R1234ze(E) Specialized Refrigeration Lubricant in HFO Blend Application

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ABSTRACT

HFOs with low GWP characteristics can be directly use or blend with other refrigerants like HFCs to expand application to meet new regulations in HVAC system. The representative HFOs are R1234ze(E) and R1234yf, which are structural isomers and are regarded as R134a alternative refrigerants. However, the two refrigerants have much different properties in application. Comparing to R1234yf, R1234ze(E) possesses much better affinity to incumbent refrigeration lubricants than that in R134a system. The strong affinity of R1234ze(E) would result in the lower miscibility temperature in evaporator, higher solubility and lower working viscosity in compressor under the same working condition as in R1234yf systems. To overcome these disadvantages from high affinity, one method is to use higher viscosity refrigeration lubricants to protect the compressor, but it will lead to more operation drag force, and subsequently lower compressor efficiency. The other method is using specialized refrigeration lubricant of R1234ze(E) to meet the higher working viscosity requirement. However specialized refrigeration lubricants of R1234ze(E) are typically immiscible with R134a and R1234yf, which will limit its scope of use.

In this paper, we design the new structure of specialized R1234ze(E) refrigeration lubricants and compare the solubility and working viscosity with current refrigeration lubricants for R134a in the same compressor working condition. To extend application scope, we also conducted experiments with some HFO blend refrigerants such as R513A and R515B. With this research study, we hope to find the appropriate base lubricants with a balanced miscibility, solubility, and lubricity, which work for R134a alternative HFO blend application.

1. INTRODUCTION

After COP26, we realized the impacts of climate change are immediately happening and the temperature is growing faster than we expected. With more countries ratifying the Kigali amendment to reduce greenhouse gases emission and lower the tendency of temperature rising, it means HFCs phase down is well in progress. R134a, a refrigerant widely used in today's HVAC systems, possess high GWP (1,530) on a 100-year time scale (AR6). As such, seeking the R134a alternative refrigerants with lower GWP is the most pressing issue. Two kinds of HFO isomers, R1234ze(E) and R1234yf, are regarded as R134a alternative refrigerants due to their low GWP characteristics and similar physical properties with R134a.

R1234ze(E) possesses much better affinity to these lubricants than that of R134a system in full range of temperature. Therefore incumbent refrigeration lubricants used in R134a refrigeration systems can be directly used in the HFO or HFO blend refrigeration systems (Seeton and Karnaz, 2016, Chen *et al*., 2018), but some problems will accompany with this usage. For such refrigerant-lubricant mixtures, while obtaining good miscibility at low temperature evaporator, the other parts that must be sacrificed are their higher solubility and lower working viscosity at high temperature compressor. These characteristics will lead to some severe problems, such as insufficient oil film thickness, lower efficiency of oil separator, higher foaming phenomenon, and finally affect the reliability of compressor operation (Chen et al., 2016, Karnaz *et al*., 2017). To overcome these obstacles of R1234ze(E) system, the simple way is using incumbent higher viscosity refrigeration lubricants to get higher working viscosity. However, the real condition shows that working viscosities are usually insufficient due to high degree of dilution by refrigerant in high temperature condition, and poor EER due to higher drag force in low temperature condition. The more practical way to overcome these drawbacks is using the specialized refrigeration lubricants for R1234ze(E).

In this study, we developed a kind of new R1234ze(E) refrigeration lubricant and compare the solubility and working viscosity with current refrigeration lubricants for R134a in the same compressor working condition. Not only

R1234ze(E) refrigerant, but we also extend application scope to HFO blend refrigerants with another new developed R1234ze(E) refrigeration lubricant.

2. EXPERIMENTAL

2.1 Miscibility

Following the ASHRAE 218-2019 method by using sealed glass tubes, miscibility test can be conducted with oil percent ranging from 5~30 wt% of mixture. Alternating the environment temperature of sealed tubes to observe the oil-refrigerant mixture phenomenon till separating into two phases in the tube, and then recording miscibility temperature.

2.2 Solubility and Working Viscosity

An experimental test facility has been constructed, tested and calibrated for measurement of lubricant refrigerant mixture properties (Figure 1). The lubricant is first charged into the oil tank (±0.1 grams) and then the refrigerant is charged (±0.1 grams) into test system under condition: -10°C and high vacuum. Using the pump to circulate the system and then heated to a suitable temperature based on the type of refrigerant. Measuring the related temperature, viscosity, pressure, and density data only when vapor-liquid equilibrium has been achieved in mixture system. The numbers of measuring for each specified refrigerant-lubricant mixture are around 50 points. (Figure 2) Then the P-V-T diagram can be drawn based on PISM model (Hung et al., 2014) (Figure 3).

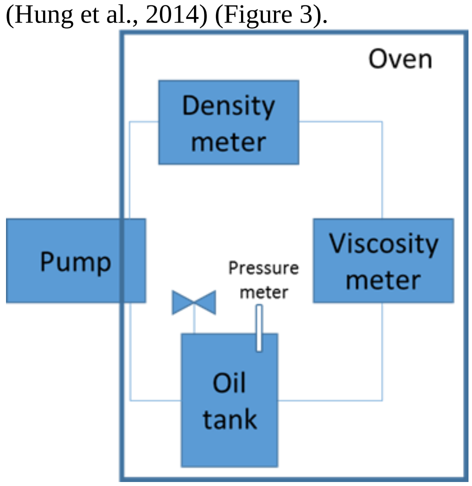

Figure 1: Pressure-Viscosity-Temperature test facility model

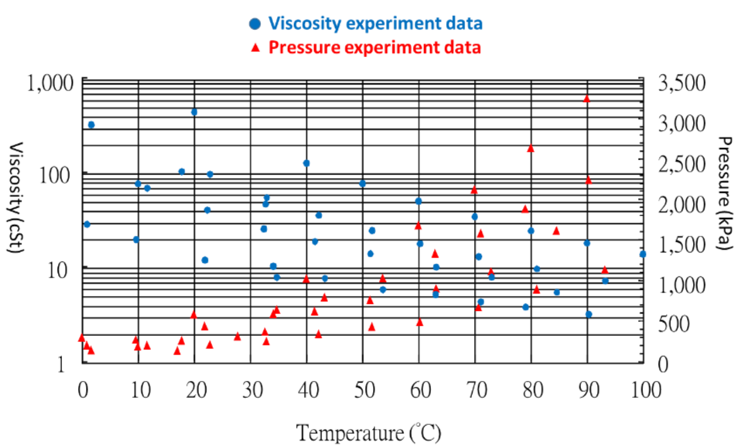

Figure 2: Pressure-Viscosity-Temperature experiment data

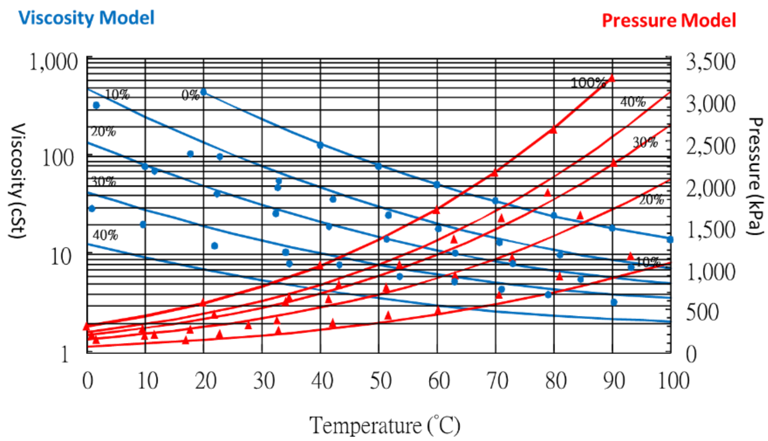

Figure 3 P-V-T diagram

3. REFRIGERANTION LUBRICANTS FOR R1234ze(E)

3.1 Miscibility of Refrigeration Lubricants in R1234ze(E) and HFO blend

POE lubricants are chosen as the candidates of new R1234ze(E) refrigeration lubricants. By esterifying the polyol with the different linear or branched acids, refrigeration lubricants with specific properties are synthesized, and miscibility tests are further conducted following ASHRAE 218 method. The related miscibility data are shown in Table 1, Figure 4, and Figure 5. POE-A is the current POE lubricant for R134a and POE-B is the new specialized R1234ze(E) refrigeration lubricant. Based on Table 1, POE-A shows the highly miscible property with HFO and HFO blend refrigerants. Compare to POE-A, POE-B is only partial miscible with R1234ze(E), R515B and R450A, and miscibility temperature values vary with the composition ratio of R1234ze(E) in the different HFO bend refrigerants. POE-B is immiscible with R134a, R1234yf and R513A. Due to the miscibility characteristics and oil return consideration, specialized R1234ze(E) refrigeration lubricant POE-B can utilize in the R1243ze(E) and R1234ze(E) blend refrigeration system, but it is not suitable for R134a, R1234yf and R1234yf blend refrigeration system.

Table 1: Miscibility comparison of refrigeration lubricants in refrigerants

Typical value		POE-A	POE-B
Test item	unit		
Kinetic Viscosity @40°C	cSt	170	170
Miscibility, 10% oil in R134a	°C	-16	immiscible
Miscibility, 10% oil in R1234yf	°C	<-60	immiscible
Miscibility, 10% oil in R1234ze(E)	°C	<-60	-32
Miscibility, 10% oil in R450A	°C	<-60	3
Miscibility, 10% oil in R513A	°C	<-60	immiscible
Miscibility, 10% oil in R515B	°C	<-60	-41

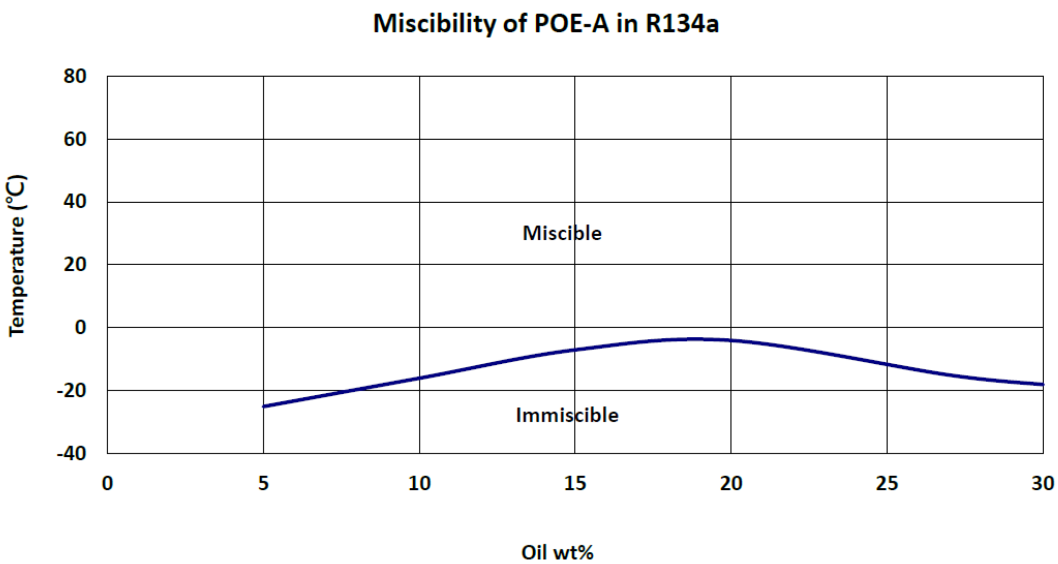

Figure 4: Miscibility chart of POE-A in R134a

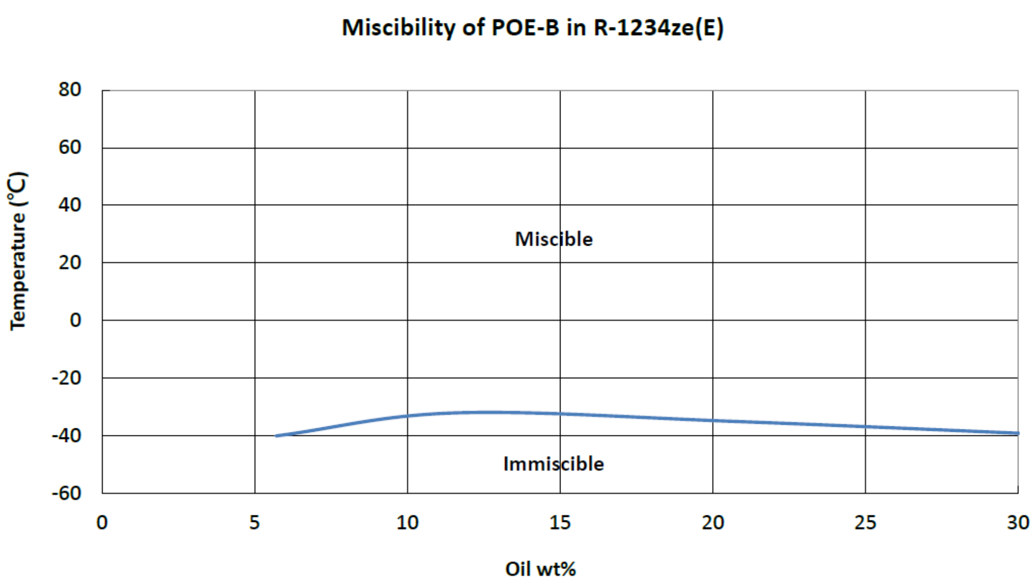

Figure 5: Miscibility chart of POE-B in R1234ze(E)

3.2 Solubility and Working Viscosity of Refrigeration Lubricants in R1234ze(E) and HFO blend

Using the in-house instrument we constructed, we were able to measure and record the viscosity, temperature, density and pressure value. Afterwards, utilizing the simulation model (Hung et al., 2014), we can then draw the P-V-T diagram (Figure 6). We chose ASHRAE standard working condition (Condenser temperature 54.4°C), and oil temperature 65°C to calculate the POE-A and POE-B's solubilities and working viscosities in the R134a, R1234ze(E) and R515B system and are shown in Table 2.

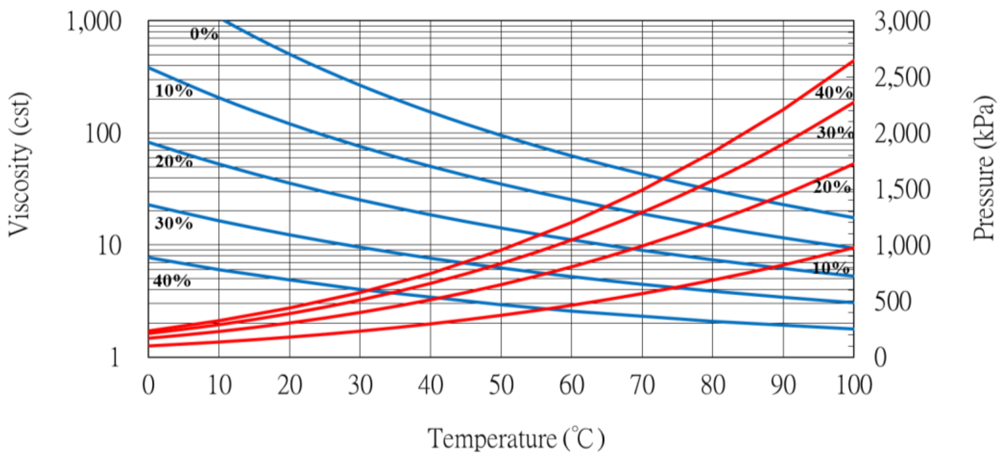

Figure 6 P-V-T diagram of POE-B in R1234ze(E)

Table 2: The solubility and working viscosity of POE-A and POE-B in different refrigerants

Condition			POE-A		POE-B	
Refrigerant	Oil temp.	Pressure (Condenser: 54.4°C)	Solubility (%)	Viscosity (cSt)	Solubility (%)	Viscosity (cSt)
R134a	65°C	1470kPa	32.7	4.8	--	--
R1234ze(E)	65°C	1114kPa	35.1	3.7	27.8	5.6
R515B	65°C	1107kPa	37.2	3.4	32.2	5.8

With good miscibility of R1234ze(E) and R515B, POE-A brings higher solubility, and the lower working viscosity compared to the same condition in R134a system. Reducing lubricant affinity with R1234ze(E) like POE-B shows the lowering solubility and higher working viscosity than same condition of POE-A.

4. DISCUSSION

Compare to R-1234yf, the special property of R1234ze(E) will dilute the current R134a lubricant severely, and it may cause some issue in drop-in R134a system. However, R1234ze(E) still deserves more investigation to solve these problems because of its low GWP and more economic value than R1234yf. That is why R1234ze(E) refrigeration lubricants are necessarily developed. A drawback of the R1234ze(E) specialized lubricants should be noted that they must restrict to R1234ze(E) or R1234ze(E) blend systems used only as we mentioned above. To overcome such application limit, we try to develop another new type of POE with high compatibility to different type of HFO blend refrigerants. POE-C is developed based on this reason, and miscibility, solubility and working viscosity in different HFO blend are shown in Table 3 and 4.

Table 3: The miscibility of POE-C in the HFO blend

Typical value		POE-A	POE-B	POE-C
Test item	unit			
Kinetic Viscosity @40°C	cSt	170	170	170
Miscibility, 10% oil in R134a	°C	-16	immiscible	immiscible

Miscibility, 10% oil in R1234yf	°C	<-60	immiscible	immiscible
Miscibility, 10% oil in R1234ze(E)	°C	<-60	-32	-43
Miscibility, 10% oil in R450A	°C	<-60	3	-28
Miscibility, 10% oil in R513A	°C	<-60	immiscible	-5
Miscibility, 10% oil in R515B	°C	<-60	-41	-43

As the results shown in Table 3, the miscibility character of POE-C is between POE-A and POE-B. POE-C is still immiscible with R134a and R1234yf, but it is possible to be miscible with R513A and better miscible with R1234ze(E) and R1234ze(E) blend. In addition, ASHRAE standard working condition (Condenser temperature 54.4°C), and oil temperature 65°C to calculate the POE-C's solubility and working viscosity in the R-134a, R1234ze(E) and R513A system and are shown in Table 4.

Table 4: The solubility and working viscosity of POE-A and POE-C in different refrigerants

Condition			POE-A		POE-C	
Refrigerant	Oil temp.	Pressure (Condenser: 54.4°C)	Solubility (%)	Viscosity (cSt)	Solubility (%)	Viscosity (cSt)
R134a	65°C	1470kPa	32.7	4.8	--	--
R1234ze(E)	65°C	1114kPa	35.1	3.7	31.4	4.0
R513A	65°C	1531kPa	34.1	3.5	31.9	4.4

Comparing the working viscosity of POE-C in R1234ze(E), it is lower than that of POE-A in R134a, but higher than that of POE-A in R1234ze(E). This tendency is same in R513A system. The working viscosity of POE-C in R513A is closer to that of POE-A in R134a. That imply reducing the affinity from HFO and HFO blend will raise the working viscosity and get the similar solubility of POE-A in R134a.

5. CONCLUSIONS

Miscibility and solubility are the main factors for HVAC system working efficiency. Miscibility is related to the affinity between two components in liquid type refrigerant-lubricant mixture, and it is usually considered in low temperature evaporator for oil return. On the other hand, solubility means the affinity between vapor type refrigerant and lubricant. It can describe the phenomenon inside high temperature compressor, and also affect working viscosity and lubricity. Due to the dramatic characteristics difference for refrigerants in different temperature leading to different affinity with lubricants, the miscibility and solubility may appeal different trends for some kinds of different mixtures. This is why we must consider miscibility and solubility together for real applications when we evaluate the new lubricants.

To meet requirements from different HFO or HFO blend refrigerants and different working conditions, we successfully developed two kinds of POEs in this study. One specialized for R1234ze(E) and some R1234ze(E) blend and provides better solubility and working viscosity properties. The other is for wider range of HFO blend refrigerants application and possesses acceptable properties. Both new POEs show better properties comparing with that of incumbent refrigeration lubricants using in HFO or HFO blend refrigerants.

NOMENCLATURE

HFO	hydrofluoroolefin
GWP	global warming potential
HFC	hydrofluorocarbon
POE	polyolester

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