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Development Of Refrigeration Oils With High Electric Resistivity For New Energy Vehicles

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Development of refrigeration oils with high electrical resistivity for new energy vehicles

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ABSTRACT

In this study, we have developed Polyol Ester (POE) oils with excellent electrical performance suitable for electric compressors. The chemical structure of the POE is designed appropriately to show good miscibility with R134a and R1234yf, the refrigerants generally used in car air conditioners. Additionally, it is also achieved to improve the refrigeration oils viscosity at low temperature. For new energy vehicles (NEVs), it is expected to use heat pump heating in cold environment to prevent power consumption. Our newly developed POE oil is flowable at low temperature under 0 °C, it therefore should be applied for the heat pump heating system. The POE refrigeration oils presented are expected to be used in car air conditioners of NEVs.

1. INTRODUCTION

Achieving Carbon Neutral (CN) is a crucial task to build the sustainable society. The transportation sector accounts for approximately 25% of the worldwide CO2 emissions. Since electrification of mobility, including automobiles, is a major issue for the achieving CN, many countries are working to popularize NEVs. While the compressor in car air conditioner is driven by engine power in internal combustion engine vehicles (ICVs), that in NEVs is driven by battery power. Therefore, the use of electric compressors is expected to increase in the future. Nakajima reported that refrigeration oils are required to have different properties from general lubricants, such as miscibility with refrigerant, because they are used in the presence of refrigerant. Furthermore, Fukuta et al., mentioned that it is necessary to consider dealing with electric leakage at the motor terminals for electric compressors. Therefore, high electrical resistivity is an essential requirement for refrigeration oils used in electric compressors. The electrical resistivity of refrigeration oils is greatly affected by the molecular structure of the base oil. It is known that POE have excellent electrical resistivity, so that POE refrigeration oils are suitable for electric compressors.

Additionally, PTC heater is mainly used as the heating system for NEVs at present, but its power consumption could shorten the cruising range. Instead of the PTC heater, heat pump heating system have been gradually spreading because of the lower power consumption. For refrigeration oils used for the heat pump, kinematic viscosity at low temperature becomes important. When the heat pump heating system works in cold climates, the temperature in the evaporator reaches considerably lower, which potentially makes refrigeration oils to stay in the evaporator due to the increased viscosity at low temperature. This may cause the lack of lubricity due to the insufficient oil return to the compressor, as well as the decrease of heat exchange efficiency in the evaporator. Therefore, it should be important to improve the flowability of refrigeration oils at low temperature condition to meet the heat pump application in cold regions. Furthermore, it needs to keep the viscosity at high temperature at sufficient level in order to ensure the durability in compressor, which means that refrigeration oils with higher viscosity index are necessary.

As a result of various studies, we have developed POE refrigeration oils for car air conditioner that can achieve both excellent electrical resistivity and other required properties. The low temperature flowability of POE was also improved by adjusting its chemical structure. These POE lubricants must be suitable for electric compressors for NEVs.

2. EXPERIMENTAL

The volume resistivity of oils was measured according to JIS C2101. The miscibility with refrigerant was evaluated using the method specified in JIS K2211. For the evaluation of anti-seizure property, Falex Pin/Vee-Block test was conducted with ASTM standard test specimen (SAE 3135/AISI 1137). Following 5-minutes break-in at 250 lbf, the seizure load was measured at 290 rpm under room temperature with refrigerant blown at 10 L/h. In the evaluation of anti-wear property, Falex Pin/Vee-Block test was conducted with ASTM standard test specimen (SAE 3135/AISI 1137). Following 5-minutes break-in at 250 lbf, the wear amount was measured after the test at 500lbf for 30 min at 290 rpm under room temperature with refrigerant blown at 10 L/h. The stability of oils was evaluated in 200 ml autoclave vessel following the autoclave test specified in JIS K2211 (Fig. 1). It was carried out with Fe, Cu, and Al were immersed in oils as catalysts, and with water content of 500 ppm. The test temperature and duration are 175°C and 336 h consequently.

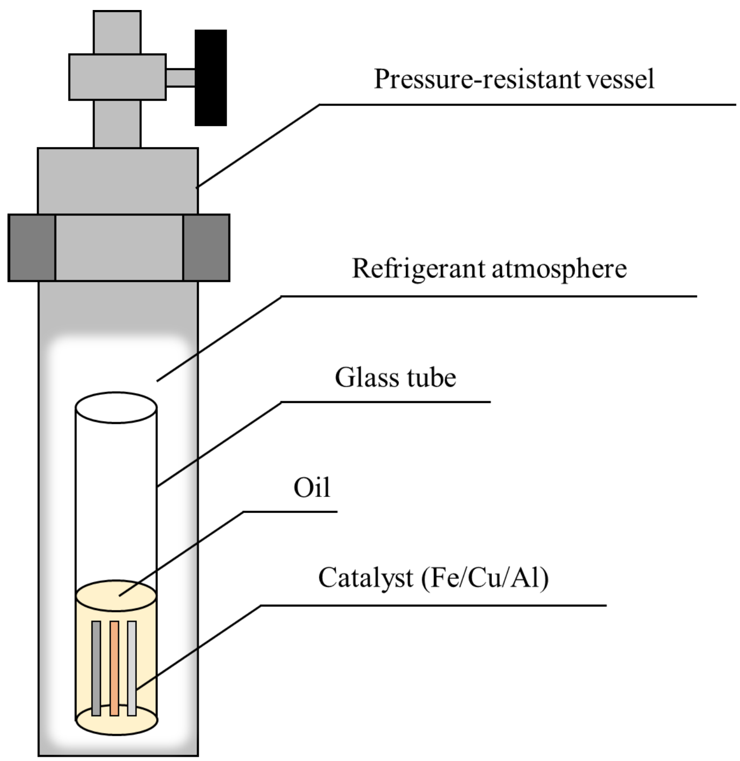

Figure 1: Schematic diagram of Experimental Apparatus for the stability test

3. DEVELOPMENT OF POE OILS FOR ELECTRIC COMPRESSORS

3.1 Properties of developed POE refrigeration oils

POE is composed of polyhydric alcohols and fatty acids, and various properties such as kinematic viscosity can be controlled by modifying the composition. POE A and B are widely used as refrigeration oils for compressors in car air-conditioner, and their properties are showed in Table 1. The oil film can prevent direct contacts between the sliding parts under hydrodynamic lubrication. The higher the kinematic viscosity of the oil, the thicker the oil film, which contributes to better lubricity. On the other hand, lower kinematic viscosity at low temperatures is preferable for heat pump applications in cold regions. It is therefore necessary to satisfy higher viscosity at high temperature and lower viscosity at low temperature simultaneously. The viscosities of POE A and B at 40°C are designed to be about 68 mm^2/s and 85 mm^2/s respectively, while their pour points are -42.5 °C and -40.0 °C. They have excellent viscometric balance and can be selected according to the compressor capacity. The volume resistivity of POE A and B were 11

TΩ · m and 2 TΩ · m. The excellent electrical resistivity is required for electrical compressors in order to prevent energy loss and failure due to electric leakage, so that the refrigeration oils are also required to have high electrical resistivity. Electrical resistivity is affected by the molecular structure, and it is generally known that POE exhibits high electrical resistivity derived from its molecular structure. POE A and B also present remarkable electrical resistivity.

Table1: Properties of POE A and B

Sample			POE A	POE B
Kinematic Viscosity	(40°C)	mm^2/s	65.6	83.9
	(100°C)	mm^2/s	8.2	9.6
Viscosity Index			90	91
Pour Point		℃	-42.5	-40.0
Volume Resistivity		TΩ・m	11	2

3.2 Evaluation of miscibility with refrigerant

When the refrigeration oil is discharged into the refrigeration cycle separated from the refrigerant, there are concerns of decreased heat exchange efficiency due to the stuck oil on the heat exchanger as well as the lack of lubricity due to insufficient oil return to the compressor. Consequently, miscibility with refrigerant is required for refrigeration oil.

The phase separation temperature of POE A and B in R134a is shown in Fig. 2. In the low-temperature range, separation temperatures of POE A and B were below -10°C in the range of 10-30% oil rate, confirming that they have adequate miscibility comparable to the commercial refrigeration oils for car air conditioners. In the high-temperature range, separation temperatures of POE A and B were both above 70°C in the 10-30% oil rate range, which means that miscibility with R134a of them are also sufficient in the high temperature range.

Subsequently, the separation temperature of POE A and B in R1234yf is shown in Fig. 3. It was confirmed that miscibility of POE A and B with R1234yf are excellent in both the low and the high temperature range.

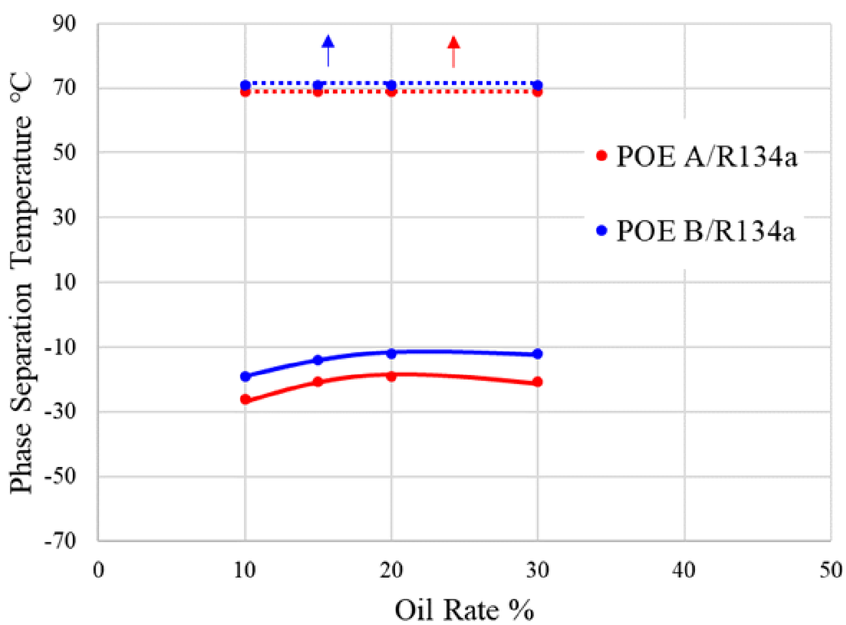

Figure 2: Phase Separation Temperature of POE A and B in R134a

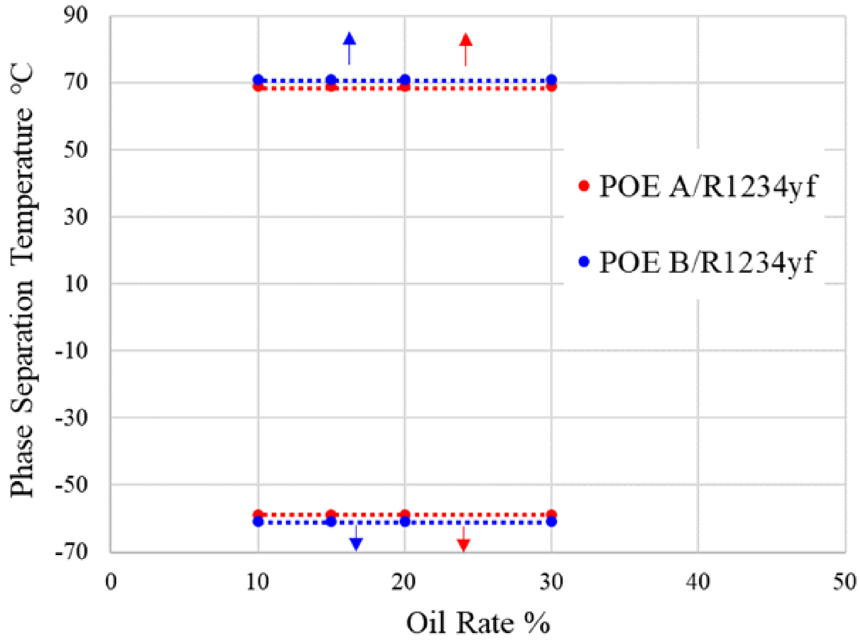

Figure 3: Phase Separation Temperature of POE A and B in R1234yf

3.3 Evaluation of lubricity and chemical stability in refrigerant atmosphere

Anti-seizure performance of POE A and POE B was evaluated with Falex Pin/Vee-Block test in the presence of refrigerant (R134a, R1234yf at 10 L/h). Both POE A and POE B had seizure load in excess of 700 lbf, confirming that they are sufficient for practical use as shown in Fig. 4.

In addition, we tried to improve extreme pressure performance in order to deal with higher load capacity or severe running conditions. The additive formulation of POE C is modified based on POE B for increasing extreme pressure property. As shown in Fig. 4, POE C presents seizure load obviously improved from POE A and B in both refrigerant atmospheres. In addition, anti-wear property of POE A to C were evaluated. As shown in Fig. 5, the wear amount of POE C were extremely less than that of POE A and B. The additive formulation of POE C are effective in not only extreme pressure performance but also anti-wear performance. However, the chemical stability of POE C under refrigerant atmosphere becomes slightly worse than that of POE A and B as shown in Fig. 6. The acid number of POE C after the stability test is 0.13 mgKOH/g in R134a and 0.13 mgKOH/g in R1234yf, larger than the results of POE A and B.

In order to enhance the chemical stability of POE C, POE D was prepared by modifying the additive formulation of POE C. The acid number after the stability test of POE D was suppressed to less than 0.1 mgKOH/g as shown in Fig. 6, while the seizure load and the wear amount were maintained almost equal to those of POE C as shown in Fig. 4. and Fig. 5. These results confirm that it is possible to arrange the lubricity and chemical stability by utilizing additive formulation. POE refrigeration oils can be designed appropriate for various types of compressors.

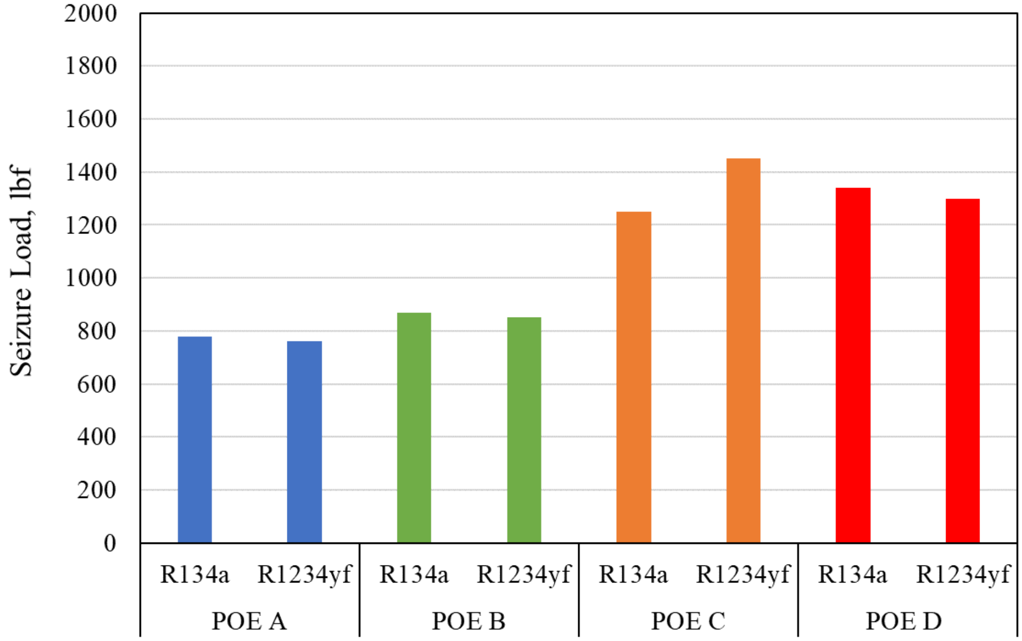

Figure 4: Seizure Load of POE A to D in refrigerant

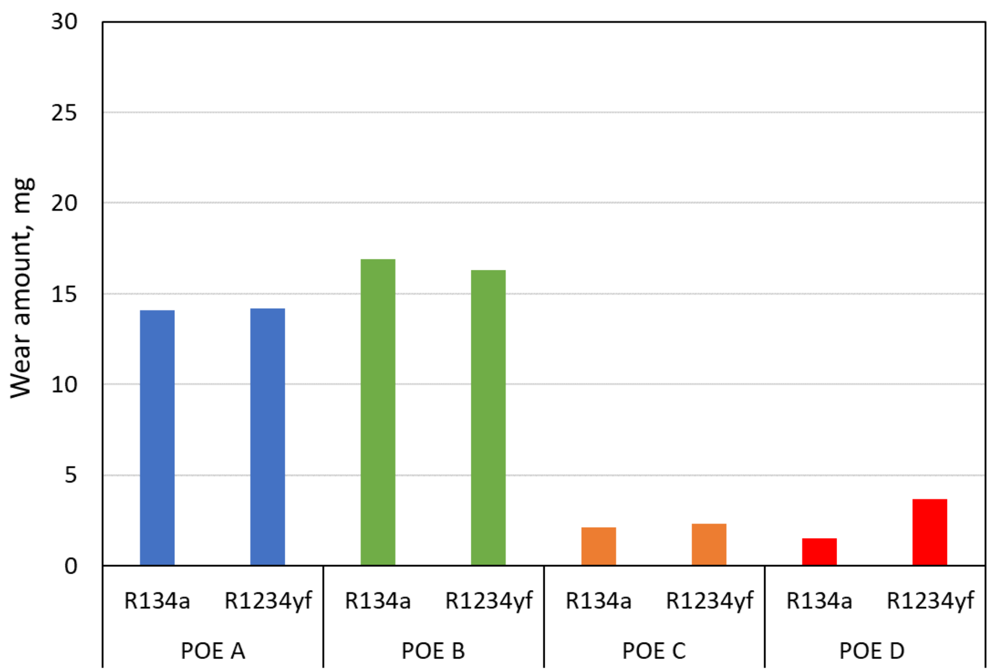

Figure 5: Wear amount of POE A to D in refrigerant

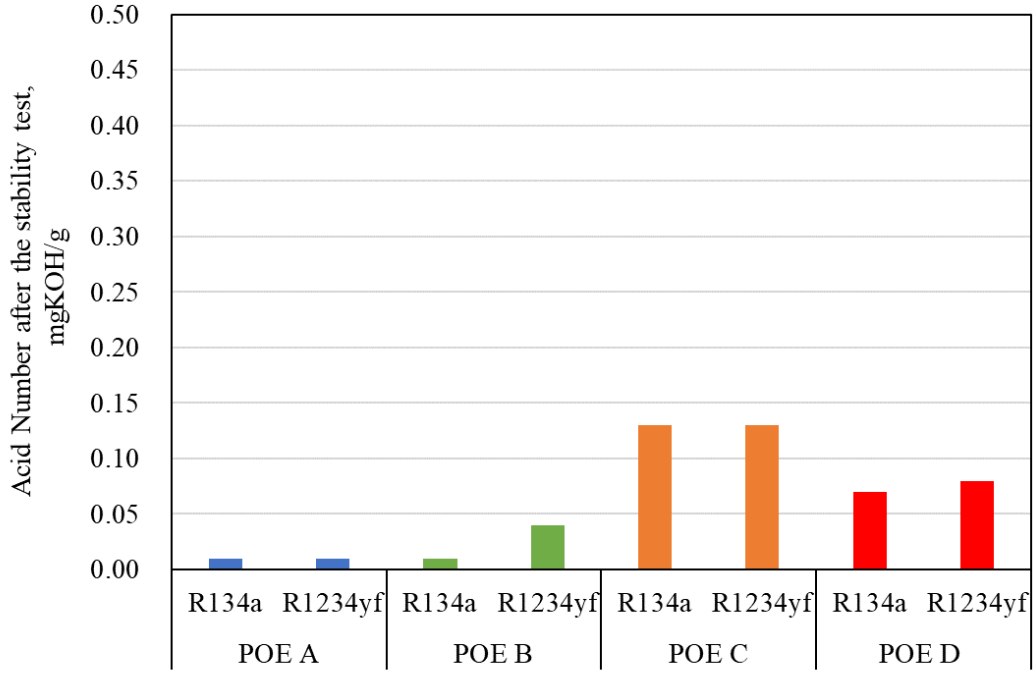

Figure 6: Acid number of POE A to D after the stability test

3.4 Improvement of viscometric properties at low temperature

The low temperature kinematic viscosity of refrigeration oils prefers to be lower when applied for the heat pump heating system used in cold climates, while it requires sufficient viscosity at high temperatures simultaneously. We have developed POE E with improved low temperature viscosity by modifying the chemical structure of POE. The kinematic viscosity of POE E at 0 °C and -20 °C are remarkably reduced from POE A or B as shown in Fig. 7, while its viscosity at 100°C is designed to be greater than that of POE A and B. This approach should be useful for heat pump applications used in cold environment.

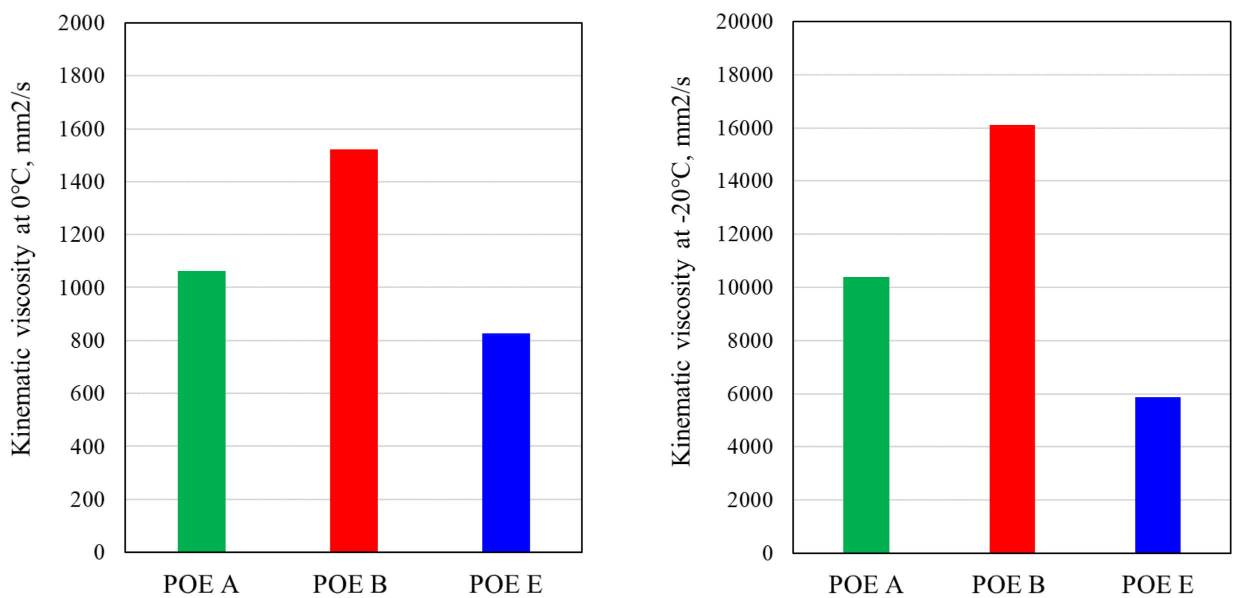

Figure 7: Kinematic viscosity of POE A, B and E (left : 0℃, right : -20℃)

4. CONCLUSIONS

In electric compressors, refrigeration oil must have high electrical resistivity in order to prevent troubles due to electric leakage. The developed POE refrigeration oils exhibit excellent electrical resistivity contributed to the chemical structure of POE. These oils also exhibit sufficient performance required for car electric compressors; miscibility with the refrigerants, lubricity and chemical stability. In addition, improvement of the POE oils in anti-seizure property and low temperature viscosity is successfully presented. The enhancement of lubricity was achieved by modifying the additive formulation, while it was capable to reduce the viscosity at low temperature by designing the chemical structure of POE. The presented technology with POE refrigeration oils should be used effectively for electric compressors of NEVs.

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