LUBRICANT DIRECTION FOR COMFORT COOLING AND HEAT PUMP APPLICATIONS

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ABSTRACT

Quality of life and environmental aspects have created increased need for comfort cooling and heat pump applications. Cooling is becoming more prevalent around the world to benefit health and welfare while expansion to heat pump usage profits global decarbonization efforts. Intertwined in this is the changing of refrigerants to benefit environmental reduction of higher global warming potential refrigerants. With these changes comes the need to either evaluate new lubricant options or modify existing options to fully meet the requirements the industry has become accustomed to when providing dependable and energy efficient operation. This paper will focus on lubricant options for compressor and system operation mainly in residential AC and larger HP applications. Challenges will be examined when switching to alternate refrigerants and solutions will be identified, while maintaining common evaluation approaches and advancing to new methods. Various compressor mechanisms will be evaluated that sometimes can require a range of lubricant chemistry and viscosity options.

Keywords: Lubricants, Refrigerants, Heat Pump, Cooling

INTRODUCTION

Global direction for changing to alternative lower GWP refrigerants still has some uncertainty on unity. Some regions are more dedicated to making a commitment to change as soon as posssible, while other regions are more slow to change or are montitoring the direction before making decisions. The split or indecision is centered on both a unified GWP value and the divide between what has been termed synthetic refrigerants, such as hydrofluoroolefins (HFO), hydrofluorocarbons (HFC) and hydrochlorofluoroolefins (HCFO) versus natural refrigerants such as hydrocarbons (HC), carbon dioxide (CO_2) and ammonia (NH_3). In addition to GWP values, other considerations such as safety (toxicity, flammability and pressure) and effective operating performance (capacity and efficiency) still are a vital part of choosing the right option. Figure 1 is a snapshot look at some of the options base on these considerations particularly for comfort cooling applications.

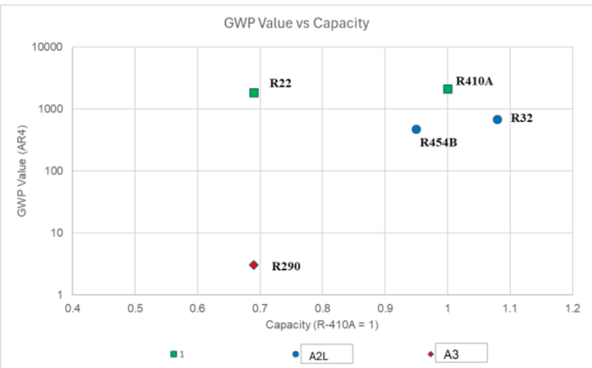

Figure 1: Refrigerant GWP Values vs Capacity

COMFORT COOLING

The market for units to produce cooling air is approximately 150-million units per year. It is estimated that 90% of the residence in the US market have an air conditioning unit along with cooling in commercial segments. Though the number of units and volume of growth can vary by region there is still a tremendous demand for comfort cooling and is estimated this number is 0.06 pieces per household. The existing volume and growth potential creates a critical need to develop technology that is not only cost effective but energy efficient, reliable and environmentally friendly. This centers around refrigerant selection first, compressor design and then lubricant options.

Currently five predominant refrigerants that play a role in the air conditioning market of past, present and future. There are still R-22 units that make up the first wave of reduced production due to ODP, then R-410A with the second wave due to GWP, while R-32, R-454B and R-290 all being developed for next generation options.

LUBRICANT CHALLENGES

Historically refrigerant changes have brought changes to lubricant chemistry and this is similar to refrigerant changes today. The five predominant lubricants used are Mineral (MO); Alkylbenzene (AB); Polyolester (POE); Polyvinyl ether (PVE) and Polyalkylene glycol (PAG). Table 1 shows the typical lubricants used with refrigerants. (X=predominant; O=secondary)

Table 1: Lubricant Options for Various Refrigerants

	R22	R410A	R32	R454B	R290
MO	X				X
AB	X	O			X
POE		X	X	X	X
PVE		X	X	X	O
PAG					X

For R-22, the challenge is with stability and miscibility for some mineral oils and applications. This was the main reason alkylbenzene lubricants were developed to help support stability and miscibility over a broader operating range. R-410A and R-32 challenge is immiscibility to poor miscibility with MO and AB along with certain chemistries of synthetic lubricants. R-454B has the same challenges of the HFC refrigerants but also reduced stability due to the unsaturation in the molecule and some flammability. R-290 challenge is high solubility that dilutes operating viscosity and high flammability that restricts charge amount and application use.

LUBRICANT OFFERINGS

HCFC's

Eventhough R-22 is still used on a global bases in developing countries for new air conditioning applications, the type of lubricant option has been set for years with no innovative development. Alkylbenzenes and mineral oils have been the predominant products particularly in rotary compressors for smaller AC units. As mentioned earlier, AB's where developed to overcome stability and miscibility issues when using MO's. But these brought some changes to other aspects, like working viscosity. Figure 2 is a comparison in the solubility factor and working viscosity difference between a 32 cSt white mineral oil and 32 cSt alkylbenzene at a set pressure of 6 bar and varying the oil temperature. We start to see the reduced miscibility of the white mineral oil, reducing solubility and increasing working viscosity over the more miscible AB. These are tradeoffs that need to be evaluated when choosing options that will provide the optimal performance and reliability.

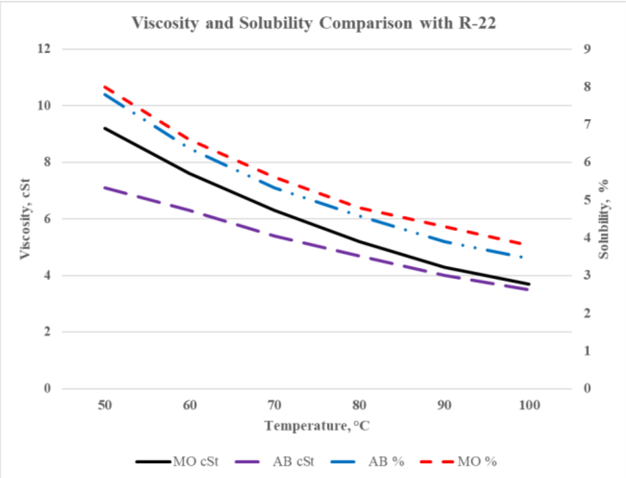

Figure 2: Mineral Oil and Alkylbenzene Comparison

HFC's and HFO's

For lubricant evaluation and options these refrigerant chemistries can still be grouped because of similar miscibility profiles regarding MO, AB and other synthetic lubricants. When evaluating lubricant options for alternate refrigerants for R-410A, use of similar candidates used with R-410A can be used with R-454B but less likely with R-32. This is mainly due to the miscibility gap between R-410A and R-32 which is much greater than between R-410A and R-454B. Typically the R-32 lubricant options have chemistries, that when formulated to have better miscibility, also result in lower working viscosity. This is why most of these options have increased in base oil starting viscosity to help compensate for bearing lubrication.

Table 2 makes a comparison when operating with the three above mentioned refrigerants and lubricants that would be used with AC applications typically using scroll compressors.

Table 2: Comparison

	R-410A	R-32	R-454B
	ISO 32	ISO 46 (ISO 40)	ISO 32
Miscibility @ 20%, °C	-25	-22 (-35)	-25
SST, °C	0	0	0
Pressure, Bara	8	8.1	6.6
Temperature, °C	60	60	60
Viscosity, cSt	8.5	10.5 (9.7)	9.0
Dilution, %	6.7	5.5 (5.8)	4.8
SST, °C	5	5	5
Pressure, Bara	9.3	9.5	7.9
Temperature, °C	70	70	70
Viscosity, cSt	6.7	8.1(7.6)	7.0
Dilution, %	6.5	5.5 (5.7)	4.9
SST, °C	10	10	10
Pressure, Bara	10.8	11.1	9.3
Temperature, °C	80	80	80
Viscosity, cSt	5.4	6.4 (6.0)	5.5
Dilution, %	6.4	5.5 (5.7)	5.0

When trying to match the bearing lubrication seen with R-410A and ISO 32 POE, there becomes a challenge if using the same R-410A lubricant with R-32. First, the miscibility of that product in R-32 becomes poorer, meaning it will have a separation at a higher temperature and there tends to be a working viscosity reduction despite having less dilution. Early studies also showed trying to find a suitable replacement based on desired miscibility and and 32 cSt viscosity tended to fall short of bearing protection in some conditions and applications. This has led to using higher viscosity lubricants with R-32 to try to maintain adequate bearing lubricant film thickness. From Table 2 we can see at some varying conditions of saturated suction temperature and oil sump supply temperature that the ISO 46 version of a new POE, achieves and goes beyond the working viscosity generated when R-410A and ISO 32 POE was used. But sometimes optimization is required to help maintain not only the bearing film thickness but also the energy efficiency associated with the amount of film. Too much film thickness can cause visco drag with the bearing, reducing performance by increasing energy draw. A comprimise was found in the development of a slightly lower viscosity product as outlined in Table 2 as (ISO 40), this product comes closer to matching the working viscosity of R-410A but also has a lower temperature miscibility profile. This lower miscibility temperature could be a better option for compressor systems operating as not only AC units but also heat pump (HP) in lower ambient regions.

Comparing R-410A with R-454B we see in Table 2 that when the same R-410A designed 32 cSt POE lubricant is used with R-454B, the miscibility is the same. This allows for limited system redesign, if any. The working viscosity is also similar which will help in compressor bearing operation without the need for potential redesign. We can also see the influence of the high concentration of R-32 in R-454A (68.9%) reducing the solubility but not effectively increasing the viscosity. Design optimization for viscosity or chemistry can be done to help in developing an optimized lubricant specific for R-454B.

HC

R-290 is a hydrocarbon (HC) refrigerant that has good thermodynamic properties and as outlined in Table 1 can be used with a number of lubricant chemistries. The benefit of R-290 is the positive miscibility profile it can present with the various lubricants while still providing some solubility reduction with certain chemistries, which can help the working viscosity. The solubility reduction can also be beneficial in charge reduction, since R-290 can be regulated for system amounts because of the high level of flammability. Lubricant chemistry can significantly change the solubility parameters with oxygenated molecules showing reduction over mineral oil and other longer chain hydrocarbon lubricants. Figure 3 shows how the lubricant chemistry can effect the solubility of R-290 into the lubricant which in turn will change the working viscosity.

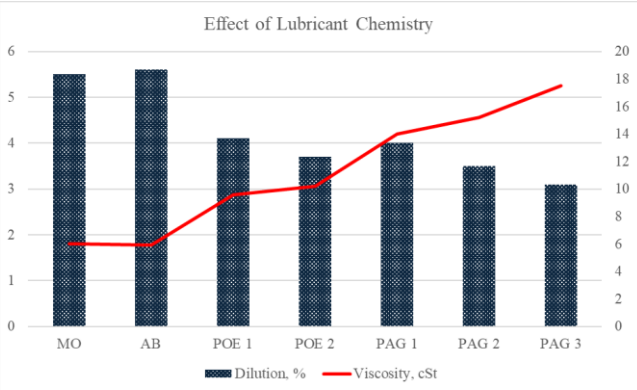

Figure 3: Dilution of R-290 in Lubricants with Viscosity

Each of the lubricants in Figure 3 are an ISO 68 product and the conditions for determining the solubility and viscosity are 70°C (158°F) oil supply temperature and 6 bara (87 psia) refrigerant pressure. Utilizing lubricants that have carbon-oxygen bonds can help reduce dilution and even within this group the number of these bonds and carbon-carbon repeating bonds can minimize dilution further. Even though there are several lubricant choices for R-290, making the right choice still depends on factors of application, compressor design, energy efficiency and cost to determine the right chemistry and viscosity.

HEAT PUMPS

The opposite of cooling is heating and methods of heating without the need for fuel burning emissions can have environmental benefits. The use of compressors to accomplish the heating is growing in popularity with advancements in stability when operating at higher compressor temperatures or reliability and performance when operating at lower and lower ambient temperatures.

Reduction in fossil fuel usage has led to many opportunities to use alternate applications based on refrigerants to generate cooling and heating, one particular method uses carbon dioxide (R-744) in district heating applications.

In many Northern Europe places, the district heating (DH) facilities are substituting or complementing the domestic individual installations that produce hot water for heating purposes, taking advantage of the economy of scale for better energy efficiency. Boilers are being substituted progressively by electrical heat pumps, contributing to the decarbonization of the network. We will review how the harsh working conditions affect the lubrication and the lubricant-refrigerant interaction, using two cycles commonly found in field operations.

R-744 District Heating Heat Pump

R-744 has a low critical temperature that can make the units operate supercritical, renaming the condenser as "gas cooler". Operating R-744 with POE lubricants creates higher dilution which will reduce the working viscosity and can compromise bearing lubrication. Operating with PAG lubricants can reduce dilution and due to its inherent higher viscosity index can provide adequate bearing protection at higher operating temperatures.

An air-to-water HP was used to provide DH to 2000-2500 homes, heating up water from 40 to 70 ºC, extracting heat from the air with conditions outlined in Table 3, showing intermediate temperature (IT) compressor and medium temperature (MT) compressor conditions.

Table 3: Northern Denmark A-W R-744 HTHP field data[1]

Situation	1	2	3	4	5
% Relative Humidity	60	75	85	90	90
Ambient Air Temp, °C	17	11	7	0	-4
Sat Evap Temp, °C	6.2	2.1	-0.7	-8.4	-11.7
Delta T, °K	10.8	8.9	7.7	8.4	7.7
MT Evap Pres, Bara	40.9	36.8	34.2	27.7	25.2
IT Evap Temp, °C	15	11.6	9.3	3	0.4
IT Evap Pressure, Bara	50.9	46.8	44.2	37.7	35.2

[1] Courtesy of Fenagy A/S, Denmark.

IT data are from the compressors reducing gas phase at the liquid reservoir. This facility is using multiple cylinder reciprocating semihermetic compressors for both the IT and the MT. As a rule of thumb (depending on compressor make and model), the target viscosity for piston compressors is about 12 cSt in the crankcase, from where the oil pump is moving the oil to provide lubrication to bearings combined with sealing in the cylinder liners. We will use this value as an example when comparing different lubricants' performance, in order to understand how different oil chemistries interact with the refrigerant in these operational conditions. The two lubricants to be compared are POE ISO 85 (85 cSt at 40 ºC) and a PAG ISO 68 (68 cSt at 40 ºC) purposedly designed to work with R-744. Based on the outlined conditions in Table 3, the data was generated from Daniel Plots of each lubricant-refrigerant combination and shown in Table 4.

Table 4: Working viscosity and solubility at MT and IT conditions

MT CS Temp			1	2	3	4	5
30°C	POE	cSt	***5.6***	***7.4***	***8.9***	*14.2*	*17.1*
	85	%	18.7	16.4	14.9	11.6	10.3
	PAG	cSt	*14.2*	*17.3*	*19.6*	*26.8*	*30.2*
	68	%	15.8	13.9	12.8	10.0	9.0
40°C	POE	cSt	***6.7***	***8.3***	***9.6***	*13.8*	*16.0*
	85	%	15.0	13.2	12.1	9.5	8.6
	PAG	cSt	*15.1*	*17.5*	*19.3*	*24.4*	*26.7*
	68	%	12.7	11.3	10.4	8.3	7.5
IT CS Temp			1	2	3	4	5
30°C	POE	cSt	***3.0***	***3.8***	***4.5***	***7.0***	***8.3***
	85	%	25.1	22.4	20.7	16.9	5
	PAG	cSt	***8.8***	***10.7***	*12.1*	*16.5*	*18.7*
	68	%	20.1	18.7	17.4	14.3	13.2
40°C	POE	cSt	***4.0***	***4.9***	***5.6***	***7.9***	***9.1***
	85	%	19.7	17.7	16.5	13.6	12.5
	PAG	cSt	***10.5***	*12.2*	*13.4*	*17*	*18.6*
	68	%	16.4	14.8	13.9	11.6	10.7
50°C	POE	cSt	***4.7***	***5.5***	***6.2***	***8.1***	***9.0***
	85	%	16.0	14.5	13.6	11.3	10.5
	PAG	cSt	*13.4*	*12.4*	*13.4*	*16.1*	*17.2*
	68	%	11.1	12.2	11.5	9.7	9.0

The higher the temperature at the crankcase, the lower the dilution, for the same pressure. This is valid to both lubricants. Sometimes an increase in the crankcase temperature can lead to a valid working viscosity (>= 12 cSt) with the same crankcase pressure. The dilution effect is counteracting the viscosity reduction by temperature. Depending on the lubricant, one effect can outweigh the other.

The higher the pressure at the crankcase, the higher the dilution, for the same temperature. Another general principle, and we can see that for defined crankcase heater / temperature setup, the lower the pressure the lower the refrigerant diluting the lubricant. For POE, we can see in some situations that for low pressures it can work. Pressures for IT compressors are 10 Bar higher than the previous ones. And we see then how the crankcase temperature must be increased even for the PAG lubricant to keep the working viscosity over the safe value when pressure is high. The high dilution rate and reduced working viscosity excludes the POE oil for this application.
This is an example of how understanding the interactions of lubricants and refrigerants can assist in screening for the best lubricant in a particular application. Sometimes increasing the viscosity of the base oil can help but is not always the only or best solution since we can manipulate the chemistry to reduce the affinity.

CONCLUSIONS

Comfort cooling is a 100 billion US$ revenue market and has a significant effect on environmental aspects from emissions to energy consumption. So it is extremely important to create products with the appropriate refrigerant and lubricant candidates for reliability and performance targets. We have shown some current products such as R-22 and R-410A, that the history can be used to benefit approaches to find lubricant options for next generation refrigerants like R-32, R-454B and R-290. Measuring miscibility, solubility and working viscosity is essential to effectively matching lubricants and refrigerants. Studies were shown that make comparisons on how interactions will change with changes to lubricant and refrigerant chemistry.

Similarly the use of refrigerants have become important to reducing the carbon footprint of fossil fuel-based heating systems. Using district heating is common in regions of moderate to cooler climates and carbon dioxide refrigerant is very effective as a heat pump in these applications. Data is shown on how selecting the right lubricants can produce results that assist performance and durability of the compressors by maintaining effective bearing viscosity when operating to generate heat.

NOMENCLATURE

GWP : Global Warming Potential
ODP : Ozone Depletion Potential
cSt : Centistokes
SST : Standard Suction Temperature

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