Influence of refrigerant on viscosity and pressure-viscosity coefficient of refrigeration compressor lubricants.

R. Tuomas and U. Jonsson
Luleå University of Technology
Division of Machine Elements
SE-971 87 Luleå, Sweden

Following the introduction of non-chlorinated HFC (hydrofluorocarbon) refrigerants and polyolester lubricants, designers of refrigeration compressors have had to re-evaluate their knowledge of compressor bearing lubrication. The higher solubility and the lack of anti wear protection in comparison to the traditionally refrigerant/lubricant makes the lubrication of bearings using the modern systems a much more difficult task than before.
A modern twin screw compressor contains several highly loaded metal-to-metal contacts lubricated with oil, including, rolling element bearings, gears and the rotors. These types of contacts are normally referred as EHD or EHL contacts (Elastohydrodynamic-Lubrication), due to elastic deformation of the surfaces. The expected life of such bearing is to a large degree related to the film thickness in the bearing. The properties of the lubricant that determine the film thickness in an EHD-contact are normally the dynamic viscosity, η, and the pressure-viscosity coefficient, α. In a refrigeration system, both those parameters are affected by the presence of refrigerant. This effect is depending on the oil and refrigerant composition.
A falling ball viscometer has been used to measure the viscosity and the pressure-viscosity coefficient as a function of the amount of dissolved refrigerant. A polyolester oil were tested with refrigerant R-22, R-134a, R-410a and R-32 at 40 and 80 °C, at refrigerant concentrations from 0 % to 30 % dilution.
It has been shown that Eyring equation can be used predict the pressure-viscosity coefficient of a mixture based on the molecular mass ratio of the refrigerants.

1 INTRODUCTION

A modern refrigeration screw compressor contains several highly loaded rolling element bearings lubricated with a mixture of oil and refrigerant. These bearings are operating in the Elasto-Hydro-Dynamic (EHD) lubricating regime, due oil film thickness and the elastic deformation of the surfaces.
In these bearings the most important task for the lubricant is to create a film that separates the interacting surfaces. The expected life of these bearings is to a large degree dependent on the reduction in film thickness caused by the dilution of refrigerant in the oil. Contact between the surfaces will cause locally high stresses resulting in fatigue of the bearing material. If asperity contact occurs it may also result in wear of the bearing surfaces. Jacobson [1] found that the rate of the wear dependents on the oil and refrigerant used and that prevention of wear of the bearing surfaces typically requires 50% higher viscosity when lubricated with a polyolester/R-134a mixture than for mineral oil/R-22 lubricated bearings.

The properties of the lubricant that determine the film thickness in a bearing are normally the dynamic viscosity,η, and the pressure-viscosity coefficient, α. This is very relevant in a refrigeration compressor since these properties are affected by the presence of refrigerant. In SKF application handbook for bearings in screw compressors [8] it is suggested that the viscosity used in calculations of bearing life should be modified to compensate for the reduction in pressure-viscosity coefficient compared to mineral oil. The adjusted viscosity, ν_{adj}, for use in bearing life calculations can be determined as follows:

$$\nu_{adj} = \nu_{mix} (\alpha_{mix} / \alpha_{mineral})^{0.72}$$

where: ν_{mix} and α_{mix} are the actual kinematic viscosity and pressure-viscosity coefficient of the oil-refrigerant mixture at the location of the bearing and $\alpha_{mineral}$ is the pressure-viscosity coefficient of reference mineral oil.

There are a lot of different methods used in the past for measuring the viscosity of oil-refrigerant mixtures. A review of different methods is presented by Speaker and Spauschus [3]. Jonsson and Höglund [4,5] have measured the η and α for oil/refrigerant mixtures using a concentric cylinder viscometer and later on by means of film thickness interferometry measurements. Akei and Mizuhara [6-8] developed the interferometry method further to estimate the viscosity and the pressure viscosity coefficient of oil refrigerant mixtures, including a polyolester with R-134a. They used the Eyring equation, Eq. (1), to estimate pressure-viscosity coefficient of oil refrigerant mixtures.

$$\alpha_{mix} = \frac{m \cdot s_{refr}(\alpha_{refr} - \alpha_{lubr})}{s_{refr}(m-1)+1} + \alpha_{lubr} \quad (1)$$

In Eq. (1), α_{mix} is the pressure-viscosity coefficient of the mixture, α_{refr} and α_{lubr} are the pressure viscosity coefficient for pure refrigerant and oil respectively. s_{refr} is the mass fraction of refrigerant and m is the apparent molecular mass ratio between the refrigerant and oil, $m=M^*_{lubr}/M_{refr}$. Were M^*_{lubr} is the apparent molecular mass of the oil and M_{refr} is the molecular mass of the refrigerant, calculated from the chemical composition. M^*_{lubr} does not give a representation of the molecular mass of the oil molecule but is rather a measure of the average weight of the segments in the oil.

The oils chemical composition and pressure-viscosity coefficient data is seldom available from the oil manufactures. It is even harder to find viscosity and pressure-viscosity coefficient for different types of oil/refrigerant mixtures. Jonsson and Lilje have developed a semi empirical model that can be used to predict the pressure-viscosity coefficients of mixtures between polyolesters and R-134a based on the amount of branched acids in the oil.

In this investigation the viscosity and pressure-viscosity coefficient was measured for mixtures of an ISO VG68 polyolester and refrigerant: R-32, R-134a, R-410a and R-22. A method has been developed that can be used to predict the pressure-viscosity coefficient of mixtures with other refrigerants than R-134a based on the difference in molecular weight of the refrigerants.

2 TESTED REFRIGERANTS

Four different refrigerants were evaluated with one ISO VG68 polyolester. The oil was a refrigeration grade basestock containing less than 100ppm water. The refrigerants were selected to represent common used refrigerants in industrial refrigeration systems. R-134a is used as a replacement for R-12 and R-410a as an alternative to R-22. R-22 was included as a reference.

Table 1 Refrigerants used in the experiments.

Refrigerant	Chemical name	Type	Molecular weight [g/mol]
R-32	Difluoro-methane	HFC	52.02
R-134a	Tetrafluoro-ethane	HFC	102.03
R-410a	50/50% R-32/R-125	HFC mixture	72.58
R-22	Chlorodifluoro-methane	HCFC	86.48

All refrigerants used in this work were obtained from a commercial source and were used as received.

3 EXPERIMENTAL METHOD

The viscosity of the mixtures was measured using a falling ball viscometer at temperatures of 40 and 80ºC and at pressures of 2, 17 and 34 Mpa. The concentration of dissolved refrigerant was varied between 0 and 40% in steps of approximately 10% to cover the range found in most applications. The results from the experiments were then fitted using eq. (1).

3.1 Experimental procedure

The viscometer used was a modified Höppler viscometer developed by Jonsson and Höglund [10], shown in figure 1.

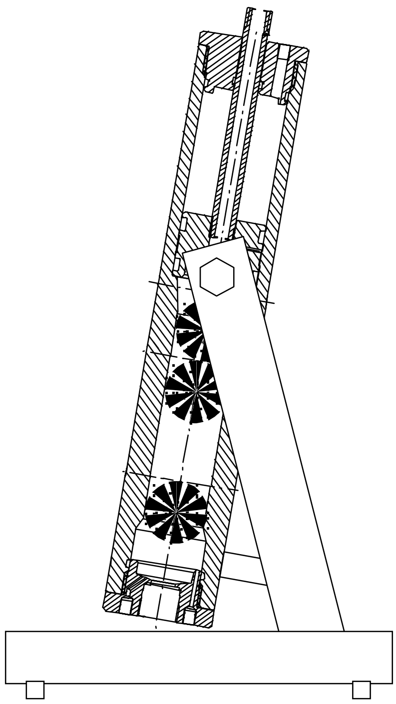


Figure 1 The modified Höppler viscometer.

The viscosity was determined by measuring the time it took for the ball to travel 100 mm in a tube containing the test liquid. Two photosensors timed the ball through two pairs of sapphire windows. The viscometer is equipped with a separating piston used to pressurize the test fluid during measurements. The test fluid and the pressurizing fluid are separated by two O-rings on the piston. The volume between the O-rings is ventilated through the piston rod to prevent contamination of the test fluid in case of a leakage at the O-rings. The viscometer was always pressurized above the vapor pressure of the test fluid.
The dilution of refrigerant was determined by taking a sample through a capillary tube into a test tube. The concentration was determined gravimetrically by evaporating the refrigerant from the mixture under vacuum. A spread sheet program was used to calculate the viscosity for each test point. The program compensates for effects of pressure and temperature on the dimensions of the ball and the bore. The pressure-viscosity coefficient was calculated for each pressure, temperature and concentration and then the results was fitted using the Eyring equation eq.(1).

To predict the pressure-viscosity coefficient the α value of pure refrigerant α_{refr} respective pure oil α_{lubr} has to be known. Together with the apparent mass ration m the α_{mix} can be calculated.

The apparent mass ratio ,m, is calculated out of the apparent molecular mass of the oil, M^*_{lubr}, and the molecular mass of the refrigerant, M_{refr}. To get the apparent molecular mass of the oil pressure-viscosity measurements has to be done for at least a combination of a single refrigerant and the oil at a few concentrations. Eq.(1) is used to fit the measured data and the regression gives a value of M^*_{lubr}. When M^*_{lubr} is known, the pressure-viscosity coefficient can be calculated for mixtures with all suitable refrigerants providing that α_{refr} is known for the actual refrigerant.

α_{refr} is given either from pressure-viscosity measurements of pure refrigerant or extrapolated from the regression when M^*_{lubr}. is calculated.

4 RESULTS AND DISCUSSION

The results show the affect of different refrigerants diluted in oil verses the viscosity and pressure-viscosity coefficient, for two different temperatures.

4.1 Affect of refrigerant dilution in the oil

Figure 2 and 3 show the variation of viscosity, η, for the polyol ester mixed with the different refrigerants and for two different temperatures. The degree of curvature is depending of the molecular weight of the refrigerant. The lighter R-32 gives a faster decrease in viscosity compared to the heavier refrigerant R-134a.

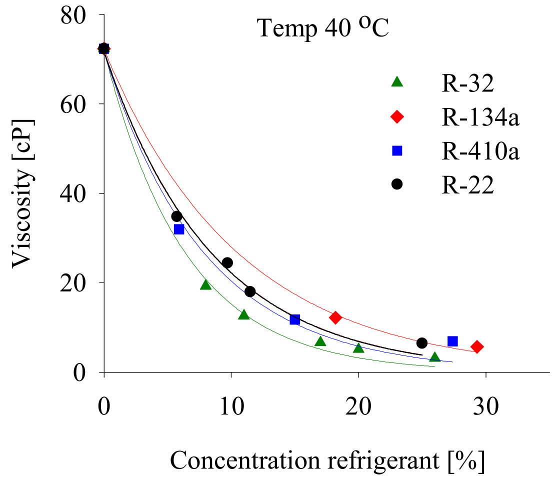


Figure 2 Viscosity vs. concentration 40°C.

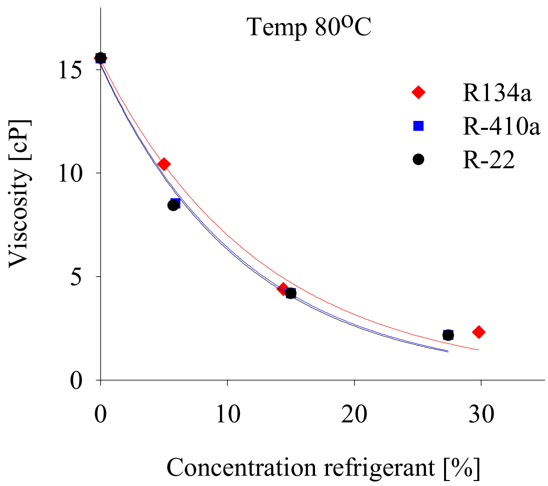
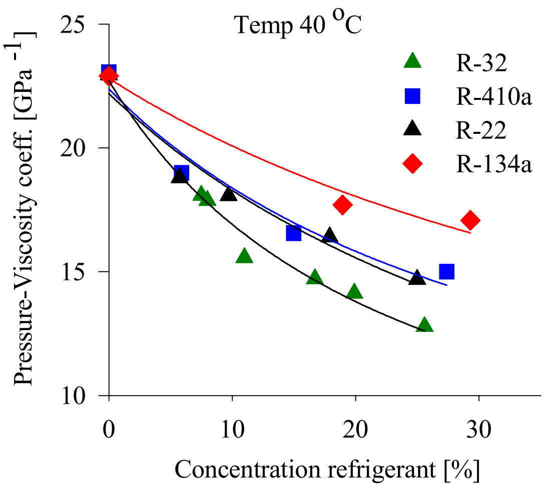
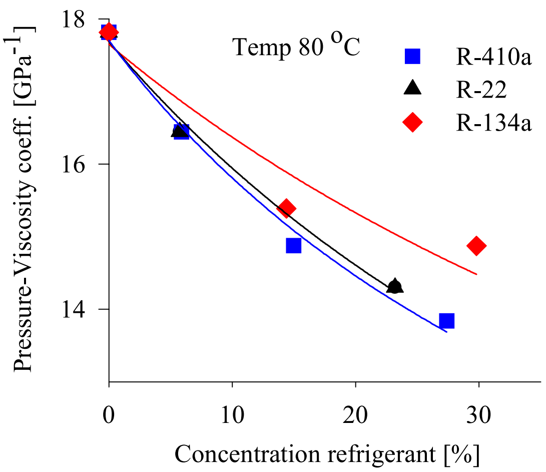


Figure 3 Viscosity vs. concentration at 80°C.

Figure 4 and 5 shows the pressure-viscosity coefficient, α, for the polyol ester diluted with different refrigerants. The same trend as for the viscosity can be found, that a light refrigerant has a more rapid decrease in pressure-viscosity coefficient than the heavier counterparts. It can also be seen that the temperature does not influence the α value as much as the viscosity. In this charts the Eyring equation, eq(1), is used to fit a curve to the data. The regression of the curve fit calculates the apparent mass ratio for the mixture and the α_{refr} for the refrigerants, later used to predict α_{mix} for all concentrations.



Figur 4 Pressure-Viscosity coefficient vs. concentration at 40ºC.



Figur 5 Pressure-Viscosity coefficient vs. concentration at 80ºC.

In figure X and W the solid lines are calculated from the molecular mass ratio obtained from measurements with R-134 and the molecular mass difference between the refrigerants. From this results it can be concluded that the Eyring equation can be used successfully to eliminate tedious measurements for different oil-refrigerant pairs.

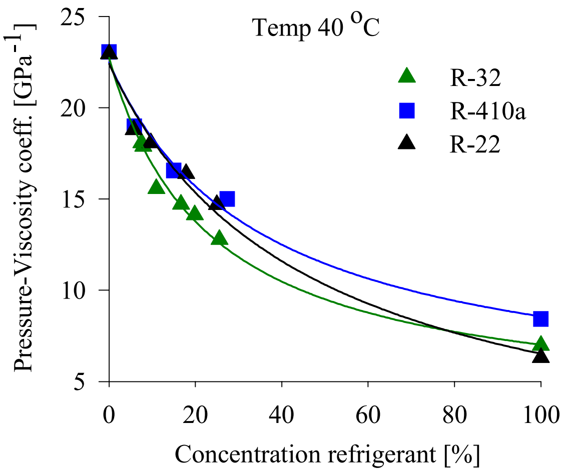


Figure 6 Predicted pressure-viscosity coefficient vs. concentration.

5 CONCLUSIONS

The pressure-viscosity coefficient and the viscosity of various refrigerants/polyol ester pairs were investigated using a high-pressure falling ball viscometer. A strong correlation was found between the molecular mass of the refrigerant and the reduction of viscosity and pressure-viscosity coefficient with concentration. It has been shown that Eyring equation can be used to predict the pressure-viscosity coefficient of a mixture based on the molecular mass ratio of the refrigerants.

6 REFERENCES

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