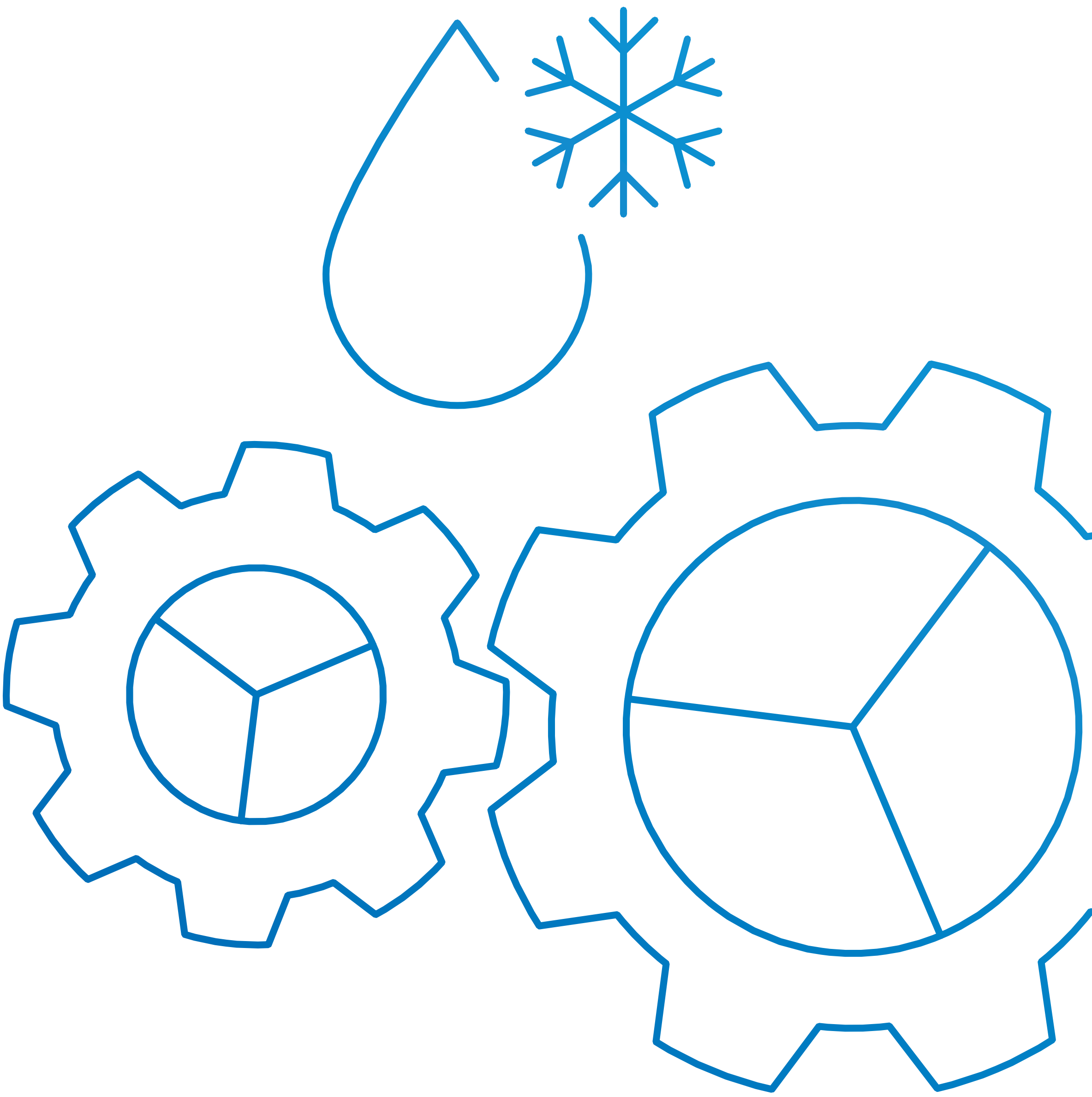
Use of Lubricants in Systems Using Natural Refrigerants



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1 Abstract

All refrigeration, air-conditioning and heat pump (RACHP) systems rely on good compressor lubrication. The role of lubricants is, however, much wider than simply providing protection from wear through friction between moving parts. For example, lubricants often provide sealing between the high and low pressure sides of compressors and they also provide cooling. In order to ensure optimal operation, plant designers need to fully understand the interactions between lubricants refrigerants to ensure the chosen oil is effective and does not reduce the performance of the refrigeration system. Significantly, the choice of lubricant is related to both the refrigerant and the nature of the RACHP application.

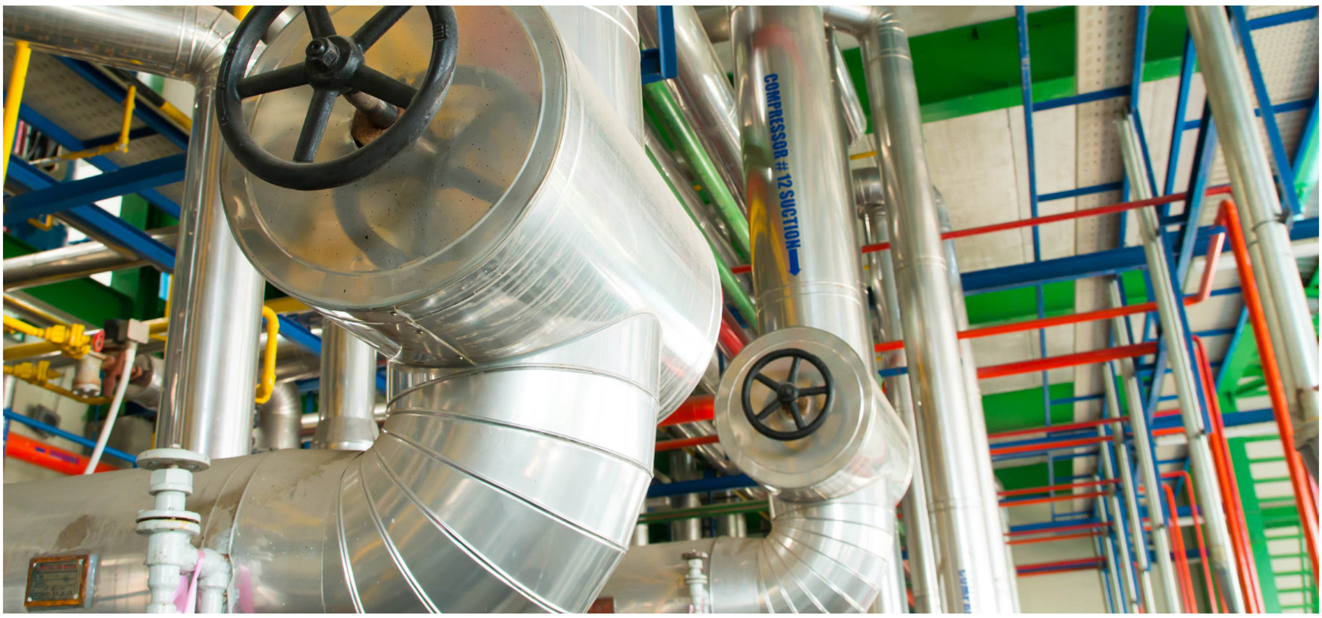
The RACHP market is rapidly changing in response to environmental regulations linked to ozone depletion and climate change. As a result, natural refrigerants are being introduced across a wide range of systems, creating the need for effective lubricants to suit these applications.

This paper describes the role of the lubricant and how lubricant/refrigerant interactions should be taken into consideration by equipment designers. In particular, the paper focuses on lubricant issues related to the use of natural refrigerants including CO2, ammonia and hydrocarbons.

2 Introduction

The refrigerants being selected for RACHP applications are undergoing a major transformation linked to environmental legislation. The phase-out of ozone depleting refrigerants (in particular HCFC-22) and the phase-down of high global warming potential (GWP) HFC refrigerants (in particular HFC-134a, R-410A and R-404A) require changes to many products. This process is being driven by the Montreal Protocol (which affects all countries) and by national and regional legislation (such as the EU F-Gas Regulation). As a result, businesses are increasingly adopting natural refrigerants – such as ammonia, carbon dioxide (CO2) and hydrocarbons – to help reduce environmental impacts.

This switch to natural alternatives presents a number of new challenges for operators – not least when it comes to lubrication. RACHP applications are amongst the most complex from a lubricant perspective. This paper provides insight into these challenges and guidance how to make an informed decision to overcome them.



3 The role of lubricants

Lubricants play a key role in the efficient operation of compressors used in RACHP equipment. The primary role is to reduce friction and wear of moving surfaces, including rotating shaft bearings and compressor components such as pistons and rotors. In addition to this role, lubricants perform a number of other important functions, including:

a) To provide a seal between the high pressure and low pressure sides of a compressor. For example, in a reciprocating compressor oil provides a seal between piston and cylinder liner and in a twin screw compressor oil provides a seal between the two rotors and between the rotors and the compressor casing. Without a suitable lubricant the compressor volumetric efficiency would fall, leading to a loss of cooling capacity and a loss of energy efficiency.

b) To provide cooling. The lubricating oil removes some of the heat of compression, helping the compressor operate well under a wide range of conditions. The heat can be vented via an external oil cooler.

c) To eliminate debris created from component wear – this can be removed in an oil filter.

d) To provide noise dampening.

e) To reduce wear and increase component life.

4 Interactions between refrigerants and lubricants: Key design issues

To meet these multiple roles, the oil needs to have the optimum characteristics, in particular in terms of viscosity. However, oils can strongly interact with refrigerants, which can potentially degrade the lubricant's capabilities. These interactions, which occur during a refrigerant's gas or liquid phases, are known as solubility and miscibility. Refrigeration plant designers need to understand how these will impact RACHP operation.

- Solubility is the capability of refrigerants to dissolve in an oil, reducing its viscosity and sometimes creating a foamy mixture. Ammonia, for example, has very low solubility in all types of oils (excepted POE, which cannot be used in this application). Despite low solubility, there can be a significant impact on viscosity. CO2 has high solubility in some lubricants, resulting in potentially excessive viscosity reductions and the possibility of CO2 outgassing on bearing surfaces, disrupting lubricant films. Other refrigerants, including hydrocarbons, are very soluble in mineral oils and less soluble in synthetic oils such as Polyalphaolefin and Polyalkylene glycole.

- Miscibility occurs when the refrigerant is in the liquid phase and mixes with the lubricant. In case of good miscibility between the refrigerant gas and the oil, if the oil is carried into the circuit it will come back easily with refrigerant. Ammonia on the other hand is not miscible and a specific system design is required to separate the oil from the condensed ammonia.

Oil viscosity is also influenced by pressure and temperature – viscosity falls when temperatures rise although lubricants with a high viscosity index are less affected by this. The solubility of a refrigerant in oil rises with pressure, which can also lead to reduced viscosity. This can be a particularly important issue for CO_2 refrigeration systems where discharge pressures are around five times higher than for most other refrigerants. There are significant differences in temperature between the suction and discharge sides of compressors, especially for low temperature refrigeration e.g. for frozen foods. The suction gas could be returned from the evaporator at -40oC. The discharge gas of an ammonia reciprocating compressor could be at around 100oC. The selected oil must be viscous enough to provide good lubrication at the highest temperature but not so viscous that it will not flow at the lowest temperature: this is referred to as its 'pour point' – the lowest temperature at which an oil will pour or flow, as measured using the standard ASTM D-97 test.

Any interactions between oil and system components needs to be considered. This is especially important for elastomeric seals, which swell by varying amounts in the presence of different types of oil. There needs to be good compatibility between the selected oil and any elastomeric materials.

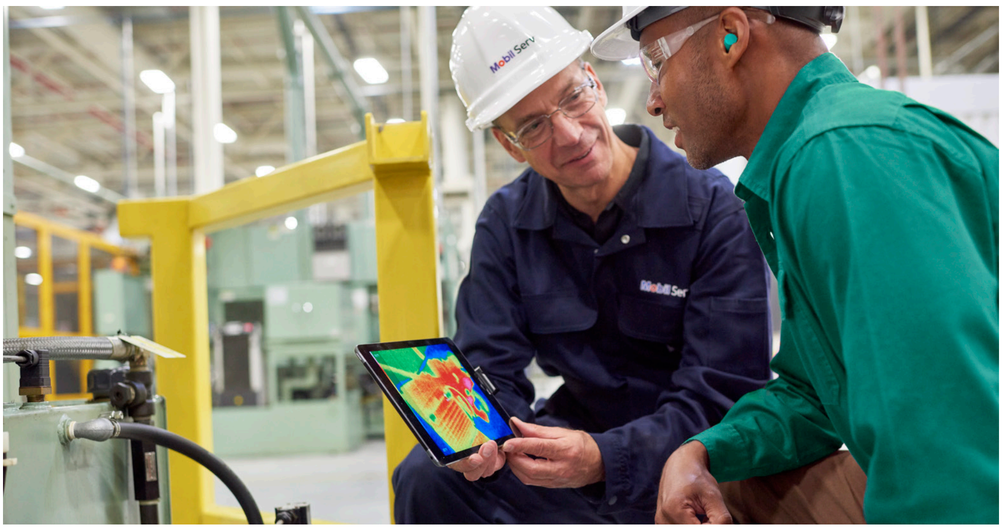
It is also worth noting that the oil needs to remain stable for many years of operation. In large installations there is the possibility to replace the oil at regular intervals, but small hermetically sealed refrigeration systems (such as domestic refrigerators) are sealed for life so an oil needs to remain effective for 20 years or more.

5 Some application specific issues

The details of how an oil interacts with a piece of RACHP equipment depends on many things. Important practical factors are:

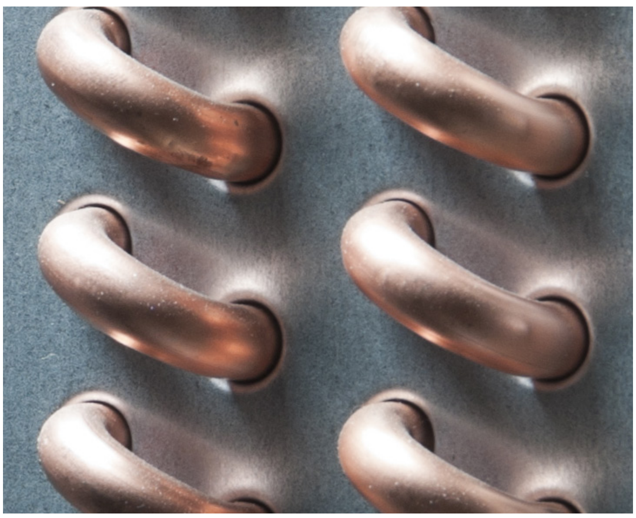
a) The type of compressor used. Large centrifugal compressors only need lubrication of rotating shaft bearings – there is little or no interaction between the lubricant and the refrigerant. Most small and medium sized compressors are 'positive displacement' machines and there is intimate mixing of the lubricant and refrigerant. This includes reciprocating, scroll and screw compressors, which are used for the vast majority of RACHP applications. Screw compressors rely significantly on the lubricant for sealing and compressor cooling – they have large and complex oil systems external to the compressor. Reciprocating and scroll compressors have smaller oil systems, integrated into the casing of the compressor.

b) Oil return systems. For all types of positive displacement compressor, there will always be oil entrained in the refrigerant discharge gas. This can be partially removed by oil separator vessels fitted in the discharge line, but it is impossible to remove 100% of the oil. Some oil will be carried over



into the condenser and then passed to the evaporator. Once the oil reaches the evaporator there is a risk it will accumulate there – evaporators are designed to only allow vapour to return to the compressor as any refrigerant liquid would damage the compressor. Equipment designers need to consider how they will protect the compressor from the return of liquid refrigerant whilst at the same time avoiding the build-up of any liquid lubricant. Oil build-up in an evaporator can significantly degrade cooling capacity and energy efficiency. The type of oil return system that is appropriate depends on the system configuration e.g. whether the evaporator is direct expansion or flooded. For effective oil return, the oil must have a low enough viscosity to flow easily at the evaporating temperature.

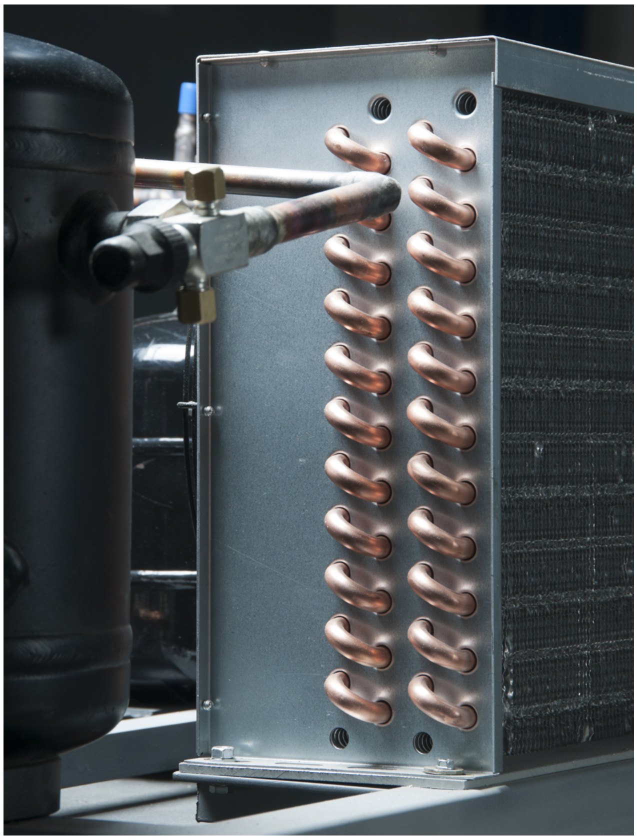
c) Hermetic and semi-hermetic compressors. Most small and some medium sized RACHP systems incorporate the electric motor within the pressure shell of the compressor. This eliminates the risk of shaft-seal leakage that is common for larger open compressors. The refrigerant suction gas flows over the motor windings to provide cooling. This suction gas will contain some lubricant – it is important that the lubricant has good insulation properties and that it does not react with any materials in the motor windings.



6 Evolution of refrigeration compressor lubricants

Prior to the phase-out of CFC refrigerants in the 1990s, most RACHP compressors used mineral oils for lubrication. Since that time there has been significant evolution of the type and sophistication of the lubricants available. Various synthetic oils have been developed and are now the best choice for most RACHP applications. In particular, polyol ester (POE), polyalkylene glycol (PAG) and polyalphaolefin (PAO) oils are used for various different RACHP applications.

Oil manufacturers include additives to enhance the oil performance e.g. for lubricity improvement, pour point depression, anti-foaming, extreme pressure and for increasing thermal and chemical stability. By balancing a lubricant's formulation it is possible to specifically design grades for use with specific refrigerants. The aim is to design oils with specific performance characteristics such as fluidity at low temperature, compatibility with the refrigerant and refrigeration system components, wear protection of the compressor part, oil durability.



7 Refrigerant trends

The types of refrigerant being used in new RACHP equipment are changing, mainly in response to the need to avoid use of high GWP HFC refrigerants.

The changes are quickest in the EU; its F-Gas Regulation driving the fastest HFC phase-down schedules. In 2018 there was a 44% cut in the GWP weighted quantity of HFCs that could be sold in the EU – this will rise to a 60% cut by 2021 and an 80% cut by 2030.

The changes are slower in other developed countries, driven mainly by the Kigali Amendment of the Montreal Protocol, which introduces a 10% cut in 2019 and a 40% cut in 2024. The timetable for developing countries is several years slower, with the first cuts in 2029. However, most developing countries are still using HCFC refrigerants, which need to be phased-out over the next 10 years. Many developing countries are considering the benefits of 'leap-frogging' the high GWP HFC refrigerants and moving to lower GWP alternatives as soon as possible. This means that lower GWP refrigerants are needed as soon as possible for all new RACHP equipment in these countries.

It is likely that the refrigerant trends already evident in the EU will be adopted in many parts of the world. Natural refrigerants already have a crucial role in many markets and that role is likely to grow. The GWP of these refrigerants is 'ultra-low', which makes them very attractive from an environmental perspective[3]. Some key examples are:

a) The use of hydrocarbons in small hermetically sealed systems. Almost all new domestic refrigerators in the EU use HC-600a (iso-butane). There is rapidly growing use of HC-290 (propane) in stand-alone commercial refrigeration units used in shops and supermarkets. HCs are also well suited to small hermetically sealed air-conditioning units and to certain types of domestic heat pump.

b) The use of CO2 in commercial and industrial refrigeration. There is rapid growth in the use of R-744 (CO2) for a range of refrigeration applications. Growth is fastest in the supermarket sector. The initial growth was restricted to large systems (due to high capital cost of small systems) in northerly locations (to maximise energy efficiency advantage). However, in the last few years these constraints have been eased. Low-cost condensing unit systems are now available and more sophisticated CO2 cycles create good efficiency in warmer climates. CO2 is also proving an effective refrigerant in many industrial applications.

c) The use of ammonia in industrial refrigeration. R-717 (ammonia) has always been used in industrial systems, for example in breweries, food factories and large cold stores. The latest designs allow much lower refrigerant charge, which reduces some of the safety related risks. This has allowed ammonia to become cost-competitive in much smaller sized industrial systems than previously possible.

d) The use of ammonia or hydrocarbons in large chillers. Liquid chillers, for air-conditioning or industrial applications, are usually located in restricted areas (e.g. plant rooms or roof-tops) which makes the application of ammonia or propane a practical option.

[3] Examwple GWPs:

Ammonia: 0	CO2: 1	Propane: 3
R-404A: 3922	R-410A: 2088	HFC-134a: 1430

8 Benefits and Challenges to be addressed

Each of the natural refrigerants discussed above has certain advantages and also various challenges that must be addressed by equipment designers. Most challenges are of a general nature, but some relate specifically to the selection of the best lubricant. Some key issues include:

a) Hydrocarbons

- **Benefits:** Ultra-low GWP, excellent thermodynamic properties creating potential for high efficiency, family of fluids can be selected or blended to suit each application, good heat transfer characteristics and good materials compatibility.

- **General challenges:** Safety related to use of a higher flammability (Category A3) refrigerant.

- **Lubricant challenges:** Hydrocarbons have high solubility with conventional mineral lubricants and ester oils. For this reason very low solubility lubricants are required. Given the very low operating temperature, the lubricants used in hydrocarbons application need to have a very low pour point and also a very low vapour pressure to increase the efficiency of the separator. The most common formulations used in these application are PAG and PAO.

b) CO2

- **Benefits:** Ultra-low GWP, small compressor swept volume and pipe diameters, good heat transfer characteristics, non-flammable and good materials compatibility.

- **General challenges**: Operating pressure very high, critical temperature very low and safety related to respiratory response.

- Lubricant challenges: The principal issues arise due to the high operating pressures and solubility that happen in both subcritical cascade systems and transcritical high pressure CO2 applications. High operating pressures (a standstill pressure of 50 to 130 bar) and temperatures place higher loads and stresses on bearings and other

contacting parts in motion compared with HFCs. This presents particular lubrication challenges. Also, because CO2 is more solvent than HFCs, lubricants for traditional applications cannot be used. There are synthetic lubricants (POE) specifically designed for refrigeration applications that withstand the high solvency of the CO2. They also help protect against insufficient lubrication, which can result in increased bearing wear, reduced component life and increased maintenance costs. Inadequate lubrication can also result in improper sealing of clearances and loss of compression, lower compression efficiency, higher operating cost and greater energy consumption.

c) **Ammonia**

- **Benefits**: Low refrigerant cost and excellent thermodynamic properties creating potential for high efficiency.

- **General challenges**: Safety related to high toxicity and use of a lower flammability (Category B2L) refrigerant and restricted materials compatibility (cannot be used with copper components).

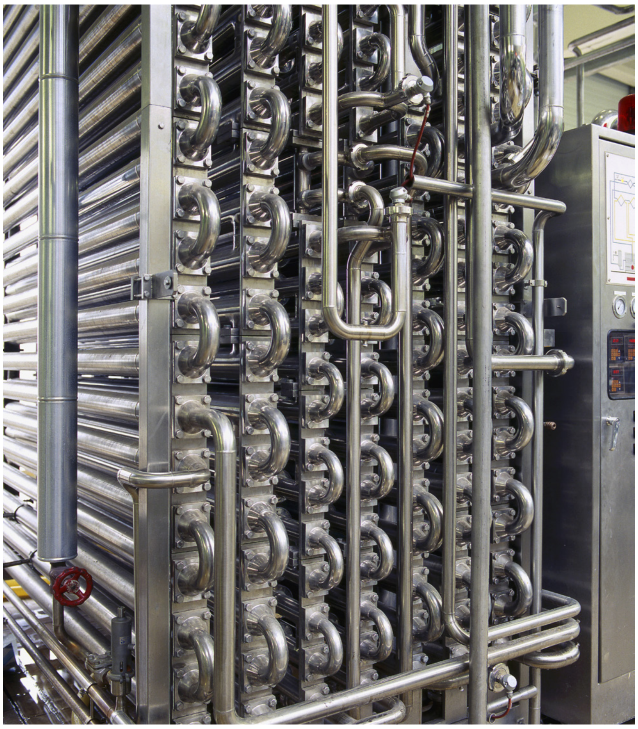
- **Lubricant challenges**: Ammonia has very low or no miscibility with most oils, which can reduce lubricant efficiency, while its high operating temperature can diminish the efficiency of mineral oils; a problem that can be overcome through the use of synthetic oils. Ammonia systems, due their high vaporization heat, produce high thermal stresses that require lubricants with high oxidation resistance, low operating temperatures, excellent fluidity and high viscosity index. Low volatility lubricants can reduce the oil thickening and carryover. PAO or PAO/AB (Alkylbenzene) blends are the preferred technologies.

9 Next generation lubricants

To overcome the lubrication challenges presented by natural refrigerants, Mobil recently introduced two new products. Mobil Gargoyle Arctic™ 68 NH, its most advanced mineral-based lubricant for ammonia applications, and Mobil SHC™ Gargoyle 80 POE, a synthetic oil for CO2 applications.

Mobil Gargoyle Arctic™ 68 NH
is designed for large industrial reciprocating and rotary refrigeration compressors. It is formulated to help improve system efficiency and offers cost and performance benefits by extending oil drain intervals while maintaining a superior oil flow across a wide temperature range.

Mobil SHC Gargoyle 80 POE
is designed specifically for the lubrication of refrigeration compressors using CO2. It offers excellent wear protection, as well as chemical and thermal stability. Its unique formulation offers excellent low-temperature fluidity, in-service viscosity control and potential contribution toward system efficiency improvements, when compared to mineral oils.



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Over more than 150 years, Mobil™ industrial lubricants has established a legacy of innovation and decades of proven performance. Our experts help customers around the world lower costs, improve productivity, enhance equipment efficiency, and become safer and more profitable organizations.

Our highly experienced Equipment Builder engineers work closely with leading OEMs to help guide our research chemists and lubricant formulators in developing leading-edge lubricants for the most demanding applications.

Regardless of the application or the industry, Mobil™ is uniquely positioned to help you meet the challenges of today and tomorrow.

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