative as a result of the greatly reduced compression ratio. All told, the CO_2 system will be considerably superior to the conventional one with regard to energy performance.

It may be contested that a two-stage system is a complication and means added cost. The difference in this respect is very modest, however. Two-stage centrifugal compressors are normal in district heating plants anyway, and the splitting of the high-side heat

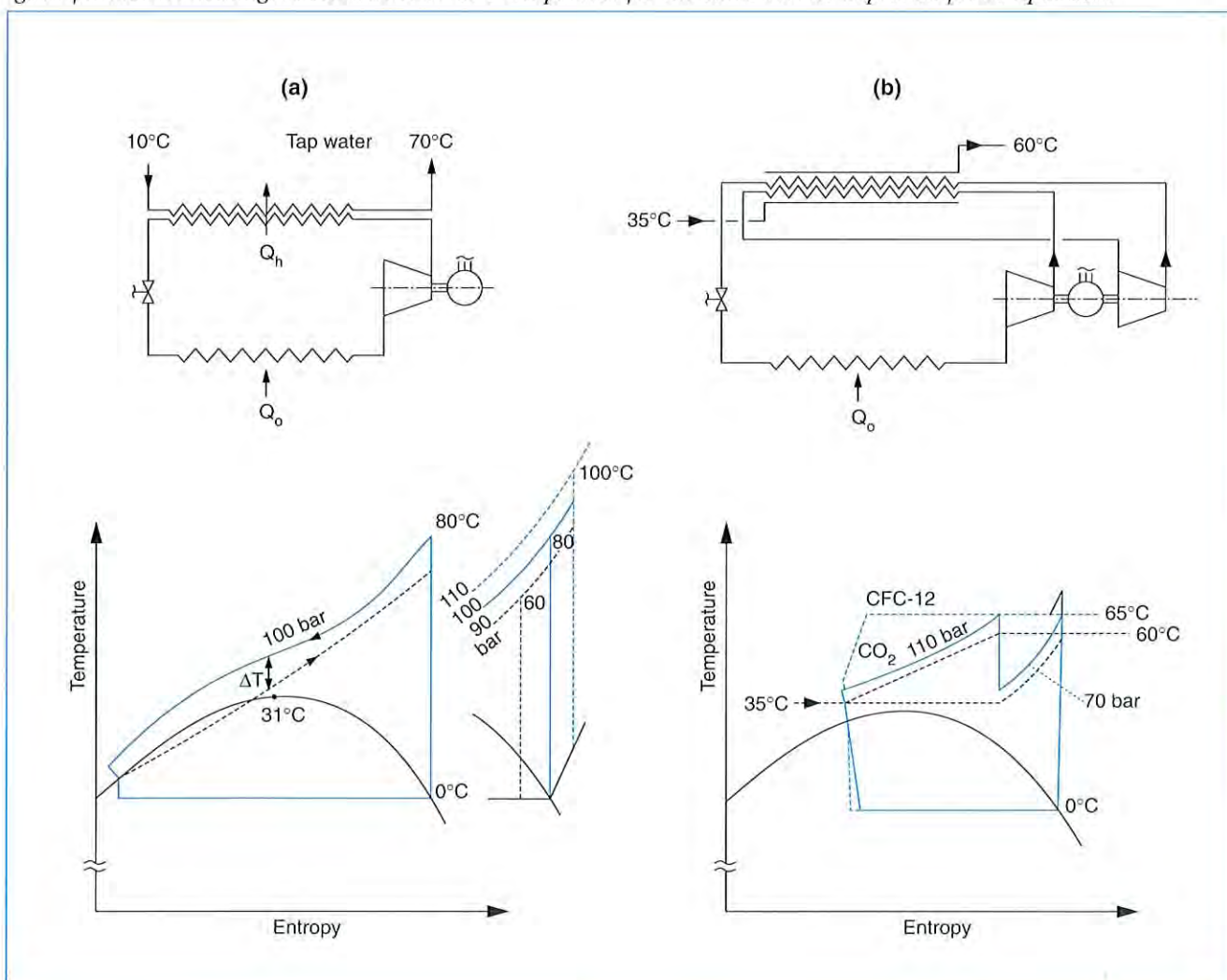
exchanger into two parallel circuits is actually a minor adjustment. The modifications will be paid for many times over by reduction in the physical dimensions alone, not to mention the important savings in power. Also important is the elimination of the heavy leakage of CFC and HCFC to the atmosphere, often associated with large district heating heat pumps.

Throttling Loss

As pointed out above, the relatively high throttling loss for CO_2 detracts considerably from the advantage of this refrigerant in a simple system. This can be amended by a number of well-known methods [3]. One solution is with a normal two-flow throttling and subcooling system. It is also expedient to recover the expansion directly, since the properties of CO_2 make this feasible.

With a conventional refrigerant such as CFC-12, most of the theoretical expansion work comes from the flash gas and the P-V diagram becomes very thin, with

Figure 2: (a) Transcritical heat pump producing hot water. (b) Two-stage CO_2 heat pump with 25 K temperature glide for district heating. A conventional CFC-12 process for the same service is plotted for comparison.



a low mean pressure (Figure 3). For CO_2 the situation is quite different, with most of the work in the liquid phase, a high mean pressure, and small volume requirement. An expansion aggregate becomes a cost-effective element in a large installation, which may take the form shown schematically in Figure 4.

Such a system, with a temperature glide in the order of 25-30 K, has the capability of increasing the COP by at least 20-25% in comparison to conventional installations. Operating under conditions deviating from the ideal temperature match, the efficiency will suffer, but will still be superior over a fairly wide range.

An Ideal Solution

Simple logic would indicate that the sensible way to solve the CFC/HCFC predicament is to use substances which are already present in the natural ambience and for which circulation systems have been long established. One alternative is CO_2 , which is absolutely ideal from a safety and environmental point of view. It is also inexpensive and readily available everywhere. Its relatively high pressure and moderate molar mass give important advantages in volume and cost of the system when the equipment is properly designed. The drawback of CO_2 is that it requires modification of the thermodynamic cycle in order to achieve a satisfactory energy efficiency. The examples given in this article show how this can be achieved for a typical large heat pump.

Figure 3: Pressure-volume flow diagrams for isentropic expansion of CFC-12 and CO_2 in a 100 MW heat pump with identical boundary conditions.

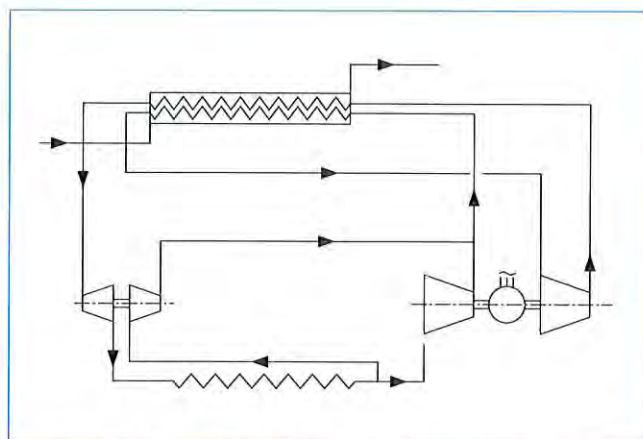
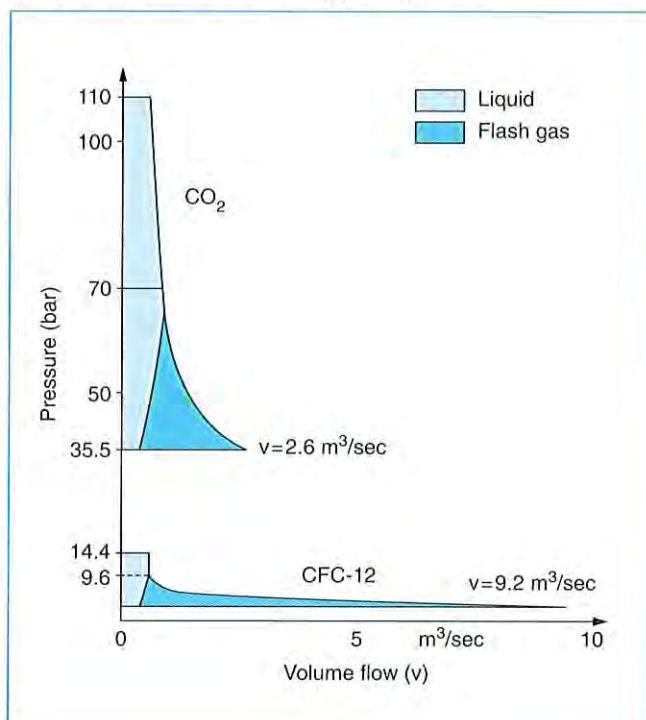


Figure 4: Schematic flow diagram for a two-stage CO_2 heat pump with expander unit for use in a district heating system with a temperature glide of 20-30 K.

Making use of the special properties of CO_2 in transcritical operation, it is possible to achieve a nearly ideal fit to the gliding temperature, which is required in applications such as large district heating schemes. The high pressure differential and relatively small flash gas volume, open up the possibility of efficient recovery of the expansion exergy in a compact expander. By taking advantage of these qualities it is possible to design large heat pumps with the following merits:

- completely safe and environmentally compatible refrigerant;
- superior performance, about 20% higher COP than conventional CFC systems;
- compact and cost-effective components.

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Sorption Heat Pumps and their Working Pairs

Hans van der Stoel, the Netherlands

Most working fluids (working pairs) used in sorption heat pumps pose little or no environmental threat and have therefore not attracted the attention that has so dominated the compression heat pump world in recent years. However, as researchers look for ways to reduce costs and to widen the applicability of sorption systems, the choice of working pairs is widening. This article examines research work in the Netherlands which concerns both improvements to existing concepts as well as the development of new cycles.

* * *

While most of today's heat pumps are compression type, there are two important arguments for putting more effort in the use and development of sorption heat pumps. Firstly, sorption systems can be driven by waste heat. Secondly, the available sorption systems use working pairs which are environmentally safe. Nevertheless, the application of sorption systems is not widespread. What shortcomings are responsible for this?

The first, and usually the most important reason, is that sorption heat pumps cost more than compression equipment. Sorption systems require expensive heat exchangers, and with water/lithium bromide ($\text{H}_2\text{O}/\text{LiBr}$), the working pair most commonly used in absorption heat pumps, expensive materials are necessary to prevent corrosion problems.

A second drawback of sorption systems is that they are much larger than compression systems. The third reason is the inertia of the system. Usually it takes quite a long time for a sorption heat pump to reach its operating conditions, making it unsuitable for use in batch processes.

Finally, sorption heat pumps suffer from the same restrictions as compression heat pumps in that their output temperature is limited. Most systems cannot operate above 150°C , although this is a higher temperature than can be reached with conventional compression technology (excluding mechanical vapour recompression systems/HPC).

Research Activities

Research in the Netherlands is focused on reducing cost, reducing component size and achieving higher

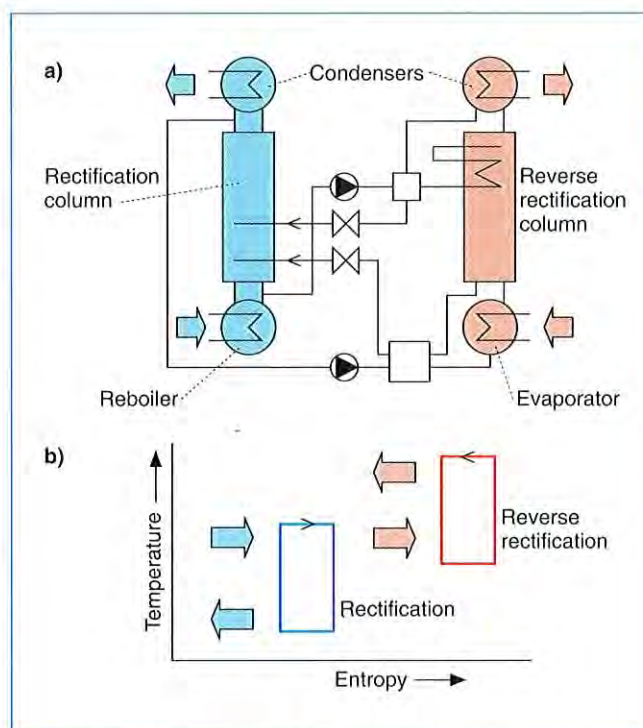


Figure 1: (a) Reverse rectification heat transformer. (b) Heat flows in reverse rectification heat transformer.

temperatures. Research activities include both new concepts and the improvement of existing heat pumps. New concepts include reverse rectification, the wet hybrid cycle and SWEAT (Salt Water Energy Accumulation and Transformation). Improvement of existing concepts is directed towards new working pairs and compact heat exchangers. Research activities are also addressing problems concerning the implementation of heat pumps in various applications.

Conventional Working Pairs

The two working pairs being applied in today's sorption systems are $\text{H}_2\text{O}/\text{LiBr}$ and ammonia/water ($\text{NH}_3/\text{H}_2\text{O}$). The most important application of $\text{H}_2\text{O}/\text{LiBr}$ is air conditioning. In the power range 300 to 5000 kW cooling capacity, a variety of systems is commercially available. An important advantage of this working pair is that the vapour pressure of LiBr is almost zero, so rectification is not required. Another strong point is the high solubility. A concentration of 70% (weight) salt is possible. At higher concentrations

LiBr crystallization takes place. Disadvantages of this mixture are its corrosion potential, especially at high temperatures (more than 150°C) and the danger of freezing at 0°C.

Ammonia/water is applied in small caravan refrigerators and (large) industrial units. It is easily available and can be applied in a wide temperature range. Drawbacks of this mixture are the toxicity of ammonia and the high pressures at high temperatures.

In the Netherlands a 250 kW absorption heat pump with the working pair ammonia/water has been developed by Rendamax/Colibri (see *IEA Heat Pump Centre Newsletter* Vol. 11, No. 2, p. 8). A special feature of this heat pump is the application of compact heat and mass exchangers (CHMEs). These fin-plate type heat exchangers provide very efficient falling-film absorption and evaporation. Another feature is the "GAX-Cycle" with internal heat exchange in the absorber. The first heat pump of this type is now operating successfully at a government building in Maastricht.

New Working Pairs

With respect to compression systems, much work is going on to find new working fluids that are environmentally safe (no ozone depletion, small global warming potential). The effort on new absorption working pairs is considerably smaller. The most promising new pair for high-temperature applications is Alkiltrate, a ternary mixture of nitrate salts with water. It has been developed in the United States for temperatures up to 260°C (see *IEA Heat Pump Centre Newsletter* Vol. 8, No. 4, p. 7). The salt components are easily available and performance seems to be good. The most important advantage, however, is that much higher temperatures can be reached than with today's heat pumps while using manual construction materials. Especially for industrial applications this is an interesting development. A possible disadvantage is that crystallization occurs at temperatures below 70°C, requiring specific control and start-up procedures. Despite the potential, there is no extensive research on Alkiltrate absorption heat pumps in the Netherlands, although great interest exists.

Another working pair for high temperatures is Tri-Fluor-Ethanol/Pyrrolidone (TFE/Pyr). It is being tested at The Technical University of Delft in a heat transformer of 10 kW heating capacity. The main advantage of TFE/Pyr over H₂O/LiBr is the higher temperature that can be reached (up to 200°C). An important drawback of TFE/Pyr is its high toxicity. With respect to the performance of the working pairs, H₂O/LiBr is better below 150°C, so TFE/Pyr should only be applied at high temperatures.

Another new working pair is a mixture of an organic solution with HFC-134a. This has been developed by HCF Industries in France and is used in liquid chillers,

with cooling capacities between 50 and 260 kW. Detailed information is not yet available.

Reverse Rectification

In the Netherlands, research on reverse rectification heat pumps has been carried out by The Institute of Environmental and Energy Research (part of the Netherlands Organization for Applied Scientific Research [TNO]) and the Technical University of Delft. Prof. P. Le Goff, of Nancy, France, first published articles on this new type of heat pump in 1989. The main difference with conventional absorption heat pumps is the absorber design. The working principle can be explained with the help of Figure 1 (a), which depicts a heat transformer.

The heat pump consists of two columns: a rectification and a reverse rectification column. In the rectification column, a binary mixture is separated into more or less pure components, by bringing the mixture in direct contact with the less volatile component (counterflow). The liquid leaving the bottom of the column contains a considerable fraction of the heavy component. Part of this liquid flow is evaporated in a reboiler and used again to rectify the mixture. The vapour leaving the top of the column mainly contains the volatile component. It is condensed and part of it is fed back into the rectification column.

In the other column, reverse rectification takes place. Volatile vapour is brought in contact with the heavy fluid, which absorbs the volatile component, while part of the heavy component evaporates. So vapour with a high concentration of the heavy component leaves the top of the column, where it is condensed. The fluid leaving at the bottom is fed into the rectification column.

A heat pump effect is created by operating the columns at different pressures. For the heat transformer the pressure in the reverse rectification column is higher than that in the rectification column. For a heat pump application it is reversed. The heat flows in the heat transformer are depicted in Figure 1 (b).

The reverse rectification principle offers flexibility in the choice of working pairs. This means that heat pumps can be built with cheap and easily available construction materials and that higher temperatures can be reached. Until now, only basic research has been carried out to learn the value of the principle. Plans exist to continue research by trying to find suitable working pairs and heat pump configurations.

SWEAT

The SWEAT (Salt Water Energy Accumulation and Transformation) system is a discontinuously working absorption heat pump with Na₂S as absorbent and water as working fluid. This heat pump has been under development at "De Beijer RTB" since 1986 and is described in *IEA Heat Pump Centre Newsletter*

Vol. 10, No. 1, p. 11. It consists of modules of two chambers, a condenser/evaporator and a desorber/absorber, which are integrated in one vertical pipe. The desired capacity can be reached by combining various modules.

At the beginning of the accumulation phase, the salt is saturated with water. The supply of heat causes the water to evaporate. Consequently, the water vapour flows to the condenser/evaporator where it is condensed at a temperature that is about 55 K lower than the temperature of the heat supply. During the discharge phase, the condenser/evaporator is heated as the water vapour is absorbed by the Na_2S salt. The heat released consists of both latent heat and bonding energy. Figure 2 shows the heat flows.

This type of heat pump is especially suited for industrial batch processes and applications in buildings. A small (18/12 kWh heating/cooling storage capacity) demonstration project at the office of electric utility PGEM at Almere, the Netherlands, provides cooling using heat from a district heating system.

During the night the heat pump is loaded with heat from the district heating system. As the outside temperature is low, the condenser can function without the help of fans. During the day, the machine is used for cooling and although the temperature outside is considerably higher, the lift is high enough to release the absorption heat easily.

One of the main advantages of using $\text{Na}_2\text{S}/\text{H}_2\text{O}$ is the large amount of water that can be absorbed by the salt, combined with the high latent heat of water. Another advantage is the high temperature lift (about 55 K). A third advantage is that the driving force does not depend on the amount of water that has already been absorbed.

As the next step a SWEAT 80 kW prototype will be developed.

Hybrid Wet Cycle

The Technical University of Delft is evaluating hybrid wet cycles (HWCs). Under study is a resorption cycle using $\text{NH}_3/\text{H}_2\text{O}$ where the absorber/generator combination has been replaced by a compressor (see Figure 3).

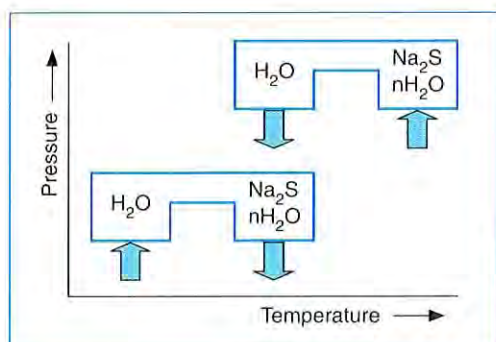


Figure 2:
Heat flows
for a
SWEAT
heat pump.

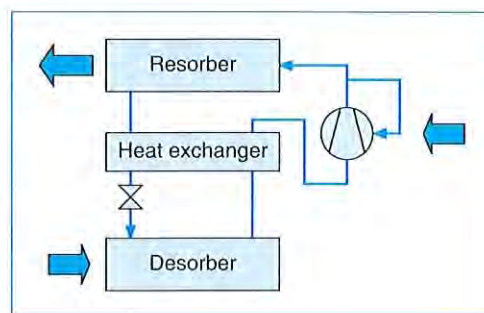


Figure 3:
Hybrid wet
cycle.

Low-temperature heat is supplied to the desorber, which causes evaporation of a part of the mixture. The vapour that is formed contains a high percentage of ammonia. The liquid/vapour mixture then enters a heat exchanger where more vapour is formed. During compression, part of the liquid is evaporated to reduce the amount of superheat in the vapour. Some of the liquid leaving the compressor is separated from the mixture and subsequently sprayed into the compressor. The rest of the mixture goes to the resorber.

Simulation and theoretical evaluations have already been performed and experimental results from a prototype are expected in 1994. The simulation results indicate that a HWC will have a higher performance than a pure refrigerant cycle. The experimental results will prove if this cycle deserves further development. Much attention has to be paid to the compression of the vapour/liquid mixture.

New Opportunities

Current experience with sorption heat pumps demonstrates the need for further research with an emphasis on reducing investment costs and on expanding the temperature range. $\text{NH}_3/\text{H}_2\text{O}$ and $\text{H}_2\text{O}/\text{LiBr}$ continue to be the most widely used working pairs for conventional sorption systems. The $\text{NH}_3/\text{H}_2\text{O}$ absorption heat pump now operating in Maastricht shows how advances in component technology can lead to a high-performance system.

But new working pairs are beginning to emerge. In particular, Alkilate deserves warm attention for high-temperature industrial applications. New working pairs are also being used in new concepts which are being developed in an effort to extend the applicability of heat pumps. For batch processes, further development (and commercialization) of SWEAT offers good opportunities. And concepts such as reverse rectification and the hybrid wet cycle deserve continued attention.

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Bibliography

Field Monitoring of a Variable-Speed Integrated Heat Pump / Water Heating Appliance

A.H. Fanney, *National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899, USA; 1993; 53 pp (English).*

This report summarizes a study in which a variable-speed integrated heat pump/water heating system was monitored for two years in an occupied residence. The results show that the total energy consumption was significantly reduced compared to previous years in which a wood stove, and window air-conditioners were used.

Heat Conversion Systems

Georg Alefeld, Germany, Reinhard Radermacher, USA; CRC Press Inc, 2000 Corporate Blvd., N.W., Boca Raton, Florida 33431, USA; ISBN 0-8493-8928-3; August 1993; 320 pp (English) US\$ 72 (US\$ 59.95 in US).

Using the "Building Block Approach" this book explains the underlying concepts of advanced Rankine-based absorption and compression cycles. Single and multi-stage systems are covered including multiple solution circuits, multiple compressors and cascades.

Ammonia Data Book

International Institute of Ammonia Refrigeration (IIAR), 1101 Connecticut Avenue, N.W., Suite 700, Washington, DC 20036, USA; 1993; 193 pp (English).

Intended for educational purposes, this book provides data on the various properties of ammonia and gives practical information on its use. It includes safety data and details US regulatory requirements.

UNEP IE/PAC Publications

The following publications are available from the United Nations Environment Programme, Industry and Environment Programme Activity Centre (UNEP IE/PAC), OzonAction Programme, Paris, France, Fax: +33-1-4437-1474.

Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer

3rd Edition, August 1993; 170 pp (Arabic, Chinese, English, French, Russian or Spanish) free.

The 1993 International CFC and Halons Alternative Conference

Proceedings, 20-22 October 1993, Washington, USA.

Catalogue of CFC-Free Technologies for the Refrigeration, Air-Conditioning and Heat Pumps Sector Available in the 1st quarter of 1994.

IIR Publications

The following publications are available from the International Institute of Refrigeration (IIR), Paris, France; Fax: +33-1-4763-1798.

Ammonia Used as a Refrigerant

1993; 100 pp (English or French) US\$ 22.

This publication reviews the advantages and disadvantages of ammonia used as a refrigerant, and explains how to maximize the former and minimize the latter.

Ammonia-Water Absorbent Mixture

1993; 88 pp (English or French) US\$ 15.

This booklet provides the thermodynamic and physical data of the ammonia-water pair for a temperature range from -50 to 316°C and a pressure range from 0.05 to 170 bar.

Energy

Energy Policies of IEA Countries - 1992 Review

International Energy Agency, Paris, France; Fax: +33-1-4524-8176; ISBN 92-64-13946-X; 528 pp; September 1993 (English) US\$ 110.

This report reviews the international energy situation in 1992 and describes trends and developments in energy demand, conservation and efficiency, supply of primary fuels, technology and R&D. In-depth reviews are provided on Australia, Belgium, New Zealand, Norway and Turkey.

Energy for Tomorrow's World

World Energy Council; Published by St Martin's Press Inc., 175 Fifth Avenue, New York N.Y. 10010; ISBN 0-312-10659-9; 320 pp; 1993 (English or French).

This book highlights the world's main energy issues, focusing on the years to 2020. It shows that it is virtually impossible to conceive that global CO₂ will be stabilized at 1990 levels by that date. In making recommendations to policy makers, the report emphasizes that strategies for sustainable energy development should be based on free-market principles.



Conferences

*Call for Papers

RECLIEN '94: 3rd International Conference on Refrigeration, Air Conditioning and New Energies
23-27 March 1994 / Havana, Cuba
Contact: Instituto de Refrigeración y Climatización,
Apartado Postal 66, Ciudad de La Habana, 11400, Cuba.
Tel: +52-20-4222; Fax: +53-20-2350

AIRAH 1994 International Conference and Exhibition
15-18 April 1994 / Gold Coast, Queensland, Australia
Organized by the Australian Institute of Refrigeration, Air
Conditioning and Heating
Contact: Conference Manager, 191 Royal Parade, Parkville
VIC 3052, Australia.
Tel: +61-3-347-4777; Fax: +61-3-347-8571

New Applications of Natural Fluids in Refrigeration and Air-Conditioning
10-13 May 1994 / Hannover, Germany
(IIR Commission B2)
Contact: Prof. Kruse, University of Hannover,
Welfengarten 1A, 3000 Hannover 1, Germany.

4th International Conference ROOMVENT 94
15-17 June 1994 / Krakow, Poland
Contact: Dept. of Heating, Ventilating and Dust Removal
Technology, Silesian Technical University,
Pstrowskiego 5, 44-101 Gliwice, Poland.
Tel: +48-3237-1280; Fax: +48-3237-2559

Annual Conference of the International District Heating and Cooling Association (IDHCA)
18-22 June 1994 / Seattle, WA, USA
Contact: Ms. C. Millunzi IDHCA, 1101 Connecticut Ave
N.W., Suite 700, Washington, DC 20036, USA.

International Refrigeration Conference
12th International Compressor Engineering Conference
19-22 July 1994 / Purdue University, Indiana, USA
Short courses are arranged for 17-19 July
Contact: Phyllis Hurst, Conference Secretary,
Purdue University, 1077 Ray W. Herrick Laboratories,
West Lafayette, IN 47907-1077, USA.
Tel: +1-317-494-0117; Fax: +1-317-494-0787

Calorstock '94
6th International Conference on Thermal Energy Storage
22-25 August 1994 / Otaniemi, Espoo, Finland
Contact: Mr Markku Kangas, Helsinki University of
Technology, Dept. of Technical Physics,
Otakaari 3, 02150 Espoo,
Finland.
Tel: +358-0-451-3212; Fax: +358-0-451-3195

CFCs - The Day After
(IIR Commissions B1, B2, E1 and E2)
21-23 September 1994 / Padua, Italy
Contact: Organizing Committee, IIR-AICARR Conference, c/o
AICARR - viale Monte Grappa, 2, I-20124 Milano MI, Italy.
Fax: +39-2-2900-0004

49th National Congress of the Italian Thermotechnical Association
26-30 September 1994 / Perugia, Italy
Contact (for heat pump topics): Eng. Carlo Nazareno
Grimaldi, Istituto di Energetica, Str. S. Lucia-Canetola,
06125 Perugia - Italy. Tel: +39-75-5852735

15th AIVC Conference - The Role of Ventilation
27-30 September 1994 / Buxton, United Kingdom
Contact: Mrs Rhona Vickers, IEA Air Infiltration and
Ventilation Centre, University of Warwick Science Park,
Sovereign Court, Sir William Lyons Road, Coventry CV4 7EZ,
UK. Tel: +44-203-692050; Fax: +44-203-416306

Heat Transfer Enhancement by Additives
10-11 October 1994 / Munich, Germany
A discussion meeting concerning sorption heat pumps
Contact: Dr Felix Ziegler, Institute E19 - Physics Dept.,
Technische Universität München, James Franck Strasse 1, D-
85748 Garching, Germany.
Tel: +49-89-3209-2535; Fax: +49-89-3209-2536

Ground-Coupled Heat Pumps Symposium
17-19 October 1994 / Giessen, Germany
The symposium language is German.
Contact: Dr Burkhard Sanner, Institute for Applied Geo-
sciences, University of Giessen, D-6300 Giessen, Germany.
Tel: +49-641-702-8248; Fax: +49-641-702-4711

Application of Adsorption for Energy Transport and Storage
13-18 November 1994 / San Francisco, USA
Contact: Dr Orhan Talu, Dept. of Chemical Engineering,
Cleveland State University, Cleveland, OH 44115, USA.
Tel: +1-216-687-3539; Fax: +1-216-687-9220

***19th International Congress of Refrigeration - For a Better Quality of Life**
20-25 August 1995 / The Hague, The Netherlands
Organized by the International Institute of Refrigeration (IIR)
Contact: Dr R.W.A.W. Mulder, Scientific Committee 19th
Congress IIR/IIF 1995, PO Box 15, 7360 AA Beekbergen, The
Netherlands or Van Namen & Westerlaken Congress
Organisation Services.
Tel: +31-80-234471; Fax: +31-80-601159



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The Impact of Heat Pumps on the Greenhouse Effect	Workshop Proceedings	HPC-WR10	80
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Heat Pump Water Heaters	Workshop Proceedings	HPC-WR12	60
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Heat Pumps - Better by Nature	Promotion Brochure	HPC-BR2	free
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Heat Pumps to the Year 2000 - Strategy Plan	Promotion Brochure	B2-HPP	free
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