FACT SHEET 5
Industrial Refrigeration

1. Description of market sector

This market sector includes refrigeration systems used in manufacturing and process industries. The majority of industrial refrigeration is used in (a) the processing and storage of food and beverages and (b) the manufacturing of petrochemicals, chemicals and pharmaceuticals. A number of other industrial operations use refrigeration, such as the manufacture of plastic products and semi-conductors. Industrial refrigeration equipment is also used in various other applications such as large cold stores, ice rinks and indoor skiing facilities.

Market sub-sectors

The industrial refrigeration sector is difficult to characterise as there is such a wide range of cooling requirements in terms of temperature level, cooling demand and processing techniques. Many industrial systems are large, with cooling demands of several MW and with a refrigerant charge of several tonnes. However, not all industrial systems are large - many factories make use of numerous small and medium sized refrigeration systems.

To help understand refrigerant use, industrial refrigeration has been split into three broad sub-sectors, to distinguish those parts of the industrial sector for which there are already good alternatives to HFCs from those which could prove more problematic. These are:

a) **Small and medium sized systems**, usually dedicated to one particular cooling demand. These systems are often located close to the cooling demand.

b) **Large primary refrigerant distributed systems**[1]. These systems are used to cool large loads in processes such as blast freezers, process heat exchangers and cold storage facilities. A primary refrigerant is piped from a central machinery room (containing large refrigeration compressors) to a number of evaporators serving one or more cooling demands. The primary refrigerant is often circulated over significant distances (hundreds of metres).

c) **Large secondary refrigerant chiller systems[2]**. A primary refrigerant is used in a chiller to cool a secondary heat transfer fluid which is circulated to a number of separate cooling demands.

Operating temperatures

Industrial systems operate over a wide range of different temperatures. A significant proportion of industrial systems (especially those used in food and beverage processing) operate at similar temperatures to those found in commercial refrigeration:

- Medium temperature (MT) for chilled products held at between 0°C and +8°C
- Low temperature (LT) for frozen products held at between -18°C and -25°C

Some industrial applications require much lower temperatures, from -25°C to well below -150°C. Industrial heat pump systems can use equipment that is very similar to industrial refrigeration – they operate at temperatures much higher than refrigeration systems.

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[1] A primary refrigerant is the fluid used in a vapour compression cycle. Cold liquid primary refrigerant is evaporated to provide cooling. The resulting vapour is then compressed and condensed.

[2] A secondary refrigerant transfers cooling to a cooling demand. The secondary refrigerant is cooled in a vapour compression chiller. Most secondary refrigerants are liquids such as chilled water (for temperatures above 0°C) or an anti-freeze solution such as glycol or brine (for temperatures below 0°C). Other types of secondary refrigerant include water / ice mixtures (the ice melts as it provides cooling) and volatile fluids such as CO_2 (the fluid evaporates as it provides cooling).

Typical system design

Given the wide range of industrial applications, this sector also has the greatest variety of system designs:

- Most systems use a vapour compression cycle.
- The majority of small and medium sized systems are based on a direct expansion (DX) design.
- Many small systems use air cooled condensers.
- Most large primary refrigerant distributed systems use flooded evaporators, supplied by either a pumped refrigerant system or a gravity circulation system.
- Large chillers for secondary refrigerant systems often use flooded evaporators, although smaller chillers could use DX evaporators.
- Large systems usually use evaporative or water cooled condensers.
- Lower temperature systems (e.g. for cooling of products below -20°C) usually use 2-stage compression to improve efficiency and reduce discharge temperature.
- Very low temperature systems (e.g. for products below -40°C) utilise cascade systems[3].
- Large cryogenic systems (e.g. air liquefaction plants that produce liquid oxygen and liquid nitrogen) usually use air cycle refrigeration systems[4].

Alternative Technologies

There is some use of heat driven sorption systems (liquid absorption and solid adsorption), although they are usually cost effective only where there is a source of waste heat to drive the system. Sorption systems can be used in regions where the electricity grid is unreliable.

Changes driven by ODS phase out

The industrial sector was the only refrigeration market using a significant amount of non-fluorocarbon refrigerants prior to 1990. In particular, R-717 (ammonia) was in widespread use. There were also specialised applications of HCs (hydrocarbons) in the petrochemical sector and of air cycle in cryogenic applications. Most small and medium sized systems used fluorocarbons such as CFC-12, HCFC-22 and R-502 prior to 1990. From around 1997 various HFCs were introduced in non-Article 5 countries including R-404A[5] and HFC-134a. HCFC-22 has now been phased out and substantially replaced in non-Article 5 countries. In Article 5 countries the use of HCFC-22 remains significant and there is some use of HCFC-123 in industrial chillers.

Technical characteristics of HFC systems

The key characteristics are summarised in Table 1.

A significant portion of new **small and medium sized systems** in non-Article 5 countries use HFCs. In this size range R-717 is often not considered cost effective. R-404A is the dominant HFC refrigerant used in small and medium sized industrial systems. It has a GWP[6] of 3922.

Many **industrial chiller systems** use HFCs, especially HFC-134a for large chillers and R-407C and R-410A for small and medium sizes. A significant proportion of large industrial chillers use R-717.

Most **large distributed systems** use either R-717 or HCFC-22. HFC blends are not suited to large systems due to their temperature glide (which can lead to fractionation in flooded evaporators).

[3] In a cascade system a low temperature refrigeration circuit rejects heat into a higher temperature circuit. The 2 circuits are separate and utilise 2 different primary refrigerants.

[4] Air cycle creates a cooling effect by the expansion of compressed air.

[5] R-507A is also used for industrial systems although less widely than R-404A. Comments about R-404A in this Fact Sheet also apply to R-507A.

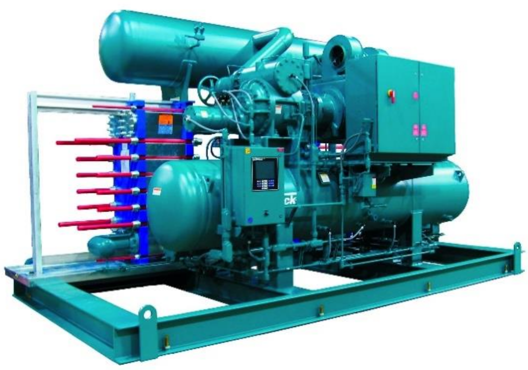
[6] All GWP values are based on the IPCC 4th Assessment Report

Table 1: Industrial refrigeration: summary of characteristics for HFC systems

<table>
<tr><th colspan="2">Market sub-sector:</th><th>Small / medium sized systems</th><th>Large distributed systems</th><th>Industrial chiller systems</th></tr>
<tr><td colspan="2">Typical refrigerant charge</td><td>10 to 100 kg</td><td>250 to 5000 kg</td><td>100 to 2000 kg</td></tr>
<tr><td colspan="2">Typical cooling duty</td><td>20 to 100 kW</td><td>100 to 5000 kW</td><td>200 to 5000 kW</td></tr>
<tr><td colspan="2">HFC refrigerants widely used (with GWP)</td><td>R-404A (3922)
HFC-134a (1430)</td><td>None
small use of R-404A and R-507A; significant use of HCFC-22</td><td>HFC-134a (1430)
HFC-407C (1774)
HFC-410A (2088)</td></tr>
<tr><td colspan="2">Typical refrigeration circuit design</td><td>Direct expansion</td><td>Distributed pumped</td><td>Flooded chiller</td></tr>
<tr><td colspan="2">Manufacture / installation</td><td colspan="2">Site installed refrigerant pipework</td><td>Factory built</td></tr>
<tr><td colspan="2">Typical location of equipment</td><td colspan="3">Class C (authorised occupancy by persons acquainted with safety procedures)</td></tr>
<tr><td colspan="2">Typical annual leakage rate</td><td>5% to 10%</td><td>4% to 8%</td><td>2% to 5%</td></tr>
<tr><td colspan="2">Main source of HFC emissions</td><td>Operating leakage</td><td>Operating leakage</td><td>Operating leakage</td></tr>
<tr><td rowspan="2">Approx. split of annual refrigerant demand</td><td>New systems</td><td>30%</td><td>30%</td><td>40%</td></tr>
<tr><td>Maintenance</td><td>70%</td><td>70%</td><td>60%</td></tr>
</table>

Compressors for large distributed system

Small industrial system - evaporator in chill store



Industrial glycol chiller

2. Alternatives to currently used HFC refrigerants

Table 2: Lower GWP alternatives for industrial refrigeration

Refrigerant	GWP	Flammability[7]	Comments
Alternatives to avoid use of R-404A (in new equipment and for retrofit of existing)			
R-407A	2107	1	There has been significant use of these blends in Europe as R-404A alternatives (for new systems and for retrofit). Can have higher efficiency than R-404A systems.
R-407F	1825	1	
R-448A	1387	1	Newly developed blends with properties similar to R-407A and R-407F, but lower GWP. Currently there is limited commercial experience or availability.
R-449A	1397	1	
Alternatives, new equipment only			
R-717 (ammonia)	0	2L	A widely used refrigerant for large systems and chillers. This refrigerant is an important option for industrial applications. It has high toxicity and a strong pungent odour. Various safety precautions are required, which can make it difficult to use R-717 cost effectively for small and medium sized systems.
HC-290 HC-1270	3 2	3 3	Used in large industrial systems (distributed and chillers), especially in petrochemical plants that are processing high flammability products. Appropriate safety precautions are required. HCs are less used small and medium industrial systems.
R-744 (CO_2)	1	1	R-744 has been introduced in the last 10 years for a number of large industrial applications such as cold stores and freeze dryers. R-744 is being considered for some small and medium systems.
HFO-1234ze	7	2L	Being introduced for industrial chillers as an alternative to HFC-134a. Other HFOs are also under development, such as HFO-1233zd and HFO-1336mzz which are suitable for low pressure chillers (as an alternative to HCFC-123).
R-450A R-513A R-451A R-451B	601 631 140 150	1 1 2L 2L	Newly developed blends with properties similar to HFC-134a. Being considered for small and medium sized MT systems.
Blends awaiting ASHRAE number	150 to 300	2L	Development blends with properties similar to HFC-404A. Being considered for small and medium sized LT systems.
R-446A R-447A	460 582	2L 2L	Newly developed blends with properties similar to HFC-410A. Being considered for small and medium sized systems.
HFC-32	675	2L	Being considered for small and medium sized systems.

[7] Flammability classes based on ISO 817 and ISO 5149
3 = higher flammability; 2 = flammable; 2L = lower flammability; 1 = no flame propagation

Small and medium sized systems

A challenging sub-sector in terms of lower GWP alternatives because the refrigerant charge is relatively high and flammability is an important issue. Many of these systems are not large enough for R-717 to be cost effective. An early move away from R-404A is a possible strategy (both for new plants and for retrofit of existing plants) – various non-flammable options with GWPs in the 1400 to 2100 range are readily available in some regions. For medium temperature applications there are new non-flammable blends with GWPs in the region of 600. Lower GWPs are available through use of lower flammability HFO/HFC blends. Use of R-744 technology being developed for the supermarket sector could make R-744 a suitable option for small and medium sized industrial systems.

Large distributed systems

R-717 is often the best option – it is already widely used. R-744 has useful advantages in some applications (e.g. it is well suited to combined cooling and heating) and can have very high efficiency for freezing applications.

Chiller systems

A number of cost effective options are available. R-717 is already used in large industrial chillers and HCs can be considered (chillers can be located in special machinery rooms or outdoors which helps address safety issues). HFO-1234ze chillers are being introduced and will suit many industrial chiller applications. Low pressure chillers using other HFOs may also become available.

Alternative system design

The choice of a suitable low GWP refrigerant can be made easier if a different system design is chosen. This is especially important for small and medium sized systems:

- In factories that use a large number of small and medium sized systems, it is possible to replace several small systems with a larger central system. This can make it more cost effective to use R-717 and/or R-744 and in many situations higher energy efficiency can be achieved. However, care must be taken if the cooling demands are at varied temperature levels, as the system efficiency could fall if a central system operating at the lowest required temperature is used.
- It is also possible to consider a switch from DX or distributed primary refrigerant systems to a central chiller with a secondary refrigerant. This reduces the primary refrigerant charge and restricts flammability issues to a limited access machinery room. Again, care must be taken over energy efficiency, as some secondary systems using glycol or brine are less efficient than DX or distributed systems. Use of R-744 as a volatile secondary refrigerant can also be considered for some industrial applications – this can improve the efficiency of a secondary system.

3. Discussion of key issues

Safety and practicality

Small and medium sized systems: If non-flammable fluorocarbon alternatives are selected there are no new safety issues. To minimise the GWP it may be necessary to use HFO / HFC blends with lower flammability – relevant safety standards must be followed. R-744 is a possible option for some small and medium sized industrial systems, using components and technologies that are currently used in supermarket systems.

Large distributed systems: R-717 is already widely used and safety issues are well understood. There have been recent fatal accidents on industrial ammonia plants in Article 5 countries because standards and regulations were not followed. The need for good training of design engineers and maintenance technicians is essential. It is worth noting that many of the new HFC and HFO/HFC blends have a temperature glide that make them unsuitable for large distributed systems based on flooded evaporators.

Chiller systems: R-717 is widely used and safety issues are well understood. Some new HFOs are well suited to chillers and may be easier to use than R-717 (as they have lower toxicity). The lower flammability of HFOs must be taken into account (this is no more difficult than using R-717 which also has lower flammability). HC chillers are also sometimes used in small and medium sized applications as well as in large scale in hydrocarbon processing and petrochemical industries where safety for handling HCs are already in place.

Commercial availability

Small and medium sized systems: There is good availability of some non-flammable R-404A alternatives, with GWPs around 1800 to 2100. There is currently little experience in the use of the lower GWP alternatives suited to small and medium sized industrial systems (e.g. HFO / HFC blends or R-744). Work is required to develop industrial components optimised to these refrigerants.

Large distributed systems: R-717 systems are widely available. R-744 is much less common although it is being considered in a number of applications. Many R-744 components are available, but more component development is needed to suit the wide variety of industrial applications.

Chiller systems: R-717 chillers are widely available. A number of new HFO chiller models have been introduced during 2014 and a wide range of industrial HFO chillers will be available within 5 years. HC chillers are available in Europe and many other countries.

Cost

Small and medium sized systems: For new systems, there is little or no cost impact to move from R-404A to R-407A or R-407F. Cost issues associated with the use of the lower GWP options shown in Table 2 are not yet clear. For non-flammable options, the main extra cost is likely to be the refrigerant, although this is only a small proportion of the total cost. For lower flammability options there is a need for extra investments related to safety precautions, but these are not expected to be significant. R-744 systems are likely to be more expensive in this size range – a cost increment of 20% to 40% is possible, although there is little data yet available on costs in this sector.

Large distributed systems: R-717 is already the lowest cost option for many applications.

Chiller systems: Where an HFC-134a chiller was previously selected, HCs have a similar cost and it is likely that an HFO chiller will also have a similar cost.

Energy efficiency

Small and medium sized systems: Use of R-407A and R-407F in place of R-404A is likely to lead to improved energy efficiency, especially for MT systems. There is little experience in use of the new HFO / HFC blends, although early trials indicate that it is likely that these will have equal or better efficiency than exisiting HFC-404A systems. R-744 is likely to have good efficiency with appropriate system design.

Large distributed systems: R-717 systems are well suited to high efficiency at both MT and LT conditions. R-744 can be very efficient and can provide extra opportunities for heat recovery.

Chiller systems: HFO-1234ze chillers are expected to have equal efficiency to current HFC-134a systems. HFO-1233zd may offer the improved efficiency that has been available through low pressure chillers that previously used HCFC-123. HCs have at least the same or better efficiency than HFC-134a. R-744 can be used as a volatile secondary refrigerant in place of glycol or brine – this can offer significant efficiency improvement.

Applicability in high ambient

Small and medium sized systems: New equipment can be designed for effective operation in high ambient using HFC-407A, HFC-407F, HCs and the various non-flammable and lower flammability HFO / HFC blends. R-744 can only be used efficiently at high ambient in a cascade configuration – this may be too expensive for small and medium sized industrial systems.

Large distributed systems: R-717 systems can be used at high ambient temperature if water cooled or evaporative condensers are used. For LT operation it is essential to use 2-stage compression. R-744 systems can only be used efficiently at high ambient using a cascade configuration e.g. in cascade with R-717 on the high stage and R-744 on the low stage.

Chiller systems: R-717, HC and HFO chillers can be designed for operation at high ambient with no efficiency detriment compared to HFC-134a.

Opportunities to retrofit existing equipment

Small and medium sized systems: Existing R-404A systems can be retrofitted with various refrigerants with much lower GWPs, in the range 1400 to 2100 as shown in Table 2. Retrofit of small and medium sized industrial systems can lead to significant early reductions in HFC consumption.

Retrofit of **large distributed systems** and **large chillers** is not usually an appropriate option.

Technician training

R-717: Technicians doing maintenance need training that addresses handling of R-717, especially in relation to use of a higher toxicity refrigerant. There are well established training courses available for R-717 technicians in many countries.

Lower flammability HFCs/ HFOs: Training will be essential for maintenance of systems with lower flammability refrigerants. These are not yet widely used, so little training is yet available.

R-744: Systems using R-744 operate at a higher pressure than HFC systems and may be based on unfamiliar system design. Technicians need extra training to work on R-744 systems. There are well established training courses available for commercial refrigeration in regions already using R-744, but training is less common amongst industrial refrigeration technicians.

HCs: Technicians doing maintenance need training that addresses handling of higher flammability refrigerants. There are established training courses available although only a small proportion of industrial refrigeration technicians have skills to deal with large HC systems.

For all new refrigerants, training is also required for system design engineers.

Minimising emissions from existing equipment

Small and medium sized systems: Most emissions occur through leakage during the operating life. Small sized industrial systems often use site installed copper pipework and compression connections, which can be prone to leakage. Applying best practice in both design and maintenance can lead to significant leakage reductions. Emissions during servicing and at end-of-life can be avoided through use of good refrigerant recovery procedures using suitable recovery machines.

Large distributed systems: All R-717 systems use steel pipework. Leakage rates are already relatively low due to strength of steel piping and importance of avoiding leakage of a higher toxicity refrigerant. Some industrial HCFC-22 systems have much higher levels of leakage, which can be avoided through improved maintenance practices.

Chiller systems: Chiller systems are factory built and have the potential for very low levels of leakage if best practice design and maintenance is carried out.