Lubricants for Sustainable Cooling

Peter Gibb, Steven Randles, Michael Millington and Andrew Whittaker

Uniqema Lubricants, The Wilton Centre, Wilton, Redcar, Cleveland, TS10 4RF, U.K.

Summary

Over the last decade, the refrigeration industry has faced-up to two pressing environmental challenges:

- The need to move away from chemicals with high Ozone Depleting Potential (ODP) and meet the targets outlined in the Montreal Protocol
- The need to move towards products which result in reduced Global Warming Potential (GWP) and contribute to meeting the targets outlined in the Kyoto Accord

This paper demonstrates the role that the refrigeration lubricant can play in meeting these targets. It discusses the development of oils that enable the use of non-ozone depleting refrigerants and which can deliver up to 15% energy saving, leading to indirect reductions in emissions of the greenhouse gas CO_2. The benefits have been delivered while maintaining the high level of lubricity and reliability required in a modern system. The paper also discusses the integrated social, environmental and economic implications of these commercially important advances in lubricant technology.

Introduction

Conducting business in the 21st century will depend on our ability to create products and services that generate economic prosperity and contribute to environmental quality in a socially responsible and equitable manner.

Over the last decade, industry has faced-up to two pressing environmental challenges:

- The need to move away from chemicals with high Ozone Depleting Potential (ODP) and meet the targets outlined in the Montreal Protocol
- The need to move towards products which result in reduced Global Warming Potential (GWP) and meet the targets outlined in the Kyoto accord

The refrigeration and air-conditioning sector has a very important role to play in meeting these targets.

Air-conditioning has moved from being a luxury to a basic requirement of modern society, enabling us to control the quality of our interior environment whether in the office, at home or on the move in a bus, car or aeroplane. The same technology applied to the preservation of food on both a commercial and a domestic scale provides an indispensable means of minimising waste. Moreover, refrigeration plays a critical role in the storage of sensitive vaccines and medicine, sustaining our health and quality of life.

A critical component in all refrigeration and air-conditioning systems is the compressor, the mechanical pump used to compress the circulating refrigerant gas. It controls the degree of cooling achieved in the equipment. In many applications the lubricant, which is essential for lubrication of the moving parts, is charged during the manufacture of the compressor and is expected to work reliably for the entire life of the unit.

Refrigeration lubricants have to fulfill a number of duties. Their primary function is to lubricate the internal moving parts of the compressor. In addition, the lubricant provides a seal between the moving parts enabling efficient gas compression, it helps to transfer heat from the crankcase to the compressor exterior keeping the moving parts cool, and it reduces noise generated by the compressor.

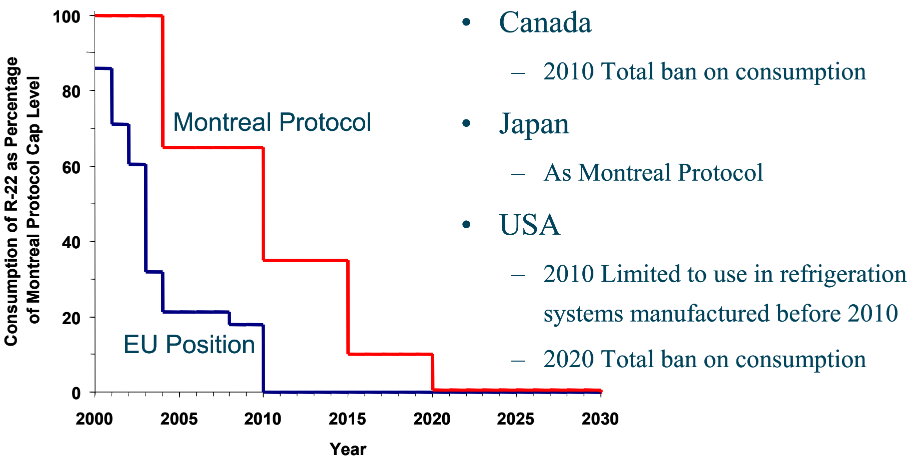
This paper demonstrates that optimization of the lubricant formulation can deliver significant energy savings to refrigeration and air-conditioning systems, while at the same time maintaining performance and reliability. Adoption of the new lubricant technologies outlined below have enabled manufacturers to simplify system design and will deliver energy savings of US$2 billion over the next 25 years in the USA alone (1).

1 Ozone Depleting Potential – Montreal Protocol

Under the Montreal protocol the ozone depleting chlorofluorocarbon (CFC) refrigerant R-12, which was then universally used in refrigeration and air-conditioning systems, was required to be phased-out. It was mainly replaced by a new range of non-ozone depleting hydrofluorocarbon (HFC) refrigerants, including R-134a, R-407C and R-410A, although in larger industrial refrigeration and air-conditioning applications an interim hydrochlorofluorocarbon (HCFC) refrigerant R-22 is currently in use. In the developed world the conversion to HFCs for domestic refrigerators and freezers, along with automotive air-conditioning was essentially completed in 1995, and is now well underway for larger industrial refrigeration and air-conditioning systems (see figure 1). In the less-developed world, where the timelines for phase-out are further out, significant progress is being made towards technology conversion.

This changeover from one technology to the other is not straightforward and requires considerable ingenuity with a particular focus on redesign of the lubricant, without which the Montreal targets could not be met. Further difficulties have arisen by the diversity of HFC refrigerants developed to replace R-22, each with characteristics optimised for specific applications.

Figure 1. Phase-out of R-22 in Developed Countries



The mineral oil lubricants traditionally used with R-12 refrigerants were found not to be compatible with the new HFC refrigerants and this lack of a suitable lubricant posed a serious threat to meeting the Montreal Protocol timetable. The transition was made possible only by the development of a new range of synthetic polyol ester lubricants that possessed sufficient lubricity and compatibility to operate successfully with HFCs.

The design of a lubricant capable of meeting such diverse needs is a complex process. Many lubricant parameters need to be taken into consideration. Desirable properties of a refrigeration lubricant include high lubricity and chemical stability combined with compatibility with the metallic and non-metallic materials of construction of the compressor. A good lubricant also requires a relatively high thermal conductivity to aid heat transfer and a low electrical conductivity to avoid shorting the electric motor windings that are immersed in the lubricant. Compressor reliability is also critically dependent on mutual solubility of the lubricant and refrigerant gas that is essential for good oil transport characteristics that prevent oil starvation and seizure.

The development of this technology was a major factor in allowing the refrigeration industry to meet its Montreal Protocol targets.

2 Reduction in Green House Gas Emissions - Kyoto Accord

As a result of the Kyoto Accord on climate change, significant legislative requirements have been imposed on air-conditioning systems. For example, the U.S. Department of Energy (DOE) has imposed a 20% increase in the SEER (Seasonal Energy Efficiency Ratio) of air-conditioners and heat pumps by 2006 (2).

Similar efficiency targets are also in place in Japan, where the introduction of the 'Top Runner' programme of energy efficiency standards demands an improvement in air-conditioner efficiency of 14% over 1999 levels by 2007.

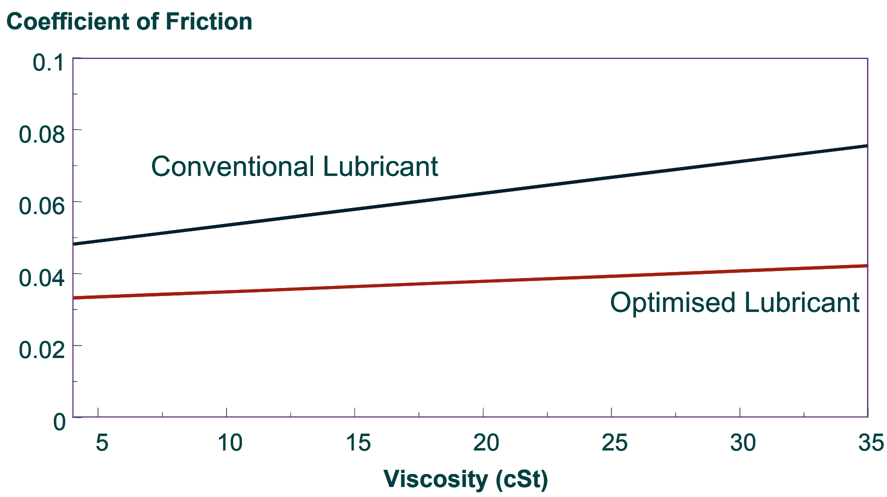
The lubricant, as a critical component of the air-conditioning system, can play a fundamental role in reducing the power consumption. Recognising that the refrigeration and air-conditioning industry would need to respond to these increased energy demands, enlightened compressor and lubricant manufacturers anticipated a need for more energy efficient compression technology. The opportunity for refrigeration lubricants that would enhance the energy efficiency of existing compressor designs set clear targets for innovation.

Extensive research was carried out to explore how lubricant design affects energy efficiency, using specially designed state of the art bench and compressor tests, combined with sophisticated analytical techniques. It was found that the lubricant could affect system energy consumption by modification of the friction within the compressor, and the transfer of heat across the evaporator and condenser.

2.1 Compressor Friction

Detailed theoretical calculations predicted that energy efficiency performance of most compressor types will be dominated by losses arising from lubricant transport and friction losses, and that the most significant impact on energy efficiency would be obtained by reducing the lubricant viscosity (3). Following on from this work, a series of lubricants has been developed with greatly reduced friction and viscous drag. Figure 2 demonstrates the significant improvements in friction that can be obtained by optimising the lubricant formulation.

Figure 2. Effect of Lubricant Formulation on Friction

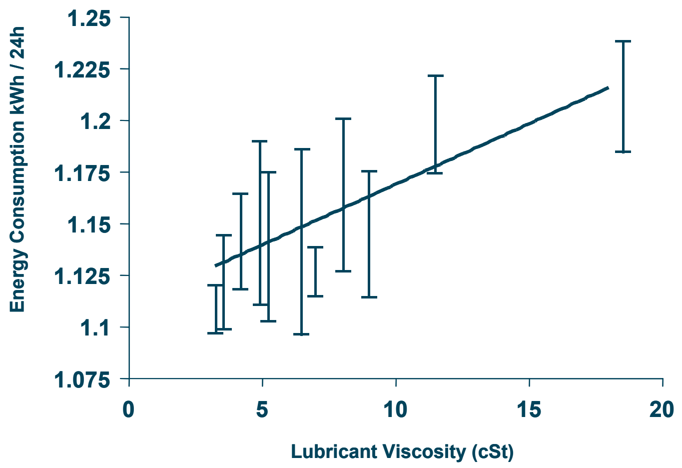


Close co-operation with equipment manufacturers to understand how these novel lubricant formulations interacted with a variety of compressor designs and surface treatments enabled the speed and reduced the costs of technology implementation.

These developments are not limited to the developed world, and increased efforts are being focussed on the introduction of this new technology to lesser-developed countries. For example, China has set itself a goal to reduce greenhouse gas emissions by a total of over 100 million tons of carbon dioxide from 20 million households over the next 15 years. As 80 percent of China's electricity is generated by coal-burning plants introduction of this technology can reduce emissions of many other significant air pollutants (4).

The benefit of the introduction of more energy efficient refrigeration lubricants is already realised in domestic refrigeration, where the use of new, low viscosity lubricant technology has contributed to a reduction in energy consumption of around 15% compared to traditional lubricants (figure 3).

Figure 3. Effect of Lubricant Viscosity on Appliance Energy Efficiency



2.2 Heat Transfer

An alternative approach to the improvement of energy efficiency is to develop systems with enhanced heat transfer. Refrigeration compressors pump a small amount of oil with the refrigerant. The installation should have been designed to ensure that this oil circulates around the system and returns to the compressor, however the presence of oil in the heat exchangers can have a significant effect on their efficiency. Blocking or partial blocking of the fin coil due to any obstruction will drop the evaporating temperature; a 1°C drop in evaporating temperature increases the energy use by up to 4%. The capacity of the system is also reduced and the cooled space may not achieve the desired temperature (5).

Studies have shown that the lubricant can be designed to have a beneficial rather than negative effect on the efficiency of heat transfer. Early results have demonstrated that an optimised lubricant formulation might increase the heat transfer capability of an evaporator by up to 20%. This could lead to further energy efficiency improvements or the ability to save costs and resources by the implementation of smaller heat exchange devices.

It is estimated that up to 80% of the industrial refrigeration and air-conditioning systems replaced in the next twenty years in the USA could use this new lubricant technology, due to its inherently low cost of implementation (6). The total annual energy that would be saved with the use of the new technology is estimated as up to 200,000 GWh corresponding to 11 million metric tons of carbon in reduced CO_2 emissions.

3 Total Environmental Impact

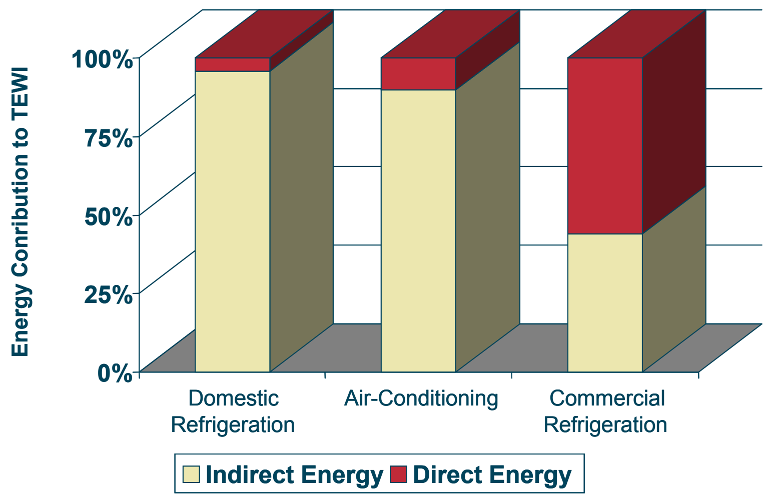
3.1 Global Warming Impact

The concept of the Total Equivalent Warming Impact (TEWI) of refrigeration systems was created when new refrigerants were being substituted for ozone-depleting substances. The objective was to create an index to compare different refrigeration systems that are meant to be more environmentally benign with respect to their global warming effect. Both the direct contribution of greenhouse gases used to make or operate the systems and the indirect contribution of the carbon dioxide emissions resulting from the energy required to run the systems over their normal lives must be taken into account when determining the total global warming impact of a system. The sum of the direct and indirect emissions of greenhouse gases represents the TEWI of the technologies being compared.

The calculated TEWI is sensitive to assumptions of the system lifetime, emission losses, and the integration time horizon chosen to calculate global warming potential (GWP) values as well as the source and consumption of energy. For example, the TEWI of any given system in a country where a large proportion of electricity is generated through wind power would be less than in one where coal-fired power stations are dominant.

A press release from the IIR noted that room air-conditioning installations are currently consuming around 15% of all the electricity-produced worldwide (7). The impact of the sector on global warming has two origins: 20% from refrigerant emissions and 80% from secondary CO_2. In contrast to domestic refrigeration and air-conditioning systems, the direct contribution of greenhouse gases to the TEWI of commercial refrigeration systems is larger than the indirect effect (8), due to both leakage of the refrigerant and the greater energy required for system construction and maintenance (see figure 4). It is clear that improvements in system reliability will have a significant effect on the total environmental impact on such systems.

Figure 4. Direct and Indirect Part of TEWI



The more rigorous concept of Life-cycle Climate Performance (LCCP) is now gaining support. LCCP is generally considered by the scientific community and industry to be the most accurate means of comparing the overall global warming impact of systems over their lifetime, including component manufacture, operation and disposal of equipment (9). LCCP is expressed as kilograms of carbon dioxide (CO_2) emitted. This includes both the greenhouse gas emissions from the refrigerant (direct effect), and the resultant CO_2 emissions from producing energy using fossil fuels to power the refrigeration system (indirect effect). System leakage and refrigerant loss during installation, commissioning, servicing and decommissioning must also be included in the direct effect calculations.

However, despite the fact that many European governments accept LCCP or similar life-cycle analysis as valid tools, some of them still wish to take the GWP into account for decision making on global warming. In doing so, they fail to recognise that the GWP reflects the potential rather than the actual contribution to the greenhouse effect, and that the real focus should be on preventing emissions over the full life of a product and improving energy use in both energy-saving or energy-consuming applications.

3.2 System Reliability

The tribo-molecular structure of the new lubricant technologies imparts a significant advantage in terms of thermal stability and lubricity when compared to conventional oils. This obviates the need for additives in normal applications and serves to minimise the level of additives required for operation under extreme conditions.

Simplicity and reliability are directly related. A system without additives is a simple and reliable system. Incorrect use of additives has caused many problems in the field including: mechanical seal failure, deposit formation, incompatibility with other lubricants and additive depletion leading to a marked deterioration in performance at some point in time (10,11).

The new family of polyol ester lubricants that have been developed for use with all commercially available HFC refrigerants are also compatible with R-22, R-600a and carbon dioxide refrigerants. As such, these lubricants can be used for the retrofitting of existing equipment, as well as bringing the advantages of excellent lubricity and low energy consumption to systems operating with ‘natural’ refrigerants.

4 The Value of Sustainable Refrigeration

It has been estimated that air-conditioning and refrigeration equipment in the USA consumes more than 15% of the total energy consumption in a modern building, amounting to over 1.5 million GWh per year. In addition, refrigeration accounts for 50-60% of electricity usage of an average grocery store, of which half is expended on operating the compressors (12). In the commercial refrigeration sector, primary energy savings of about 80GWh have been identified, assuming implementation of the most economically attractive technologies (13). To put this into context, this saving is the equivalent of 88 million 100-watt light bulbs running continuously for 1 year.

When implemented, the USA SEER standard will save 880,000 GWh of energy over 25 years, avoiding the construction of three 400 megawatt coal-fired power stations and twenty-seven 400 megawatt gas-fired power stations. This is expected to result in net savings of $2 billion to the nation’s consumers (1).

The major energy efficiency improvements delivered through the lubricant enable manufacturers to avoid costly re-engineering to achieve enhanced energy efficiency. For example, the new high efficiency lubricants can deliver at least half of the 30% efficiency improvement achieved by the new super-efficient refrigerator models. This gain allows manufacturers to simplify their system design and save money by removing certain electronic components. Energy-efficient equipment can also lead to savings via tax rebates (in the USA) and increased sales.

5 Conclusions

The global economy has become highly dependent on air-conditioning and refrigeration equipment. Whether used for comfort-conditioning homes and commercial buildings, preserving food and medical supplies, or maintaining environmental conditions for manufacturing, this equipment has become ubiquitous.

Sustainable development poses a challenge to industry. For far-sighted companies able to anticipate the emerging needs of industry and society, such challenges present an excellent incentive to innovate and develop new products capable of displacing their less sustainable predecessors, thereby creating new opportunities for business growth. By leading the development of these new lubricant technologies, we have been able to increase efficiency, reduce energy use and minimise the environmental impact of technologies that are vital to our way of life. The role that the new lubricant technologies have been able to play in these developments has been independently recognised through the grant of the Queen's Award for Sustainable Development in 2003 (14).

Over 4 billion people do not have access to refrigeration, since prohibitively high costs in many rural areas prevent its wider dispersion (15). Developments in refrigeration technology could make this basic commodity more widely available throughout the developing world and contribute to an improved quality of life for many people.

References

1. Air Conditioning and Refrigeration Institute website, www.ari.org

2. Association of Home Appliance Manufacturers website**,** www.aham.org

3. P. Gibb, S. Randles, S. Boyde, S. Corr and I Takahashi, "The Effect of Lubricant Physical Properties on Energy Consumption of Refrigeration Compressors", Kobe Conference (2000).

4. A Chan, Lawrence Berkeley National Laboratory News Release (1999).

5. N Mitchell, "Annual System Inspections Reduce Electric Energy Consumption", ASERCOM Symposium, Nuremburg, 2000.

6. US Department of Energy, Energy Efficiency and Renewable Energy (EERE) website www.eren.doe.gov

7. Japanese Air Conditioning and Refrigeration News, February 2001.

8. H Kruse, "A Study of Energy Consumption in Refrigeration / Air-Conditioning Market Segments", ASERCOM Symposium, Nuremburg, 2000.

9. The United Nations Framework Convention on Climate Change – Fluorochemicals and the Kyoto Protocol, 2000.

10. S Randles, A Whittaker, S Corr, and T Nishizawa, "Field Experience with Plugging of Capillary Tubes and TXVs in POE Lubricants", International Conference on Ozone Protection Technologies, Baltimore, 1997.

11. S Randles, "The Advantages and Disadvantages of Additives in Polyol Esters: An Overview", American Society of Heating, Refrigeration and Air-Conditioning Engineers, Summer 1996 Meeting, San Antonio.

12. J Monahan, "Save Energy By Controlling Refrigeration Costs", Natural Foods Merchandiser, August 2001.

13. D Westphalen, R Zogg, A Varone and M Foran, Energy Savings Potential for Commercial Refrigeration Equipment Final Report prepared by Arthur D Little, Inc. (1996).

14. Queen's Award for Enterprise: Sustainable Development 2003, awarded to Uniqema Lubricants.

15. G Klok, "Affordable Refrigeration for Developing Countries", Technology and Development ed. 4, 2000.