Thermal Stability and Lifetime Prediction of PAG and POE Oils for a Refrigeration System

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ABSTRACT: An experimental study has been carried out to analyze the thermal stability and to estimate the lifetime of refrigerating lubricants. PAG and POE oil are considered as test oils in this study. The viscosity of PAG and POE oil was measured by the vibration type viscometer while temperature is varied periodically in the range of 0 ℃ ~ 100 ℃. In order to estimate lifetime of PAG and POE oil with temperature, the viscosity was measured while the test temperature of oils was maintained continuously at 180, 200 and 220 ℃. The lifetime of oils is estimated as the decrease in viscosity change by 15%. The results indicate that the reduction rates of viscosity of PAG and POE oil are less than 5% after 510 temperature variation cycles. However, when the oils are kept at high temperature, it is found that the lifetimes of PAG oil is seen to be 244, 177 and 89 hours at the test temperature of 180, 200 and 220 ℃, respectively, where as the lifetimes of POE oil are estimated to be 1,744, 1,007 and 334 hours at the temperature of 180, 200 and 220 ℃, respectively. Thus, the lifetime of POE oil is found to be much longer than that of PAG oil. The lifetime correlations of PAG and POE oil are also obtained by Arrhenius's equation method in this paper.

Nomenclature

A : frequency factor
E : activation energy [cal/mol]
K : activation velocity constant
R : gas constant [cal/mol·K]
T : absolute temperature [K]

Greek letters

μ : absolute viscosity [mPa·s]

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1. Introduction

The primary function of lubricant oils for a refrigeration system is to reduce friction and to minimize wear of the mechanical systems. The function of a lubricant extends beyond preventing surface contact. Lubricants should not only remove heat but also provide a seal to keep out contaminants. It also inhibits corrosion and carries away debris created by wear. Among various properties of lubricant oils, viscosity is the most important factor to consider in choosing a lubricant under full fluid film conditions.(1)

The refrigeration oil is always mixed and compressed with refrigerants in a refrigeration system. It must be used for very long time even at severe temperature conditions, which are high temperature in the compressor part and low temperature in the evaporator part. Therefore, special quality as refrigeration lubricant is required not to react chemically with refrigerant and other materials of cylinder and bearing etc. Another important factor of refrigeration oils is the thermal stability for lubrication of compressor part. If oil is not superior to thermal stability, it may cause a critical problem to damage compressor of a refrigeration system. Thus, thermal stability of oils is very important matter in durability of refrigerating machine.

There are several methods to evaluate thermal stability of oil. One of them is DSC (Differential scanning calorimetry) method, which measures heat flux. The oxidation stability analysis (FED-STD 791) method[(2)] measures viscosity and TAN (Total Acid Number) while TGA (Thermogravimetric Analysis) method measures mass change rate. Bowman and Stachowiak[(3)] predicted lifetime of steam turbine oil by SCDSC (Sealed capsule differential scanning calotimetry) and Kauffman and Rhine[(4)] estimated the lifetime of lubricants by DSC. Also Yang et al.[(5)] evaluated thermal stability of oil and estimated lifetime of oil in each test temperature by Arrhenius's equation using TGA and oxidation stability analysis and proposed that lifetime estimation by viscosity is more correct than that by TAN.

The present study is directed at evaluating thermal stability of oil from measurement of viscosity variation by two ways. First, periodic temperature change is given to oils to simulate a compressor operating condition. Second, oils are kept at fixed high temperature for long time. The correlations to estimate the lifetime of PAG and POE oils are proposed, based on viscosity variation method.

2. Experimental system

Thermal stability of oils are evaluated in a periodic temperature variation by measurement of viscosity. The Fig. 1 shows the periodic temperature cycle varied between 0 ℃ and 100 ℃. A cycle consists of 4 processes, which are heating process from 0 ℃ to 100 ℃, soaking process at 100 ℃ for 30 min., cooling process from 100 ℃ to 0 ℃, and soaking process at 0 ℃ for 30 min. Heating and cooling time strongly depend on characteristics of the experimental apparatus, such as cooler capacity, heat capacity of bath. It takes 132 minutes for a cycle in the present experiment. A manufactured controller is attached to constant temperature bath to repeat the cycle automatically. The controller also displays the number of cycle during experiment.

The viscosity grades (VG) of used oils are ISO VG 100 for PAG (Poly Alkylene Glycol)

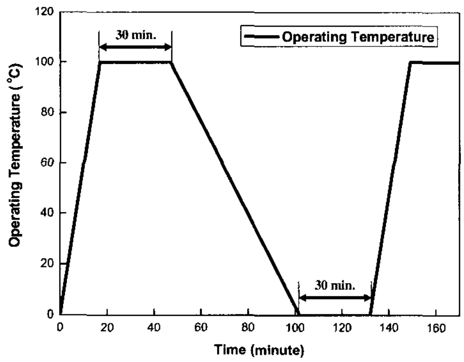


Fig. 1 Periodic temperature cycle.

Table 1 Typical properties of the oils

Type	PAG oil	POE oil
Manufacturer	Laporte	MOBIL
Model	RFL 100-X	EAL Arctic 68
Specific gravity at 15 ℃	-	0.971
Density at 15℃(kg/m^3)	-	971
Pour point (℃)	-43	-43
Flash point (℃)	200	254
Viscosity at 40 ℃(cSt)	107.3	63
Viscosity at 100 ℃(cSt)	20.0	8.3

and ISO VG 68 for POE (Polyol Ester) oil. Table 1 shows the typical properties of oils, used in the present study. 10 ml of glass vessels are prepared to be filled with oils. The glass vessels are tightly sealed to prevent leakage as well as infiltration from brines in the constant temperature bath and lubricants. After every 30 cycles, the viscosity of PAG and POE oil is measured by vibration type viscometer (A&D corp., SV-10 model) at 20, 40 and 60 ℃, respectively.

Another experiment is conducted to estimate lifetime of oils. Due to time constraint, the test oil must be exposed in severe temperature condition. The glass vessels are filled with PAG and POE oil and put in the convection oven, whose maximum operating temperature is 260 ℃.

The PAG and POE oil in Pyrex glass vessels are kept continuously in the convection oven at test temperature, such as 180 ℃, 200 ℃ and 220 ℃. According to ASHRAE STANDARD, lubricant stability is typically evaluated in the range of 175 ℃ to 200 ℃. As time elapses, the glass vessels are picked out from the oven and cooled to 40 ℃. The viscosity of PAG and POE oil are measured at 40 ℃ by vibration type viscometer.

3. Data reduction

Lifetime of oil can be estimated from the measurement of viscosity reduction at severe temperature condition. The lifetime of oil is generally defined as the time taken to be 15% reduction of viscosity at a given temperature.

Oil degradation speed is expressed by Arrhenius's equation as follows.[6-8]

$$K = A\exp(-E/RT) \qquad (1)$$

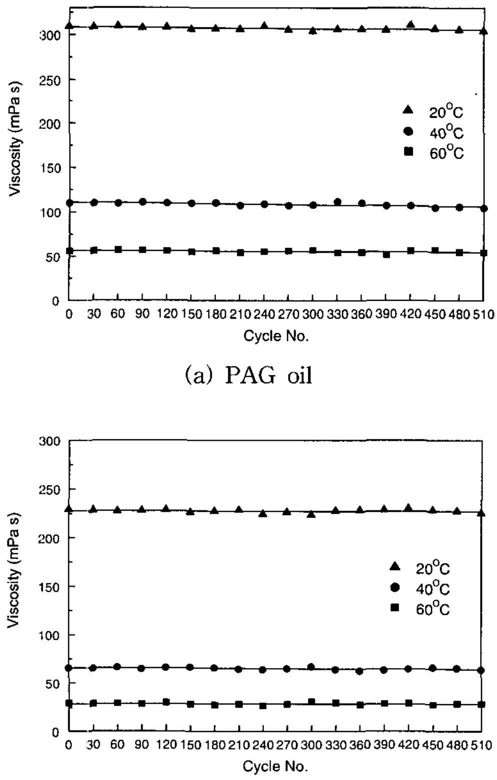
Here, K is activation velocity constant, A a frequency factor, and E activation energy (cal/mol), R gas constant (cal/mol · K), and T absolute temperature (K). Since oil degradation reaction velocity becomes faster with an increase in the activation velocity constant, the lifetime of oil is inversely proportional to the degradation speed. Therefore, equation (1) can be represented by equation (2) and (3).

$$lifetime \propto (1/A)\exp(E/RT) \qquad (2)$$

$$\log(lifetime) = C/T - B \qquad (3)$$

$$(where\ \ C = E/R\ \log e,\ \ B = \log A)$$

If log(lifetime) is plotted as a function of 1/T, the slope of straight line become C. A linear equation to estimate oil lifetime can be suggested using log scale of lifetime and reciprocal of T, 1/T.



(a) PAG oil

(b) POE oil

Fig. 2 Viscosity variation with periodic temperature cycles.

4. Results and discussion

4.1 Thermal stability

Fig. 2 shows the viscosity variations of PAG and POE oil while oils are immersed in the bath during periodic temperature cycles. The viscosity of PAG and POE oil is slightly decreased as temperature cycles precede. The viscosity of PAG oil is decreased by 1.4%, 3.6%, and 1.9% at the test temperature of 20 ℃, 40 ℃ and 60 ℃, respectively after 500 cycles (about 45 days). The viscosity of POE oil is decreased by 1.4%, 2.4% and 4.5% at the test temperature of 20 ℃, 40 ℃ and 60 ℃, respectively after 500 cycles. Since the reduction rate of viscosity is seen to be less than 5%, both PAG and POE are stable in periodic temperature cycles from 0 ℃ to 100 ℃.

4.2 Lifetime prediction

It is also found that the viscosity variation is too small to estimate the lifetime of present oils by temperature cycle test. Another method is employed to estimate the lifetime of oil. The oils are exposed to very high temperature conditions and measured the viscosity variation. The transient variation of viscosity of PAG oil is shown in Fig. 3 at a given temperature, such as 180 ℃, 200 ℃ and 220 ℃. Since lifetime of oils is defined as the time taken to be decreased in viscosity by 15%, the lifetimes of PAG oil is seen to be 244 hrs, 177 hrs and 89 hrs at the test temperature of 180 ℃, 200 ℃ and 220 ℃, respectively. Using these results,

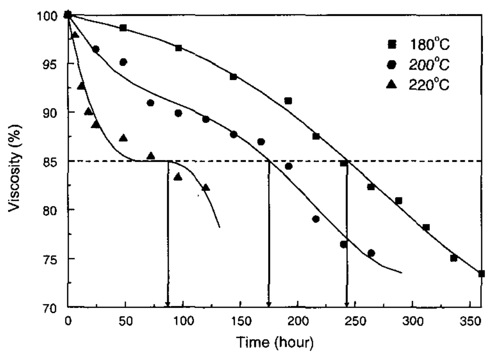


Fig. 3 Viscosity reduction rate of PAG oil.

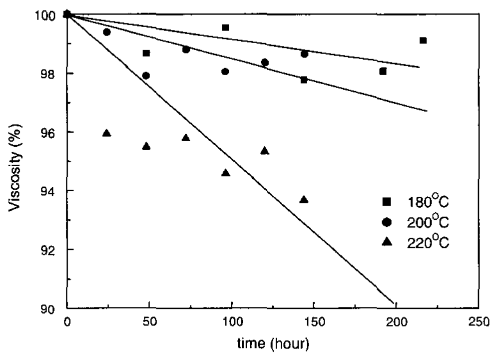


Fig. 5 Viscosity reduction rate of POE oil.

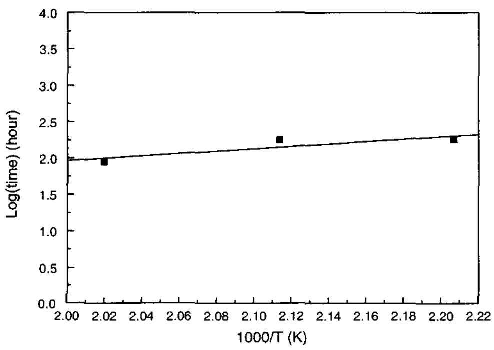


Fig. 4 Correlation on lifetime estimation of PAG oil.

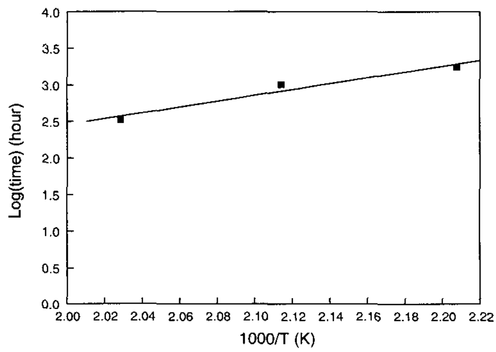


Fig. 6 Correlation on lifetime estimation of POE oil.

the graph can be drawn by setting 1/T in x-axis and log scale of lifetime in y-axis as shown in Fig. 4. From this figure, the lifetime estimation equation of PAG oil can be expressed, depending on only temperature, by equation (4)

$$\log lifetime = -1.306 + 1.636 \times 10^3 / T \qquad (4)$$

As same manner, POE oils are tested and estimated. However, in case of POE oil, it takes too much time to reach the 15% viscosity reduction since the viscosity variation is very little, as seen in Fig. 5. Therefore, the viscosity data of POE oil was fitted linearly to obtain the time of 15% viscosity reduction by extrapolation. The lifetimes of POE oil can be estimated to be 1,744 hrs, 1,007 hrs and 334 hours at a given temperature of 180, 200 and 220℃, respectively. Using these results, lifetime estimation correlation is plotted in Fig. 6. The lifetime of POE oil is estimated by the following equation (5).

$$\log lifetime = -5.514 + 3.986 \times 10^3 / T \qquad (5)$$

Comparing equation (4) and (5), C-value in equation (3) of POE oil is much higher than that of PAG oil. This means the lifetime of POE oil is much longer than that of PAG oil.

5. Conclusions

An experimental study has been carried out to analyze the thermal stability and to estimate the lifetime of PAG and POE oils, based on viscosity change. The viscosity of PAG and POE oil was measured by the vibration type viscometer while temperature is varied periodically in the range of 0 ℃ ~ 100 ℃. Since the reduction rate of viscosity is seen to be less than 5% after 500 cycles (about 45 days), both PAG and POE oils are stable in periodic temperature cycles from 0 ℃ to 100 ℃

The transient variation of oil viscosity at a given high temperature was measured to estimate the lifetime, depending on temperature of oil. It is found that the lifetimes of PAG oil are seen to be 244 hrs, 177 hrs and 89 hrs at the temperature of 180 ℃, 200 ℃ and 220 ℃, respectively. And the lifetimes of POE oil are estimated to be 1,744 hrs, 1,007 hrs and 334 hours at the temperature of 180, 200 and 220 ℃, respectively. The lifetime of POE oil is seen to be longer than that of PAG oil. Finally, the lifetime correlations of PAG and POE oil by Arrhenius's equation have been developed. It is possible to forecast the lifetime of PAG and POE oil by using these correlations at any operating temperature.

Acknowledgment

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