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Solution Properties Of Polyol Ester Lubricants Designed For Use With R-32 And Related Low GWP Refrigerant Blends

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Solution Properties of Polyol Ester Lubricants Designed for use with R-32 and Related Low-GWP Refrigerant Blends

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ABSTRACT

The purpose of this paper is to compare thermophysical properties of refrigerant-lubricant mixtures containing traditional POE lubricants to those containing advance (or optimized) POEs. The general methods for data acquisition and processing, along with creation of Daniel charts were in accord with those developed by Seeton (2009). The results of measurements involving mixtures of traditional POEs with R-32 or R-410A show that lubricant viscosities in the compressor at various conditions within the normal operating envelope decrease by as much as 25-54%. This illustrates the excessive lubricant viscosity dilution of R-32 relative to R-410A with traditional POEs used today with HFCs refrigerants. The solution property measurement technique was also used to develop a class of advanced ester POE lubricants optimized for R-32 to eliminate the viscosity dilution problem. Significant energy savings can be achieved through proper optimization of lubricant/refrigerant solution properties to provide the best balance of lubrication in the compressor while maintaining excellent heat transfer in the refrigeration cycle. Miscibility between new low Global Warming Potential (GWP) refrigerants and POE lubricants is a property that has to be considered, since a miscibility gap at concentrations between 10% to 20% (or higher to 30%) in volume may become an issue in oil return in refrigeration systems and its performance evaluated as Coefficient of Performance (COP). The advanced ester POE lubricants show improvement in the miscibility and viscosity issues. The miscibility gap was eliminated such that the new products are fully miscible from -20°C to 40°C. Viscosity dilution was limited to closely match the typical viscosity dilution shown in the baseline pair of R410A and an ISO 32 traditional POE. Finally, a comparison of concentrations and solution viscosities of traditional and advanced ester POE lubricants with R410A and R32 refrigerants, using actual conditions measured in a three ton air conditioning system, show a solution viscosity improvement when as ISO grade increases, with lower concentrations of refrigerant in oil than in the baseline of R410A and an ISO 32 traditional POE.

1. INTRODUCTION

Since the Montreal and Kyoto protocols mandated the phase-out of refrigerants which deplete the ozone layer and have high global warming potential, respectively, there has been an extensive global initiative to identify suitable environmentally sustainable alternatives. Replacement of CFCs and HCFCs with HFCs has successfully addressed the objectives of the Montreal protocol. However, most HFCs used today are not acceptable for the long term because they have GWPs greater than 1,000. Low GWP refrigerants that are, or will be, considered as replacements for HFCs include R32, hydrocarbons such as R290, carbon dioxide (R744), and hydrofluoroolefins such as HFO1234yf and HFO1234ze(E). It has already been determined that in many cases new lubricants will be required for these refrigerants to ensure long term compressor reliability and the best possible system performance (Hessell et al., 2014).

The primary issue that must be addressed is the unacceptable high mutual solubility of the refrigerant and lubricant at high lubricant concentrations (Hessell et al, 2014). The first consequence of this high solubility is the excessive reduction of viscosity that affects proper lubrication of the compressor and components and the sealing of clearances between low and high pressure sides of the compressor. The second is a significant change in the steady state amount of oil in the circulation stream in the system, which can impact the heat transfer performance in both the evaporator and condenser. Another potential minor issue is refrigerant flash evaporation at discharge creating excessive foaming and noise.

2. EQUIPMENT

Miscibility was determined by utilizing seal tubes (ASHRAE Standard 97 method) with different concentrations of lubricant/refrigerant mixture. This is simply a temperature-controlled bath, where sealed tubes are observed to determine phase separation temperatures.

Solution properties as a function of Pressure, Viscosity, and Temperature (PVT) were determined using the test equipment described by Seeton (2009) to collect data to obtain constants for the set of solubility, density, and viscosity refrigerant/oil equations (Seeton and Hrnjak, 2006). The PVT test equipment is illustrated in Figure 1. The construction provides a circulation loop to maintain thermodynamic equilibrium during a slow temperature ramp. A pump circulates the fluid and promotes mixing; a mass flow meter measures rate flow, temperature, and density of the fluid; a piston viscometer measures temperature and viscosity; thermocouples measure bulk liquid phase and vapor phase temperature; and a pressure transducer measures system pressure. The loop is placed inside a thermal chamber that maintains constant temperature or a ramp temperature small enough to maintain a thermodynamic equilibrium when it sweeps a range of temperature at a constant bulk composition, (Seeton, 2009). A desktop computer records the set of properties for each run for regression analysis.

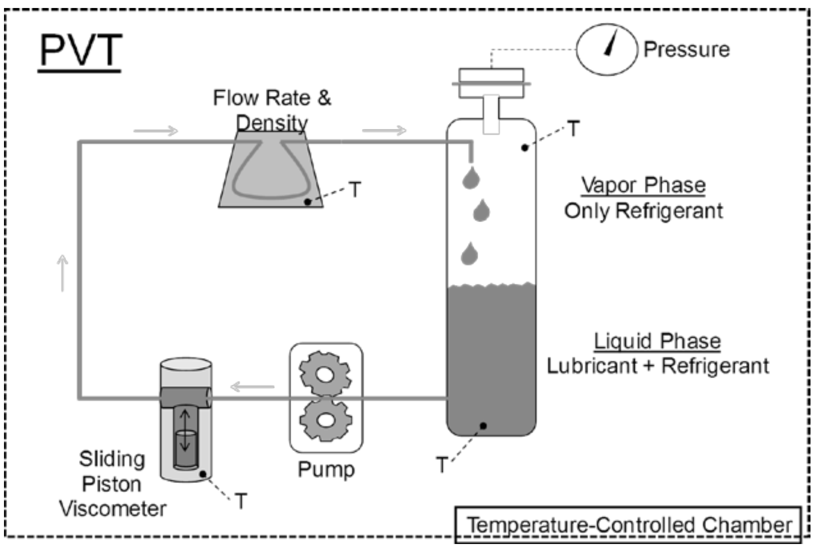


Figure 1: PVT Test Equipment

3. EQUATIONS

After the regression analysis, four sets of constants are found to use in the density, solubility (saturated vapor pressure), and viscosity mathematical models. Seeton and Hrnjak, 2006 show empirical correlated equations for density and solubility in function of temperature and mass of refrigerant concentration in the mixture oil/refrigerant. The viscosity also is an empirical correlated equation in function of temperature and concentration (Seeton and Hrnjak, 2006).

4. CTS FACILITY EXPERIMENT

Creative Thermal Solutions run a three ton scroll compressor air conditioner system following AHRI 210/240, test conditions to analyze the energy efficiency of the system and its oil retention (Benanti, 2014; Wujek 2014). Traditional and advanced POEs were tested using R410A as a baseline refrigerant, R32 and L41b as alternatives, comparing COP and oil retention results. From the point of view of miscibility and solution viscosity, several cases are presented with pressures and temperatures measured at the suction and discharge compressor, which presented in Table 1.

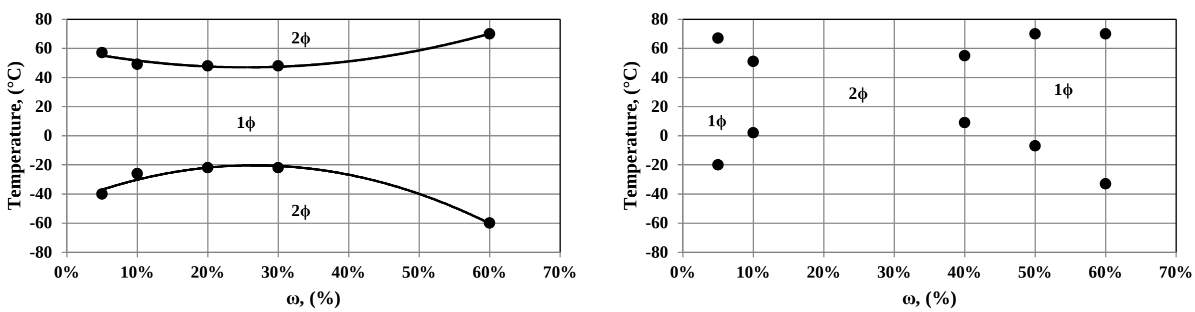
Table 1: Experimental Temperatures and Pressures of Compressor Suction and Discharge at AHRI 210/240 Condition A

Refrigerant	Lubricant	ISO Grade	$P_{Suction}$ [Bar]	$T_{Suction}$ [°C]	$T_{Discharge}$ [°C]	$P_{Discharge}$ [Bar]
R410A	Traditional	32	10.80	20.58	82.18	29.11
R32	Traditional	32	11.46	21.21	101.75	31.16
R410A	Traditional	68	11.09	19.20	77.88	29.14
R32	Traditional	68	11.16	21.25	98.12	30.07
R32	Advance	32	11.28	21.14	96.55	30.04
R32	Advance	46	11.21	21.24	97.27	29.89
R32	Advance	68	11.22	20.93	95.68	29.94
R32	Advance	80	11.39	21.81	98.24	30.52

5. STUDIED CASES

5.1 Traditional POE ISO 32 grade

The miscibility charts with R410A and R32 for these oils are shown in Figure 2. This shows the miscibility gap of the oil with R32 between 20% and 30% concentration in volume of R-32 in the traditional POE ISO 32 oil.



(a) (b)

Figure 2: Miscibility Chart (a) T-ISO-32/R410A and (b) T-ISO-32/R32 (20% and 30% immiscible)

The Daniel's charts with R410A and R32 (Figure 3) shows the dilution of the viscosity of the traditional oil ISO 32 with the two refrigerants. This could be analyzed from two different points of view.

Table 2: Traditional ISO 32 with R410A and R32 (P&T Experimental) and (ω&ν) Calculate Data

Oil-Refrigerant	Point	Temperature (°C)	Pressure (Bar)	Concentration (%)	Viscosity (cSt)
Traditional ISO 32 R410A	S (T,P SUCTION)	20.6	10.8	24.9	6.23
	DS (T DISC, P SUCT)	82.2	10.8	5.4	5.93
	D (T,P DISCHARGE)	82.2	29.1	18.0	2.76
Traditional ISO 32 R32	S (SUCTION)	21.2	11.5	21.3	4.09
	DS (T DISC, P SUCT)	101.8	11.5	3.9	3.66
	D (T,P DISCHARGE)	101.8	31.2	11.0	2.09

One is from the concentration of the refrigerant which seems to be lower with R32 than R410A at the same value of viscosity. This could be beneficial considering that most of the refrigerant will go to the system and less will remain in the compressor sump. However, the second point of view could be a problem, which at same concentration of refrigerant, the dilution of oil viscosity is greater in R32 than the dilution of oil viscosity with R410A.

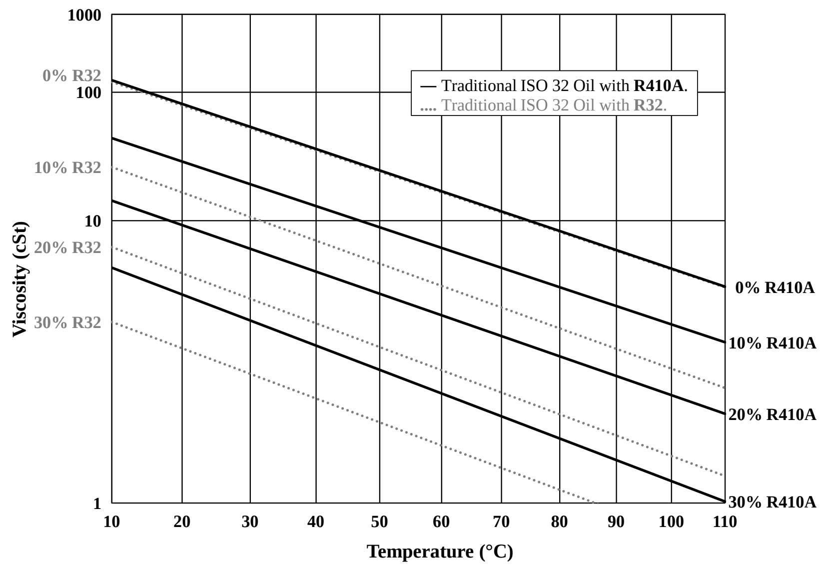


Figure 3: Daniel's Chart of R410A and R32 with Traditional POE ISO 32

The comparison of the concentration and solution viscosity at experimental pressures and temperatures from the same system is shown in Table 2 and Figure 4. The pressure and temperature at the compressor suction for both refrigerants are close (less than 1°C and 1 bar difference). The pressure at the compressor discharge is also close in both refrigerants. The major difference is in the discharge temperature of the two refrigerants, being around 20°C greater with R32 than with R410A. The result was expected in view that R410A is a mixture of R32 with R125 (50:50) and its critical point is lower than the R32.

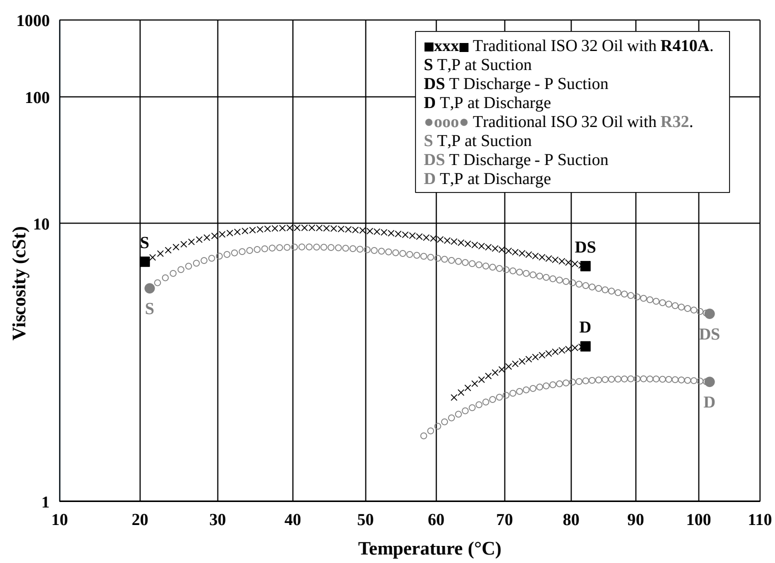
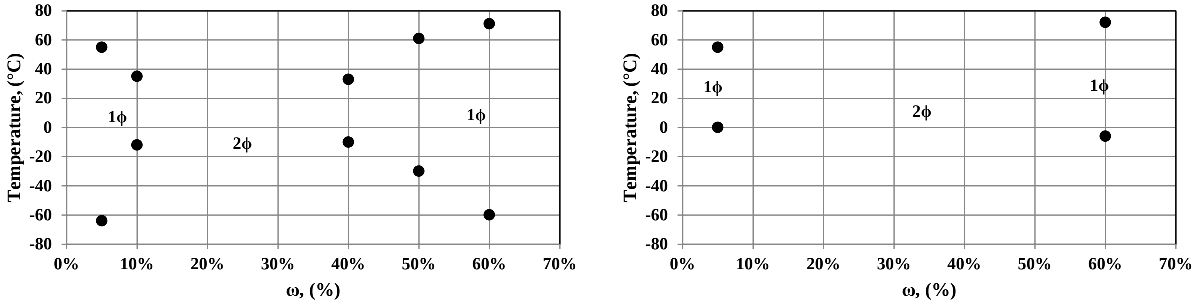


Figure 4: Daniel's Chart of R410A and R32 with Traditional POE ISO 32

The most significant comparison is the solution viscosity, which is lower in R32 than R410A. This effect could be very important to the life of the compressor because, as the viscosity of the fluid decreases, it loses its ability to lubricate bearings and sliding surfaces.

5.2 Traditional POE ISO 68 grade

One way to compensate for the lack of viscosity of the first solution will be to go to higher viscosity. ISO grade 68 will be a good point to start comparing miscibility and solution viscosities. The miscibility charts (Figure 5) show that R410A and R32 are immiscible between 20%-30% and 10%-30% concentration respectively. The concentration and solution viscosity (Figure 6) shows improvement from traditional ISO 32 oil to the ISO 68, but the problem of the miscibility is too critical to recommend working with this oil.



(a) (b)

Figure 5: Miscibility Chart (a) T-ISO-68/R410A (20% and 30% immiscible) and (b) T-ISO-68/R32 (10%, 20%, 30%, 40%, and 50% immiscible)

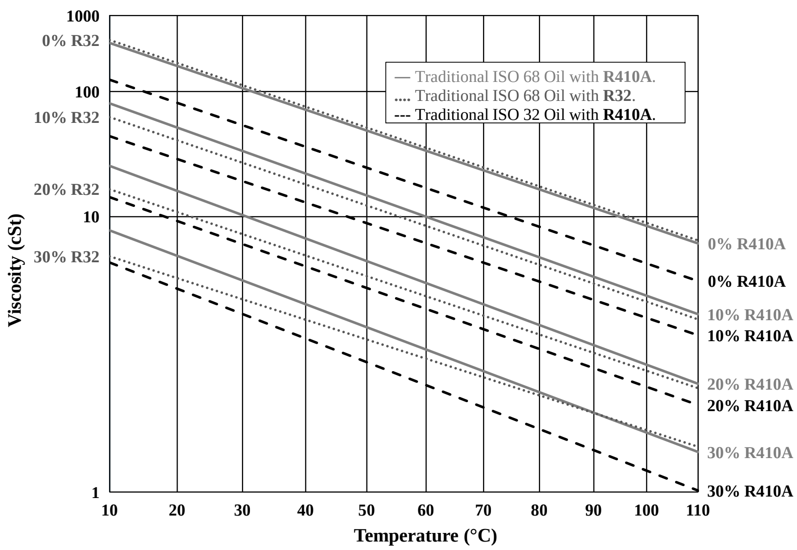
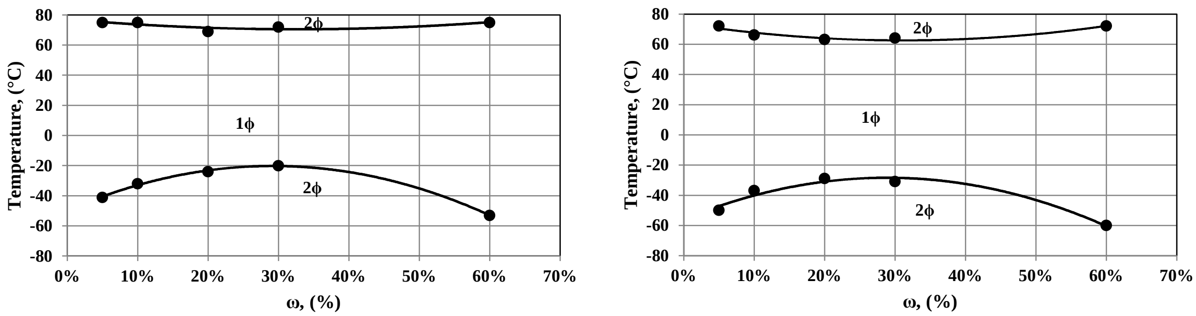


Figure 6: Daniel's Chart of R410A and R32 with Traditional POE ISO 32 and 68

5.3 Advance POE ISO 32 and 46 grade

Knowing that increasing the ISO grade does not completely solve the problem of the viscosity for traditional oils for lack of miscibility, new developmental oils were tested for miscibility and solution properties. The two new candidates are advanced POE ISO 32 and ISO 46. They are miscibility from 5% to 60% (Figure 7), which may solve the problem of poor oil return and heat transfer in the evaporator. Even though the advanced POEs (Figure 8) do not match the baseline case with R410A, their solution viscosities show improvement enough to justify the consideration of higher ISO grades (68 or 80).



(a) (b)

Figure 7: Miscibility Chart (a) A-ISO-32/R32 and (b) A-ISO-46/R32

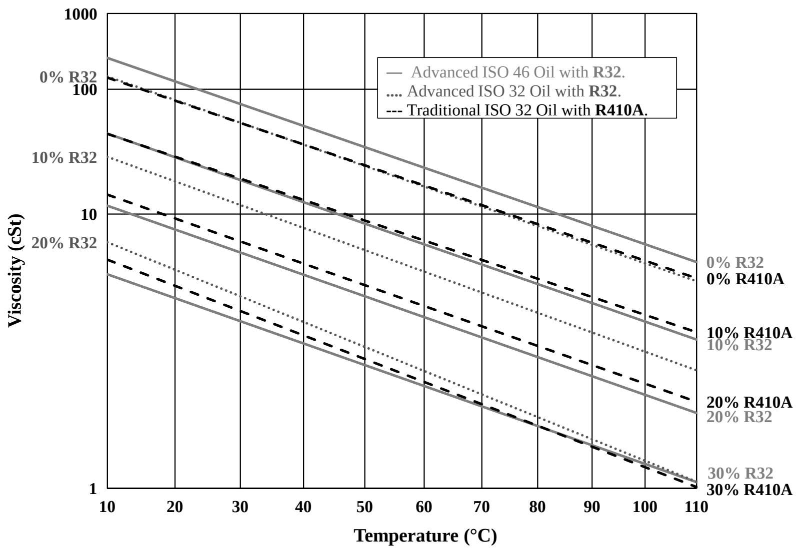
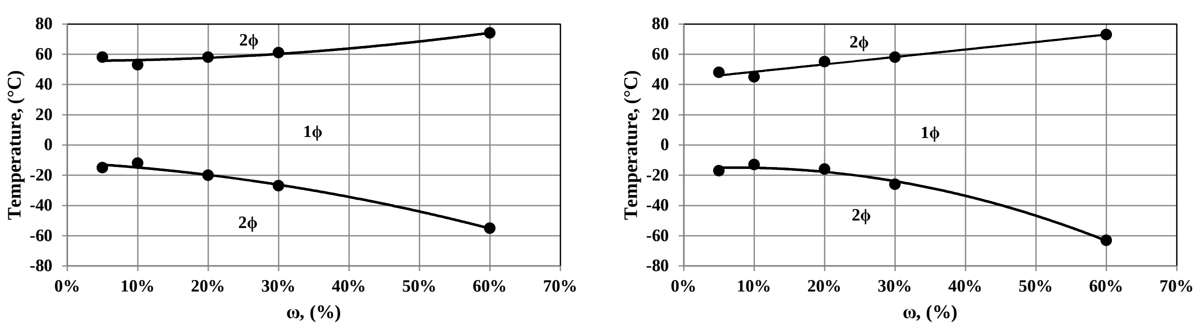


Figure 8: Daniel's Chart of R32 with Advance POE ISO 32 and 46.

5.4 Advance POE ISO 68 and 80 grades

The miscibility for these two advanced POEs in R32 (Figure 9) shows good ranges of miscibility.



(a) (b)

Figure 9: Miscibility Chart (a) A-ISO-68/R32 and (b) A-ISO-80/R32.

The Daniel's chart for these two advanced POEs (Figure 10) shows good improvement in concentration and solution viscosity. The 10%, 20%, and 30% are relatively close between these two advanced POEs in R32 and the traditional POE for R410A.

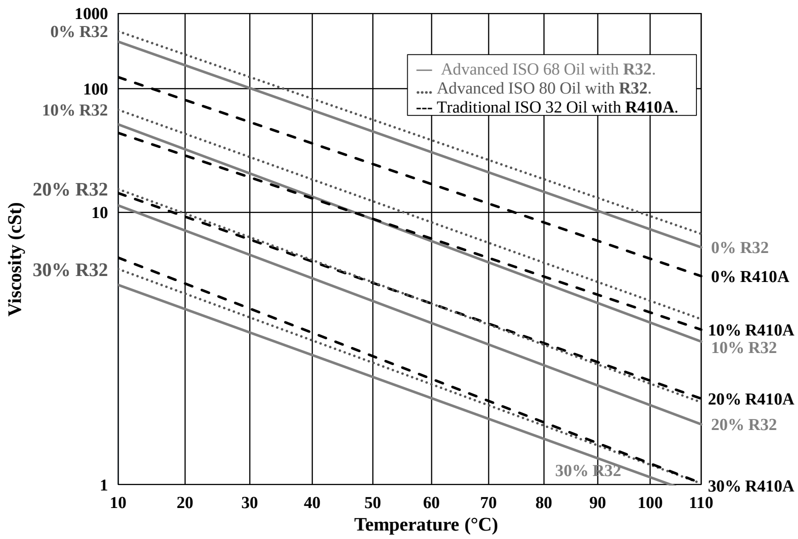


Figure 10: Daniel's Chart of R32 with Advance POE ISO 68 and 80.

6. CONCENTRATIONS AND VISCOSITIES AT COMPRESSOR SUCTION AND DISCHARGE

Table 1 showed the pressure and temperature values at the suction and discharge of the three ton compressor measured at the condition A of the AHRI 210/240. With these values, and the PVT coefficients for the oil-refrigerant pairs, concentration and viscosities can be calculated.

Results (Figures 11, 12, 13, and 14 – Tables 3 and 4) show, as expected, an increasing of the viscosity when the ISO grade increases. The concentration of R32 has a tendency to be lower than the concentration of R410 with traditional ISO32. The advanced ISO 46 has the highest refrigerant concentration on both sides of the compressor.

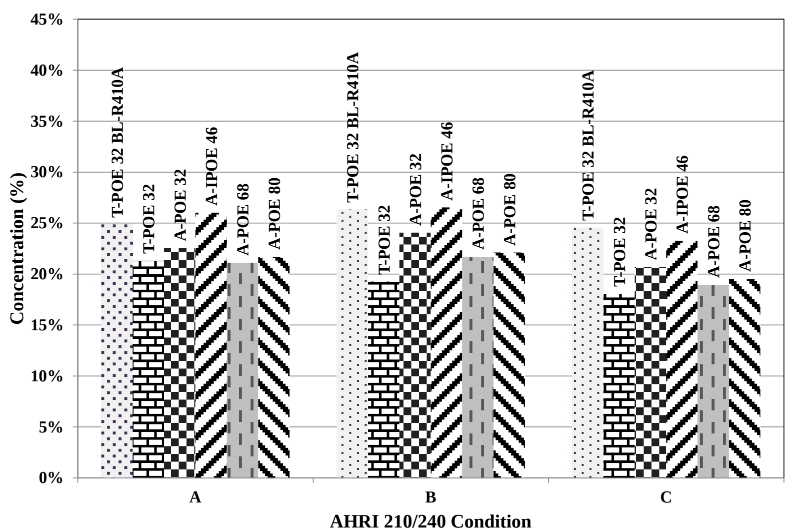


Figure 11: Concentration Comparison Charts at Compressor Suction

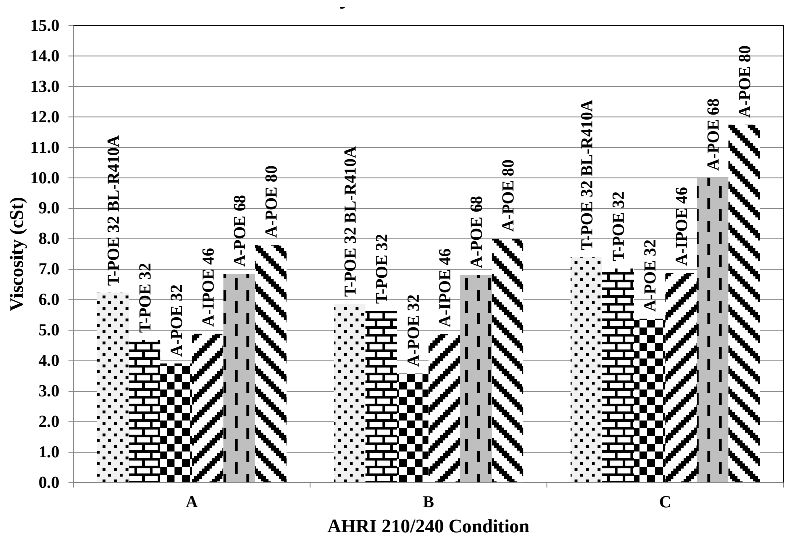


Figure 12: Viscosity Comparison Charts at Compressor Suction

Table 3: Concentration and Viscosity at Compressor Suction (AHRI 210/240 Condition A)

Refrigerant	Lubricant	ISO Grade	Pressure [Bar]	Temperature [°C]	Concentration [%]	Viscosity [cSt]
R410A	Traditional	32	10.80	20.58	24.88%	6.23
R32	Traditional	32	11.46	21.21	21.31%	4.69
R32	Advance	32	11.28	21.14	22.54%	3.91
R32	Advance	46	11.21	21.24	26.04%	4.89
R32	Advance	68	11.22	20.93	21.12%	6.85
R32	Advance	80	11.39	21.81	21.69%	7.80

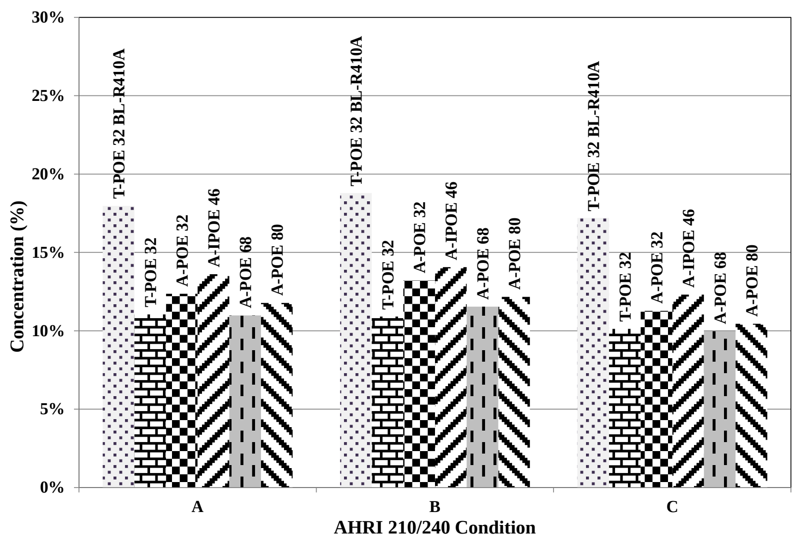


Figure 13: Concentration Comparison Charts at Compressor Discharge

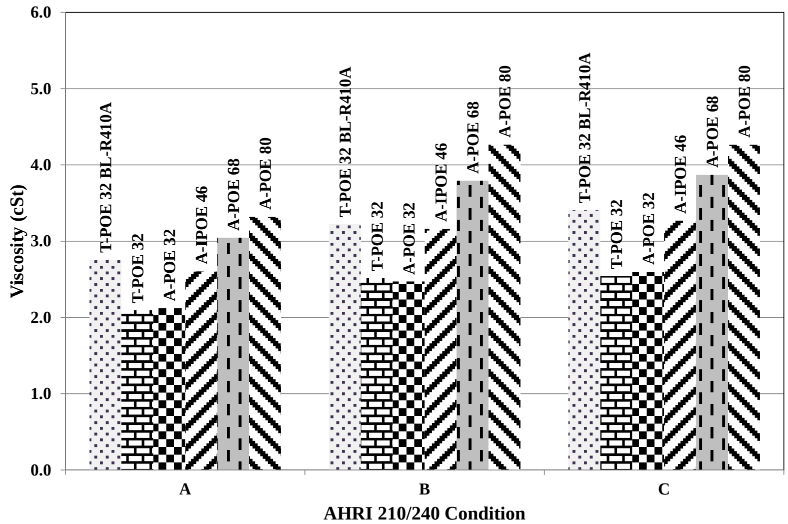


Figure 14: Comparison Charts at Compressor Discharge (a) Concentration and (b) Viscosity

Table 4: Concentration and Viscosity at Compressor Discharge (AHRI 210/240, Condition A)

Refrigerant	Lubricant	ISO Grade	Pressure [Bar]	Temperature [°C]	Concentration [%]	Viscosity [cSt]
R410A	Traditional	32	29.11	82.18	17.97%	2.76
R32	Traditional	32	31.16	101.75	11.05%	2.09
R32	Advance	32	30.04	96.55	12.37%	2.12
R32	Advance	46	29.89	97.27	13.61%	2.61
R32	Advance	68	29.94	95.68	10.99%	3.05
R32	Advance	80	30.52	98.24	11.78%	3.32

7. CONCLUSIONS

New refrigerants, such as R32, present a miscibility and viscosity properties challenge for traditional oils. Its miscibility is very poor and/or its solution viscosity is too low.

New oils, advanced POEs, provide solutions to these challenges. R32 is miscible in these advance POEs. PVT properties become closer to the traditional ISO 32 POE with R410A as the ISO grade increases.

Next step is to compare COP and oil retention of advanced POEs in R32 with the traditional ISO 32 POE in R410A.

NOMECLATURE

A-ISO	Advance POE	(–)
AHRI	Air-Conditioner Heater and Refrigeration Institute	(–)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers	(–)
ASTM	American Society for Testing and Materials	(–)
CFC	Chlorofluorocarbon	(–)
COP	Coefficient of Performance	(–)
D	Discharge	(–)
GWP	Global Warming Potential	(–)
HCFC	Hydro-Chloro-Fluoro-Carbon	(–)
HFC	Hydro-Fluoro-Carbon	(–)
HFO	Hydro-Fluoro-Olefin	(–)

POE	Polyolester	(–)
PVT	Pressure-Viscosity-Temperature	(Bar-cSt-°Centigrade)
S	Suction	(–)
T-ISO	Traditional POE	(–)
ϕ	Liquid Phase	(–)
ν	Kinematic Viscosity	(cSt)
ω	Refrigerant Concentration	(%)

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