Lubricant Options for Screw Compressors Using Alternative Refrigerants

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Abstract. Environmental concerns have created need to find replacements for HFC and in some cases HCFC refrigerants used in screw compressor applications. Like most refrigerant changes it becomes necessary to assess the best lubricant option in order to maintain system reliability and performance. Regardless of the magnitude of the changes it allows opportunity to appraise alternative lubricant chemistries that are different from what was used in the past.

This paper will investigate various alternative refrigerants being evaluated for screw compressor applications. Choices will be presented that not only maintain what was seen in the past but also offers potential to advance application ranges while using of a single lubricant with various operational designs. As always needed when evaluating lubricants and refrigerants, information on the interaction properties along with stability and material compatibility will be presented. Comparisons will be made to legacy data operation and potential improvements will be presented that are available when using combinations of alternative refrigerants and lubricants.

1. Introduction
Food preservation and processing along with building comfort heating/cooling and hot water production, are essential today to our way of life. Screw compressors are used in numerous sizes, designs, operating at various conditions with different refrigerants. This variety requires compressor lubricants of varying viscosities and chemistries to provide needed bearing protection and overall operational reliability and performance.

The lubricant must provide the needed sealing between the rotors and optimal viscosity at other bearings, minimize wear and the ability to help provide ideal performance. Like in other types of compressors, lubricant and refrigerant are going to be at some level of interaction which will drive the viscosity of lubricant and refrigerant combination; sometimes referred to as the working viscosity. The concept of not only understanding this interaction, but also ways to accurately measure, are essential tools to compressor, bearing and system design engineers to calculated bearing loads and viscosity requirements. After determining requirements for lubricant chemistry and viscosity, it is essential to examine the stability and compatibility of these multiple combinations.
The type of heat exchanger design; air-cooled or water-cooled, along with other system components and special enhancements will all dictate which lubricant is chosen for the given refrigerant. This paper will dive into the market of screw compressor operation and examine what is required to provide lubricants to meet compressor demands and refrigerant interactions. The focus will be on evaluating lubricant options for screw compressor used in various refrigeration and air conditioning applications with newer low Global Warming Potential (GWP) refrigerants.

2. Refrigerants and Screw Compressor Operation
Screw compressors use several refrigerants in numerous applications, R-22 is a HCFC refrigerant that is still in use today and several of the common HFC refrigerants like R-134a are predominate. Screw compressors in industrial applications use several low GWP refrigerants in systems using natural refrigerants like ammonia (R-717), carbon dioxide (R-744); propylene (R-1270), propane (R-290) and others. Since some of these HCFC, natural and HFC refrigerants have history in operation and lubricants used in these applications, this paper will focus more on newer low GWP refrigerants such as those based on HydroFluoroOlefins (HFO) and blends. Figure 1 is an example of low GWP refrigerants that are used or under evaluation today. When compared to R-134a, these refrigerants either lack the equivalent capacity and/or are less efficient. Like R-134a, some refrigerants are designated as non-flammable (A1) but will not have the lowest GWP values while others will be mildly flammable (A2L) with smaller GWP values. This paper will emphasize lubricant evaluations for medium pressure refrigerants like R-1234ze(E) and R-513A as alternatives to R-134a [Kujak 2018]. Table 1 is a listing of various refrigerants of interest to the market, their chemical composition and global warming potential (GWP) values [Makhnatch 2019].

![Figure 1: Performance characteristic comparison of some Low GWP Refrigerants and R-134a](image-url)
### Table 1: Refrigerant Composition and GWP Value

| Refrigerant | R-134a | R-1234yf | R-1234zeE | R-32 | R-152a | R-227ea | GWP |
|-------------|--------|----------|-----------|------|--------|---------|-----|
| R-134a      | 100%   |          |           |      |        |         | 1430|
| R-1234yf    |        | 100%     |           |      |        |         | 4   |
| R-1234zeE   |        |          | 100%      |      |        |         | 7   |
| R-513A      | 44%    | 56%      |           |      | 88%    | 12%     | 631 |
| R-515A      |        |          |           |      |        | 14%     | 393 |
| R-516A      | 8.5%   | 77.5%    |           |      |        |         | 145 |

3. **Lubricant and Refrigerant Interaction Consideration in Screw Compressor Operation**

Measuring viscosity of a lubricant is straightforward and there are several methods, techniques, and equipment to produce reliable numbers. But when it comes to determining values of viscosity of lubricant and refrigerant mixtures, more sophisticated equipment and techniques are required. The system needs to be sealed and capable of sustaining high pressure. Jonsson (1998) describes a falling ball viscometer with sapphire viewing windows sealed in a chamber. Though lubricant and viscosity values can be obtained, the method lacks the ability to measure density in-situ, with limits on temperature and pressure ranges. The technique is cumbersome and time consuming in collecting the needed number of data points for accuracy. A more advanced method was developed by [Seeton 2010] which utilizes a closed loop system within an environmental chamber. The lubricant and refrigerant are in circulation while the chamber slowly goes through a temperature profile and collecting data for multiple temperature points, viscosity (usually from two in-line viscometers at different ranges), pressure, mass flow and density. The unit volume is fixed so vapor space correction can be done at each lubricant and refrigerant combination as the temperature and fluid density changes. Gathered data is used to generate ten-point coefficients for viscosity (cPs), density and refrigerant dilution which is used to create Daniel Plots and temperature-pressure solvers. This technique has been used to generate hundreds of plots of different lubricants and refrigerant combinations and is an essential tool when attempting to migrate to new refrigerant and lubricant combination as a screening method [Karnaz 2018]. This method can be used to predict how a screw compressor system operating at discharge conditions with an oil separator can utilize an oil cooler to generate the needed bearing viscosities as demonstrated below.
Figure 2: Example of Manipulating Working Viscosity in Screw Compressor Operation

Figure 2 is an example of how PVT generated data can be useful in showing how a lower viscosity lubricant can still meet minimum viscosity requirements in screw compressor operation. The plot in the example is an ISO 100 lubricant and Point A represents minimum working viscosity requirement for this particular system. Point B and C represent oil temperature and pressure at the discharge condition; in this case showing 30% refrigerant dilution and a viscosity of 8 cSt. Since in this example the compressor requires a minimum of 10 cSt, this lubricant does not meet the demand, but if the equipment utilizes one of several methods to cool the lubricant then this can change this acceptance. Moving from Point C to Point D we see if we cool the oil from 70°C to 40°C by keeping a constant dilution, we double the working viscosity to 16 cSt and move above the minimum. Even without oil cooling we can reach a needed viscosity if we move from Points C to F by increasing the temperature 10°C while maintaining the same pressure, the dilution will drop to 20% moving the viscosity to 11-12 cSt. These techniques may become more vital with the use of some of the HFO low GWP refrigerants that lower the working viscosity due to higher refrigerant solubility rates and other properties.

4. Lubricants for HFO Based Refrigerants to Replace R-134a

Measured miscibility interaction of lubricants and refrigerants is important to understand and could be vital for meeting energy efficiency requirements through heat transfer parameters, in addition to making sure the compressor doesn’t fail due to lack of lubricant [Karnaz 2019]. As lubricant moves out of the compressor into the system, it is important to make sure lubricant is effectively returned to the compressor. Some units, like those used in screw compressors, may purposely use oil separation as a lubrication point to the compressors which could make miscibility targets not as critical. Others though will rely on certain levels of miscibility to maintain what was mentioned earlier. For R-134a used with
screw compressors, POE lubricants have been a lubricant of choice; Figure 3 shows the miscibility curves for three POE lubricants of varying viscosity. For most lubricant and refrigerant combinations, as viscosity increases, the miscibility temperature will rise as seen in the figure; when these same lubricants are measured with R-1234zeE the miscibility points for all three viscosities moves below -60°C at all concentrations. Since moving to lower temperature miscibility results in higher solubility of the refrigerant in the lubricant, HFO-1234zeE solubility is going to be one way of reducing working viscosity which could negatively affect screw compressor lubrication.

Figure 3: Miscibility of POE Lubricants with R-134a and R-1234zeE

The refrigerant over solubilizing in the lubricant is not new, screw compressor operation with R-22 is an example. When R-22 operating conditions move to the point where solubility gets too high and working viscosity is reduced in mineral and alkylbenzene based lubricants, ester-based lubricants that can reach higher base viscosity levels like 300-400 centistokes are used. To successfully develop lubricants for new refrigerants with reduced working viscosities, Shrieve has established processes to evaluate candidates in a timely and effective manner. As already mentioned, initial investigation of R-1234zeE showed the potential to have high solubility particularly in lubricants that will still maintain various miscibility levels. To begin the assessment, it is important to understand what was used in the past and for purposes of drop-in scenarios, along with evaluating minimal levels of investigation and change. Compressors will function at numerous operating parameters based on temperatures and pressures which can complicate the evaluations.

If we look back at Figure 1 and use the examples of that explanation, we can start to make comparisons of traditional POE lubricants used today with R-134a and whether these can be used in a drop-in scenario with new refrigerants. Table 2 shows viscosity at 40°C, which defines the base oil, and 70°C, then proceeds to show how much viscosity will drop with 30% R-134a. As expected, addition of any refrigerant quickly drops the viscosity of the fluid mixture. Higher diluting effects of R-1234zeE over R-134a start to appear; for R-134a the move from ISO 68 to ISO 220 is doubling working viscosity then tripling to ISO 380 but for R-1234zeE this move is closer to 1.5 times for ISO 220 and double for ISO 380. So just moving to higher viscosity of the same chemistry type might not be adequate.
Table 2: Initial Studies to Evaluate R-134a versus R-1234zeE

| Lubricant | Viscosity at 40°C | Viscosity at 70°C | V40 and 30% R-134a | V70 and 30% R-134a | V40 and 30% R-1234zeE | V70 and 30% R-1234zeE |
|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| POE68     | 65 cSt          | 20 cSt          | 5.6 cSt         | 3.0 cSt         | 4.6 cSt         | 2.4 cSt         |
| POE220    | 213 cSt         | 50 cSt          | 9.9 cSt         | 4.8 cSt         | 7.5 cSt         | 3.6 cSt         |
| POE380    | 370 cSt         | 75 cSt          | 15.0 cSt        | 9.0 cSt         | 9.2 cSt         | 4.3 cSt         |

Table 3 is a look at various conditions with POE lubricants and R-134a, these values will be used for later comparisons. Both POE 120 and POE 220 have been used with R-134a in many screw compressor applications. The Polyether chemistry, PE 100, is specifically designed to work with new HFO refrigerants; and as can be seen, is also an acceptable alternative to be used with R-134a. The working viscosity of PE 100 (which is a 100 cSt lubricant) falls closer to what is seen with POE 220.

| Condition | Temp (°C) | Pres (bar) | POE 120 | POE 220 | PE 100 |
|-----------|-----------|------------|---------|---------|--------|
|           | Vis, cSt  | Dil, %     | Vis, cSt| Dil, %  | Vis, cSt| Dil, % |
| Condition A | 26        | 4          | 31      | 18      | 42     | 22     |
| Condition B | 52        | 6          | 17      | 13      | 28     | 14     | 31     | 14     |
| Condition C | 68        | 14         | 5       | 24      | 7      | 25     | 11     | 26     |

To overcome dilution and working viscosity factor of some HFO refrigerants and lubricants, Shrieve has developed lubricants that provide properties to help maintain adequate working viscosities while still maintaining traditional base lubricant neat viscosities. Figure 4 is a comparative look at a traditional POE, a modified POE and PE chemistry with refrigerant R-1234zeE. The PE chemistry is also shown with R-513A, as an example of how this one lubricant chemistry can cover multiple refrigerants. The POE 120 shown above with R-134a was not compared with R-1234zeE because it did not provide enough working viscosity at operating conditions.

Figure 4: Evaluating Working Viscosity of Lubricants for HFO Refrigerants
Further evaluation of the data in figure 4 shows the difficulties of using current POE 220 with R-1234zeE along with benefits of using PE 100 lubricant with R-1234zeE and other HFO refrigerant alternates. For Condition 1 it can be seen how much viscosity is reduced with traditional POE 220/R-1234zeE; also, modified POE 220 with R-1234zeE and even when traditional POE 220 was used with R-134a at this condition there is too much working viscosity. PE 100 provides optimized viscosity over this condition and several other working conditions even though it has half the starting base of an ISO 220 POE. For Condition 5 with R-513A the PE 100 lubricant is also a good fit, meeting the working viscosity requirement for a screw compressor during operation.

5. Lubricant and Refrigerant Stability and Material Compatibility Testing

History has shown us when changes are made to refrigerants there is ultimately some change that needs to be made to materials used in application. This change may be caused by an incompatible situation between materials and refrigerants, lubricants, combination of the two or changes to operating conditions caused by the new working fluids. It is important to try to get an initial understanding of interactions occurring within a system by first screening various candidates. This concept is typically accomplished by testing combinations of refrigerant, lubricant, and material within an enclosed vessel. The art of hermetically sealing glass tubes with these combinations has been successfully utilized in the industry to provide a visual and analytical study of both stability and compatibility. ASHRAE Standard 97 outlines the method and expertise needed to maintain the integrity of the sealed glass when heated to high temperature which generates high pressures with the refrigerants. Other methods have been developed which use metal vessels which can also be sealed and withstand higher pressures while also utilizing larger quantities of material. Once again, a standard has been developed to provide details on this concept which is outlined in ASHRAE GPC 38.

Just as when the screw compressor industry transitioned from CFC/HCFC refrigerants to HFC refrigerants making evaluation of stability and material compatibility, a similar task is required when transitioning from HFC refrigerants to more environmentally friendly options. Table 4 and Figure 5 show examples of stability testing in sealed glass tubes of a lubricant candidate with R-1234yf containing R-513A refrigerant. This combination allows for understanding the effects of R-1234yf which will have different stability profile versus R-134a which is part of this refrigerant blend. Testing is done at elevated temperature to represent an extended time in system operation. Sometimes it becomes necessary to adjust temperatures to allow for a successful time-based evaluation, too low of temperature – no valuable kinetic information is achieved to make predictions, while too high of temperature – unrealistic mechanisms of breakdown are created. Overall, stability is achieved with this combination of lubricant and refrigerant.
Within the compressor and the system, there are numerous metal, plastic and elastomer chemistries interacting with refrigerants and lubricants. Figures 6 and 7 are examples of testing material at elevated conditions with various refrigerants and lubricants. Lessons learned changing from CFC to HFC refrigerant chemistries is that elastomer material will behave differently in different refrigerants and lubricants. So, it is important to understand interaction at elevated conditions. In figure 6 we see example of testing O-ring material in PE 100 lubricant with R-513A with comparison to POE 220 and R-134a. Compared to the neat oil and POE 220/R-134a, this material has no significant hardness change in PE 100 and R-513A along with no change to the acidity of the lubricant after test.

| Lubricant Sample | Additive | Lubricant Appearance | TAN mgKOH/gOil | Fluoride Ion ppm |
|------------------|----------|----------------------|----------------|------------------|
| 1                | None (Neat Sample) | Colorless to Pale Yellow | <0.1 | 0 |
| 2                | None | Pale Yellow to Yellow | 0.2 | 41 |
| 3                | Yes | Colorless to Pale Yellow | <0.1 | 0 |

Figure 6: O-ring Material Compatibility Testing in Lubricants and Refrigerants

Figure 7 is a more detailed look at material compatibility with neoprene elastomer. Testing is done in three different refrigerants with one lubricant, PE 100, making comparison of dimensional and hardness changes. Results indicate very little change in each refrigerant and acceptability of this material.
6. Conclusions
Screw compressors that have historically operated with HCFC and HFC refrigerants with various lubricants, could require change to lower GWP refrigerants. Some of these refrigerant options starting to be used or investigated are based on hydrofluoroolefin (HFO) chemistry, one being R-1234ze(E). This refrigerant provides a low GWP value and with system modifications is acceptable in screw compressors replacing R-134a. Like historical transitions from one refrigerant to another, there is a need to determine lubricant options. Some of this investigation is out of necessity, like the transition from CFC to HFC (mineral oil to synthetics), and others provide opportunities to make improvements or expand other chemistry options.

Refrigerants bring different interaction parameters with lubricants, one of the newer low GWP refrigerants, R-1234zeE, creates reduced working viscosity. This is important in screw compressor operation that typically requires higher working viscosity for operation. This adjustment in the past has been accomplished by moving to higher viscosity lubricants but sometimes this still presents challenges. Trying to maintain levels of miscibility while adjusting the working viscosity to meet desired targets is more difficult with R-1234zeE.

To offset the working viscosity reducing effects of some of the HFO refrigerants, Polyether chemistry has been evaluated. Results of PE 100 lubricant with HFO refrigerant shows acceptability at various working conditions associated with screw compressors operating either in water-cooled or air-cooled applications. This lubricant is also shown to work with other HFO refrigerants like R-513A and others, in addition to working with current R-134a designed systems. PE chemistry also shows good stability and material compatibility at operating conditions with typical compressor and system materials. The Polyether base viscosity can be adjusted to lower values to provide optimized operation. There is also plenty of room to adjust to higher viscosities to accommodate severe operating conditions that could require higher working viscosity, all without changing other properties of the lubricant and refrigerant interaction.
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