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# The Effect of Lubricant in HFC & HFO Blend Refrigerants

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## ABSTRACT

Although HFO refrigerants are considered the low GWP solutions to the global warming problem, some properties of HFO refrigerants prohibited the direct drop in replacement application in the refrigeration system. As a result, to replace the high GWP HFC refrigerants, HFC & HFO refrigerants are blended to combine their properties to become a workable solution. Both HFC and HFO refrigerants have similar basic properties; however, one of the HFO refrigerants properties is good miscibility to incumbent refrigeration lubricants, especially HFO-1234ze. Generally speaking, refrigerant-oil mixture with highly miscible property in low temperature evaporator will lead to more soluble phenomenon in high temperature compressor. Therefore, when refrigerant is well miscible with refrigeration oil, the dissolved refrigerant will reduce working viscosity of refrigerant-oil mixture in compressor, which could results in lower lubricity, increase wear of sliding parts, and shorter compressor durability.

In our studies, we discuss the influence of lubricant in HFC & HFO blend refrigeration system, such as R513A or R450A. Compared to the lubricant performance in HFO refrigerants, the same lubricant in the HFC & HFO blend refrigerants do not lead to severe refrigerants dilution of lubricant viscosity, which causes poor lubricity due to high solubility.

According to our previous study, we know the better miscibility brings the better solubility in R1234ze system. We also developed lubricants with different miscibility properties in HFC & HFO blend refrigerants in order to investigate the miscibility, solubility and lubricity performance in the HFC & HFO refrigeration systems.

## 1. INTRODUCTION

HFC refrigerants are greenhouse gases that are widely used in today's refrigeration systems. After Montreal protocol Kigali amendment was adapted to further decrease the overall impact on global warming, HFC refrigerants are added as controlled substances to the phased down list. Therefore, at this stage, finding alternatives to replace HFC refrigerants is the most pressing issue on hand. HFO refrigerants are considered as alternative replacement candidates of HFC because of the low GWP numbers and similar basic properties. Furthermore, POE lubricants currently used in HFC refrigeration systems can directly be used in the HFO refrigeration systems. (Seeton and Karnaz, 2016) However, considering cost economy and safety, HFC & HFO blend refrigerants are more suitable than direct use of HFO refrigerants. In the previous studies, R1234ze, one of the HFO refrigerants, has better miscibility in the incumbent refrigeration lubricants. Good miscibility brings the good solubility. This property influences the working viscosity in R1234ze refrigeration system. (Karnaz *et al.*, 2017, Chen *et al.*, 2016) In this study, we want to discuss about the solubility and miscibility of HFO and HFC blend refrigerants to verify the influence of HFO refrigerants on lubricants.

## 2. REFRIGERANTION LUBRICANTS FOR R134a ALTERNATIVES

### 2.1 Miscibility of Refrigeration Lubricants in R134a and Alternatives

We choose the incumbent R134a alternatives and POE lubricants for R134a in this study. Following ASHRAE 86-1994 method, we conduct the synthetic refrigeration lubricant's miscibility tests. Table 1 shows the miscibility test results. In this table, we see that the miscibility was not influenced by the viscosity of the lubricant; rather, it was determined by the chemical structure of the lubricants and the refrigerants interaction. The similar miscibility in R134a will have similar miscibility in HFO and HFO blend, comparing POE-B and POE-C condition. However in POE-A condition, R1234ze shows the better miscibility than R1234yf, and R134a blend HFO refrigerants will raise the miscibility value, especially R513A. R513A shows the interesting results. R513A have better miscibility than individual refrigerants R134a and R1234yf.

**Table 1:** The miscibility of refrigeration lubricants in the R134a and alternatives

| Typical value | | POE-A | POE-B | POE-C |
|---|---|---|---|---|
| Test item | unit | | | |
| Kinetic Viscosity @40℃ | cSt | 170 | 170 | 100 |
| Miscibility, 10% oil in R134a | ℃ | immiscible | -16 | -20 |
| Miscibility, 10% oil in R1234ze | ℃ | <-50 | <-50 | <-50 |
| Miscibility, 10% oil in R1234yf | ℃ | immiscible | <-50 | <-50 |
| Miscibility, 10% oil in R513A | ℃ | -30 | <-50 | <-50 |
| Miscibility, 10% oil in R450A | ℃ | -42 | <-50 | <-50 |

## 2.2 Solubility and Working Viscosity of Refrigeration Lubricants in R134a and Alternatives

Using the 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. We selected ASHRAE standard working condition (Condenser temp. 54.4℃, oil temp. 65-70℃) to calculate the POE-A's working viscosity in the R134a, R1234ze and R450A system and shown in Table 2.

**Table 2:** The solubility and working viscosity of POE-A in the R134a, R1234ze and R450A

| Condition | | | POE-A | |
|---|---|---|---|---|
| Refrigerant | Oil temp. | Pressure | Solubility | Viscosity |
| R134a | 65℃ | 1470kPa (54.4℃) | 32.4 | 4.0 |
| | 70℃ | | 25.1 | 6.3 |
| R1234ze | 65℃ | 1114kPa (54.4℃) | 36.2 | 2.8 |
| | 70℃ | | 29.6 | 3.8 |
| R450A | 65℃ | 1368kPa (54.4℃) | 39.7 | 3.2 |
| | 70℃ | | 33.9 | 4.2 |

As we can see in the data, the good miscibility of R1234ze brings the solubility higher, and the working viscosity and pressure lower compared to the same condition in R134a. In R450A, the mixture of R134a and R1234ze, it shows the solubility influenced by R1234ze, resulted in the working viscosity between R134a and R1234ze in Figure 1. Table 3 shows the different lubricants follow similar trend. Working viscosity of both lubricants are between the results in R134a and R1234ze. We think this phenomenon is caused by the interaction between different components of the blend refrigerants and lubricants.

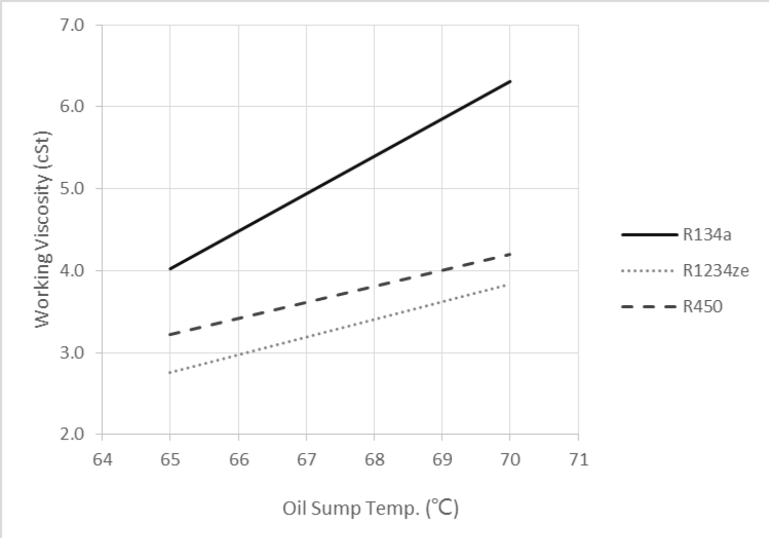


**Figure 1:** Working viscosity of POE-A in R134a, R1234ze, and R450A

**Table 3:** The solubility and working viscosity of POE in the R134a, R450A

| Condition | | | POE-A | | POE-B | |
|---|---|---|---|---|---|---|
| Refrigerant | Oil temp. | Pressure | Solubility (%) | Viscosity (cSt) | Solubility (%) | Viscosity (cSt) |
| R134a | 65℃ | 1470kPa (54.4℃) | 32.4 | 4.0 | 38.1 | 3.6 |
| | 70℃ | | 25.1 | 6.3 | 32.1 | 4.8 |
| R450A | 65℃ | 1368kPa (54.4℃) | 39.7 | 3.2 | 34.5 | 2.9 |
| | 70℃ | | 33.9 | 4.2 | 28.4 | 4.0 |

What about comparing R1234yf to R134a? In Table 4, comparing R134a and R1234yf results for POE-A and POE-B, R1234yf is shown to have lower solubility than R134a. Contrary to the earlier findings of good miscibility brings good solubility, in R1234yf, the results are opposite than R1234ze and low solubility effects the better working viscosity.

**Table 4:** The solubility and working viscosity of POE in the R134a, R1234yf, and R513A

| Condition | | | POE-A | | POE-B | |
|---|---|---|---|---|---|---|
| Refrigerant | Oil temp. | Pressure | Solubility (%) | Viscosity (cSt) | Solubility (%) | Viscosity (cSt) |
| R134a | 65℃ | 1470kPa (54.4℃) | 32.4 | 4.0 | 38.1 | 3.6 |
| | 70℃ | | 25.1 | 6.3 | 32.1 | 4.8 |
| R1234yf | 65℃ | 1445kPa (54.4℃) | 27.1 | 6.7 | 36.13 | 4.1 |
| | 70℃ | | 22.8 | 8.0 | 31.81 | 4.9 |
| R513A | 65℃ | 1457kPa (54.4℃) | 33.9 | 5.7 | 36.3 | 4.2 |
| | 70℃ | | 29.0 | 7.0 | 31.6 | 4.9 |

In R513A, the mixture of R1234yf and R134a, it shows the higher miscibility than R134a and R1234yf, but working viscosity has the same trend like R450A in Figure 2. Therefore, we can’t apply on the past common sense such as high miscibility brings high solubility with these new refrigerants and their blends.

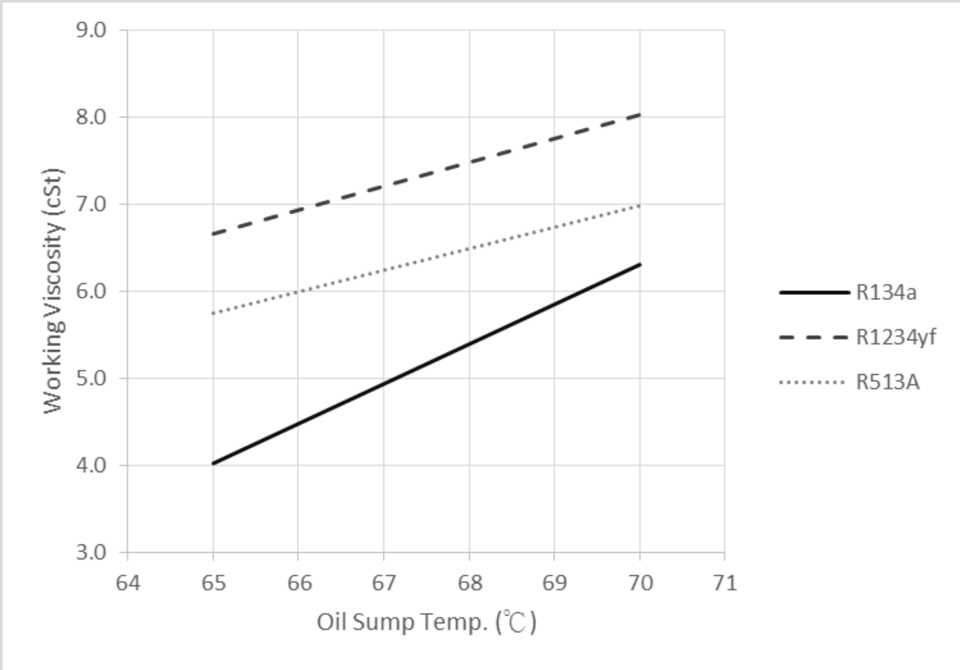


**Figure 2:** Working viscosity of POE-A in R134a, R1234yf, and R513A

## 3. REFRIGERANTION LUBRICANTS FOR R410A ALTERNATIVES

### 3.1 Miscibility of R410A Alternative Refrigeration Lubricants

We also examined the incumbent R410A alternatives and POE lubricants, following ASHRAE 86-1994 method, the results are in the Table 5. R32 refrigerant is the one of the exception in HFC refrigerants due to the low GWP property. One of the disadvantages of R32 is the poor miscibility with POE lubricants. That's why R410A (50% R32 and 50% R125) has better miscibility than 100% R32 refrigerants. R452B (R32 refrigerant blended with R1234yf and R125 refrigerants) has the similar miscibility results as R410A.

**Table 5:** The miscibility of refrigeration lubricants in the R410A and alternatives

| Typical value | | POE-D | POE-E |
|---|---|---|---|
| Test item | unit | | |
| Kinetic Viscosity @40℃ | cSt | 32 | 32 |
| Miscibility, 20% oil in R410A | ℃ | <-50 | -27 |
| Miscibility, 20% oil in R32 | ℃ | -20 | 15 |
| Miscibility, 20% oil in R452B | ℃ | <-50 | -25 |

### 3.2 Solubility and Working Viscosity of Refrigeration Lubricants in R410A and Alternatives

We selected ASHRAE standard working condition (Condenser temp. 54.4℃, oil temp. 80-95℃) to calculate the POE working viscosity in the R410A and alternatives system, shown in Table 6. Lubricants in R32 has poor miscibility than lubricants in R410A and R452B, resulting in the lower solubility and higher working viscosity.

**Table 6:** The solubility and working viscosity of POE in the R410A and alternatives

| Condition | | | POE-D | | POE-E | |
|---|---|---|---|---|---|---|
| Refrigerant | Oil temp. | Pressure | Solubility (%) | Viscosity (cSt) | Solubility (%) | Viscosity (cSt) |
| R410A | 95℃ | 3393kPa (54.4℃) | 22.0 | 2.4 | 19.0 | 2.0 |
| | 80℃ | | 30.1 | 2.0 | 26.5 | 1.7 |
| R32 | 95℃ | 3473kPa (54.4℃) | 15.6 | 2.5 | 13.6 | 2.2 |
| | 80℃ | | 21.9 | 2.2 | 18.9 | 2.0 |
| R452B | 95℃ | 3037kPa (54.4℃) | 18.1 | 1.9 | 19.5 | 2.1 |
| | 80℃ | | 24.7 | 1.5 | 25.7 | 2.0 |

Most of the time, we consider lubricant with good miscibility to have good solubility, which will increase the dilution of working viscosity. In Figure 3, POE-D with higher miscibility and solubility than POE-E, POE-D's working viscosity isn't dilution by the high solubility and better than POE-E. This relations aren't happened to all the refrigerant and lubricants. However, the same lubricants in the different refrigerants in Table 6, sometimes the higher solubility will cause the further dilution to the working viscosity.

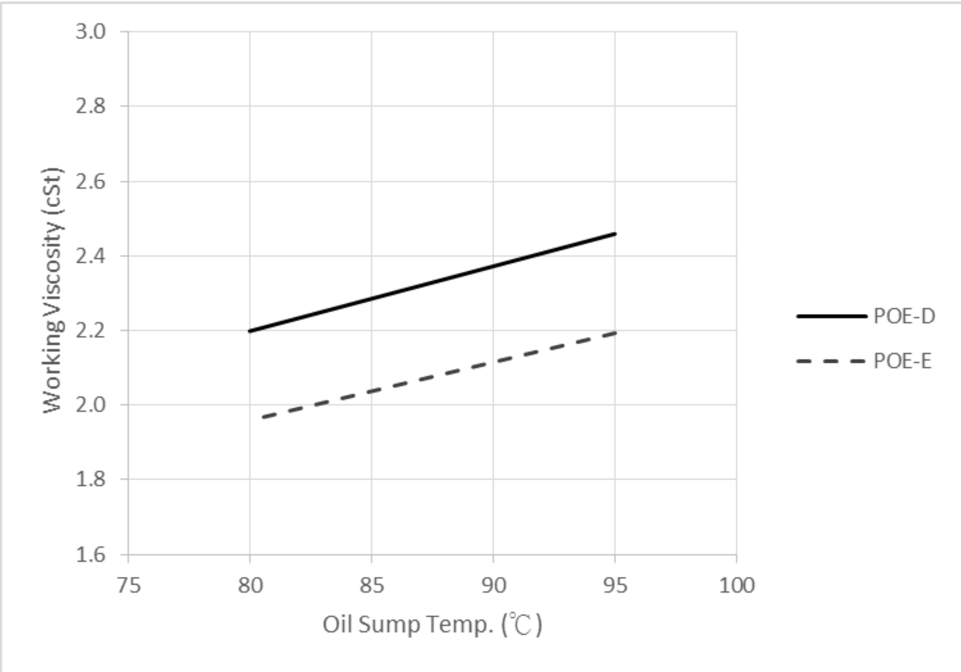


**Figure 3:** Working viscosity of POE-D and E in R32

## 4. DISCUSSION

In the compressor systems, the lubricants are influence by the refrigerant, it will bring the lubricants into the systems due to the initial starting up foaming, the low efficiency of oil separator, etc. In refrigeration system, wide range miscibility is usually required to guarantee the durability for a long working time, such as miscibility curve shown in Figure 4.

For HFC blend HFO system, miscibility curves typically possess higher miscible range due to HFO's excellent affinity with lubricant in low temperature (Figure 5). But if we focus on the miscible phenomenon in compressor, high temperature miscibility should be taken into consideration. Compare the data shown in Table 7, POE-B is more miscible in R-134a than in R-513A for high temperature condition, so it will result in higher solubility and lower working viscosity.

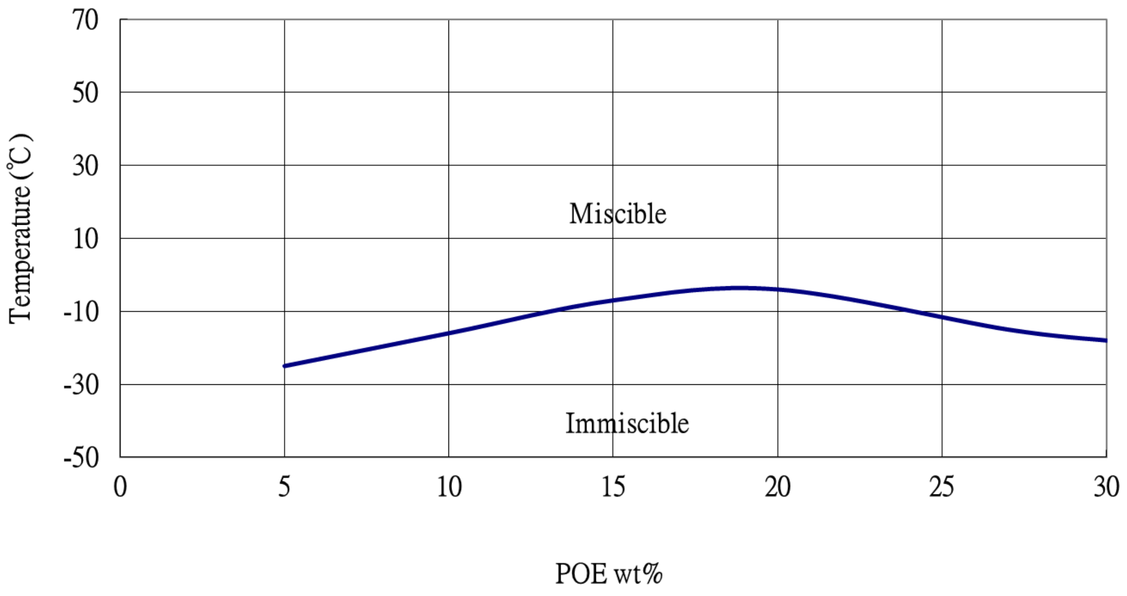


**Figure 4:** Miscibility curve of POE-B in R134a

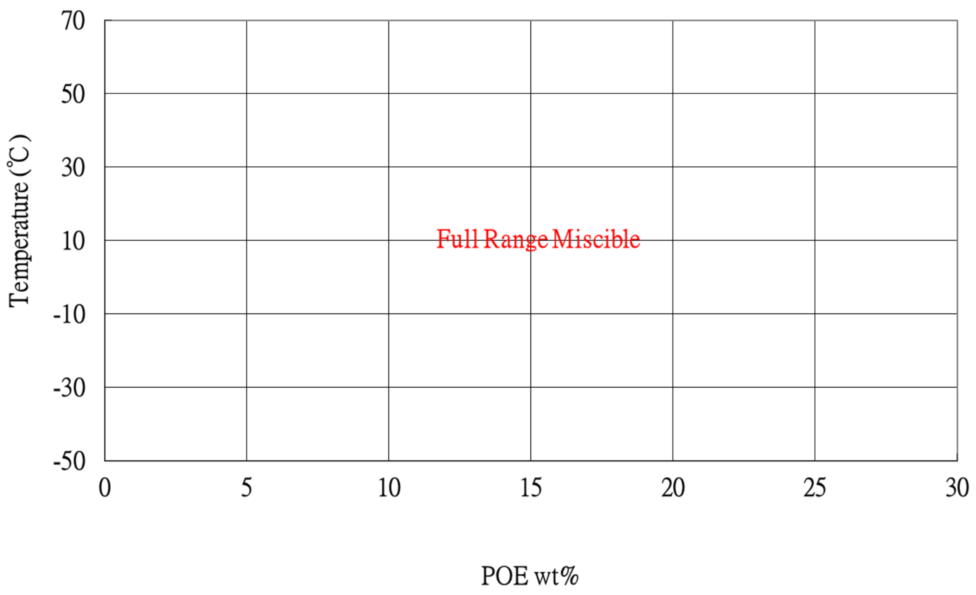


**Figure 5:** Miscibility curve of POE-B in R513A

**Table 7:** The miscibility and solubility of POE-B in the R134a and R513A

| | Miscibility, 20% oil in R134a | Miscibility, 20% oil in R513A |
|---|---|---|
| POE-B | >80~ -4℃ | 74~ <-50℃ |
| Condition | R134a | R513A |
| Oil temp. | 65℃ | 65℃ |
| Pressure | 1470kPa (54.4℃) | 1457kPa (54.4℃) |
| POE-B solubility (%) | 38.1 | 36.3 |
| POE-B working viscosity (cSt) | 3.6 | 4.2 |

For R410A and alternatives system, lower miscible range can be expected due to R32's poor affinity with lubricant both in high temperature and low temperature, such as data shown in Table 8. The narrow miscible range will lead to inconsistent phenomenon among miscibility, solubility and working viscosity.

**Table 8:** The miscibility and solubility of POE-D in R410A and alternatives

| | Miscibility, 20% oil in R32 | Miscibility, 20% oil in R410A | Miscibility, 20% oil in R452B |
|---|---|---|---|
| POE-D | 61~ -20℃ | >70 ~ <-50℃ | >76~ <-50℃ |
| Condition | R32 | R410A | R452B |
| Oil temp. | 95℃ | 95℃ | 95℃ |
| Pressure | 3473kPa (54.4℃) | 3393kPa (54.4℃) | 3037kPa (54.4℃) |
| POE-D solubility (%) | 15.6 | 22.0 | 18.1 |
| POE-D working viscosity (cSt) | 2.5 | 2.4 | 1.9 |

## 5. CONCLUSIONS

Through this study, we discovered some interesting characteristics of HFC blend HFO refrigerants.

- The lubricants with the same viscosity in R134a and alternatives systems, lubricants' miscibility will have positive relationship with their solubility. Like POE-B with better miscibility than POE-A in R134a and alternatives systems, has better solubility and causes to the dilution of working viscosity.
- The lubricants in R134a and blend HFO systems, the working viscosity is between the results in R134a and HFO system.
- The lubricants with the same viscosity in R410A and alternatives systems, their properties of miscibility, solubility and working viscosity won't have the relations. POE-D has better miscibility and solubility than POE-E, and working viscosity isn't dilution by the high solubility.

Generally speaking, better miscibility brings better solubility, which can cause the dilution of working viscosity. However multiple refrigerants will influence the interaction between lubricants and blend refrigerants. We still need much more experimental data on miscibility, solubility and working viscosity in order to draw conclusion on the relationship between lubricants and refrigerants. Understanding these relationships can help us optimize the refrigeration lubricants effect in the refrigeration systems.

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