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LGWP & HC refrigerant solubility tests performed in running scroll compressor

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ABSTRACT

This paper presents the results of investigations on Low Global Warming Potential refrigerants and R290 solubility with different lubricants. Solubility impacts a lot the final lubricant-refrigerant mixture reaching the bearing lubricant inlet and in the same way can impact compressor reliability on wet vapor flowing back to compressor inlet. Experimental data, measured in operating compressors, are compared to static steady state values coming from PVT plots. R407C and R410A, two well-known HFC refrigerants, are added as a reference. This work highlights the differences between dynamic solubility (tests performed in a compressor) and static solubility (from PVT plots). A comparison of the impact on the dynamic solubility has been done when a steering feature is added. This work allows us to define the best compromise between different lubricants in these new applications.

1. INTRODUCTION

Recent developments in regulations governing the use of refrigerants with respect to their global environmental impact (2006/842/EC "F-GAS" regulation recently voted in the EU with a new revision coming into force on January 1st 2015, or 2009/125/EC Eco-design directive about energy performance) imply the introduction of new refrigerants and the adequate lubricant for these new applications. Natural refrigerant R290 and some LGWP refrigerants based on HFO and their blends are part of the solution. For example, R290 has a Global Warming Potential (GWP) equal to 3 which is roughly 500 times lower than R407C and 600 times lower than R410A.

As a consequence, tests with R290 and several HFO based mixtures have been performed in running compressor by sampling a small quantity of lubricant/refrigerant mixture from the oil sump. The mixture was sampled at several saturation suction temperatures and superheat conditions. The compressors used were standard scroll compressors. This article presents the results of these tests and compares them with static steady state solubility values from PVT plots, especially at low superheat.

2. STEADY STATE SOLUBILITY

Steady state values are provided by PVT plots (also named Daniel plots). They indicate the solubility of the refrigerant in the respective lubricant and the viscosity of the mixture in accordance with temperature and pressure. These plots are useful for the first comparisons of refrigerants and lubricants. However, they are more suitable for heat exchangers than compressors. Actually, the accuracy of data for low superheat conditions is unsatisfactory because of the slope of pressure curves (Figure 1). Furthermore, only a few oil ratio values are given (100%, 90%, 80% and 70% in most of plots, each 10% at best).

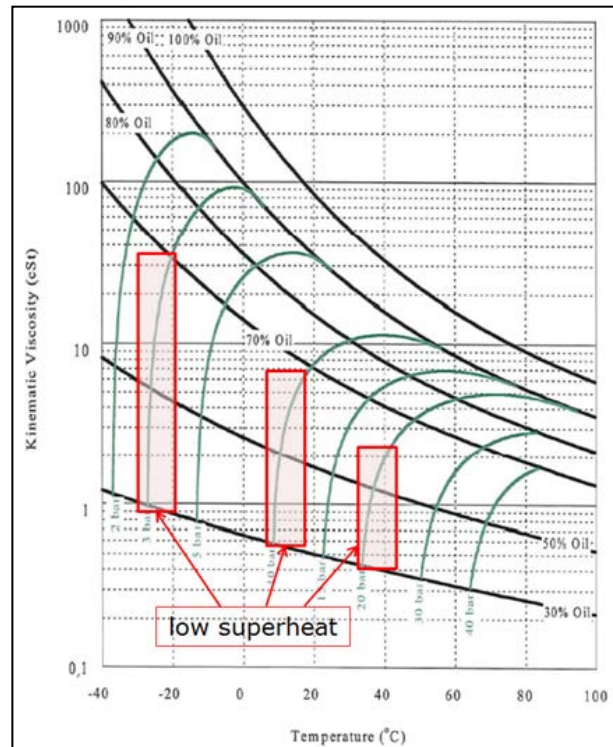


Figure 1 : R410A PVT plot with ISO 32 POE oil, low superheat highlighted

3. EXPERIMENTAL METHOD

3.1 R290 evaluation

Solubility tests must be performed in compressor in order to know the real behavior of lubricant/refrigerant mixtures at low superheat. Furthermore, the PVT plots only provide static steady state values, hence the usefulness of these tests in dynamic conditions corresponding to low super heat conditions.

These tests were run in a refrigeration loop which included a scroll compressor. An oil pump is fixed to the lower end of the crankshaft (Figure 2). Its rotation enables the oil sump lubricant to be stirred. This could homogenize the lubricant/refrigerant mixture and lead to an outgassing process.

The compressor used is a standard model. It is equipped with a valve in order to sample a small quantity of lubricant/refrigerant mixture from the oil sump. These samples are made when the system conditions are stable. Then the solubility is obtained by a similar process to the one of oil circulation rate measurement (ASHRAE standard 41.4-1996).

The tests were performed at several saturated suction temperatures (from -10°C to $+15^{\circ}\text{C}$) and superheat conditions (5K, 10K and 20K). This allows us to check the lubricant/refrigerant mixture behavior all over the application range of the compressor.

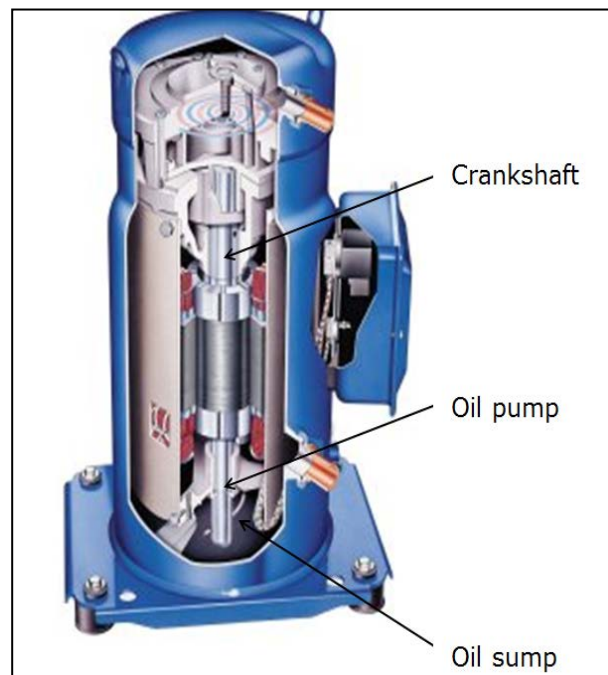


Figure 2 : Type of compressor used for the tests

RESULTS AND DISCUSSION

Five R290-based couples were tested. Two references with R407C and R410A were added. The Table 1 lists the different couples and the viscosity grade of the lubricants used.

Refrigerant	Lubricant	Grade
R407C	POE	32
R410A	POE	32
R290	Lub1	68
R290	Lub2	46
R290	Lub3	68
R290	Lub4	68
R290	Lub5	68

Table 1 : Lubricant/refrigerant couples studied

The Figure 3 presents the static steady state solubility from PVT plots data.

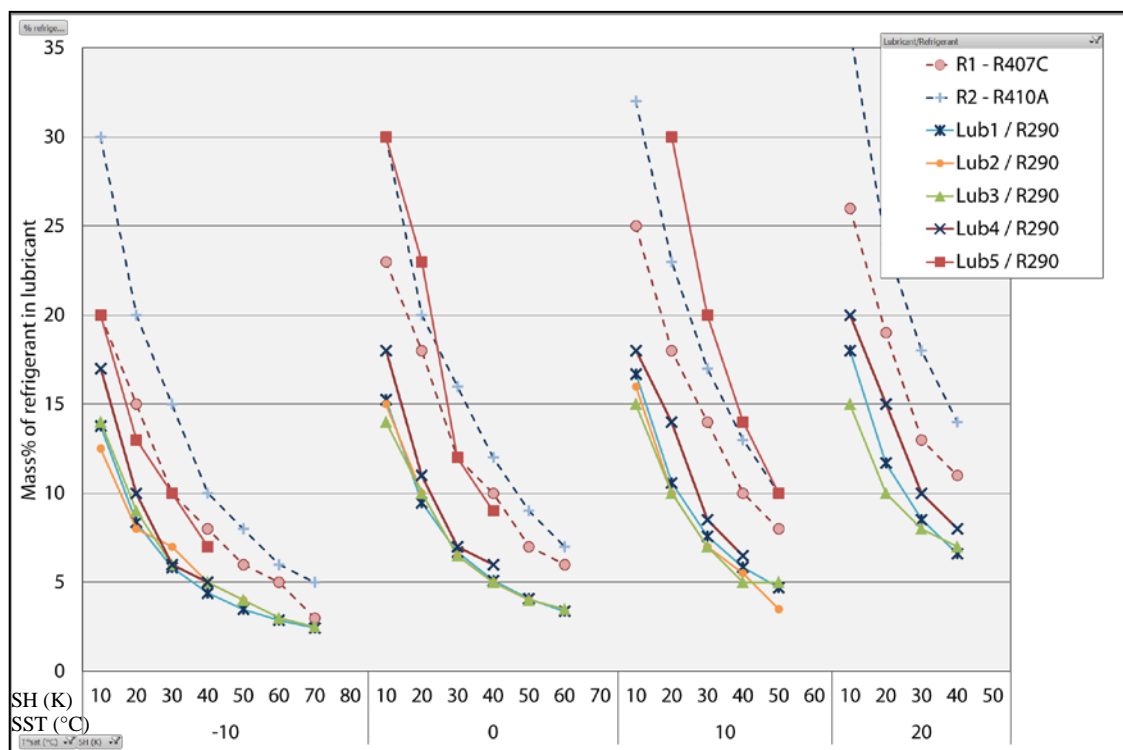


Figure 3 : Steady state solubility provided by PVT plots at different saturated suction temperatures and superheat conditions

We used the oil sump sampling method to compare several lubricants on compressors. The results are shown in Figure 4. We can see 3 different groups of solubility level: 'Lub 5'; 'Lub2' and 'Lub 1-Lub3-Lub4'.

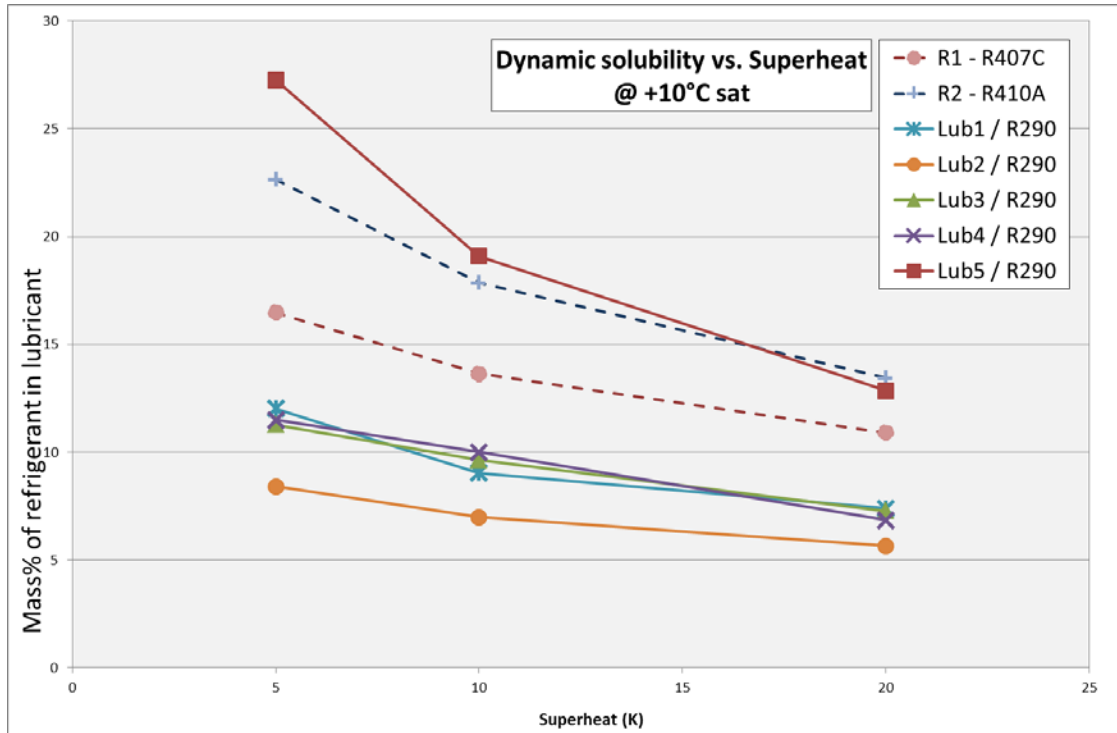


Figure 4 : Dynamic solubility measured in running compressor for T sat = 10°C

Solubility from PVT plots and tests in running compressor can now be compared in order to notice a potential dynamic effect. This comparison at low superheat for T sat = 10°C is presented by Figure 5. R407C and R410A curves are removed in the following graph.

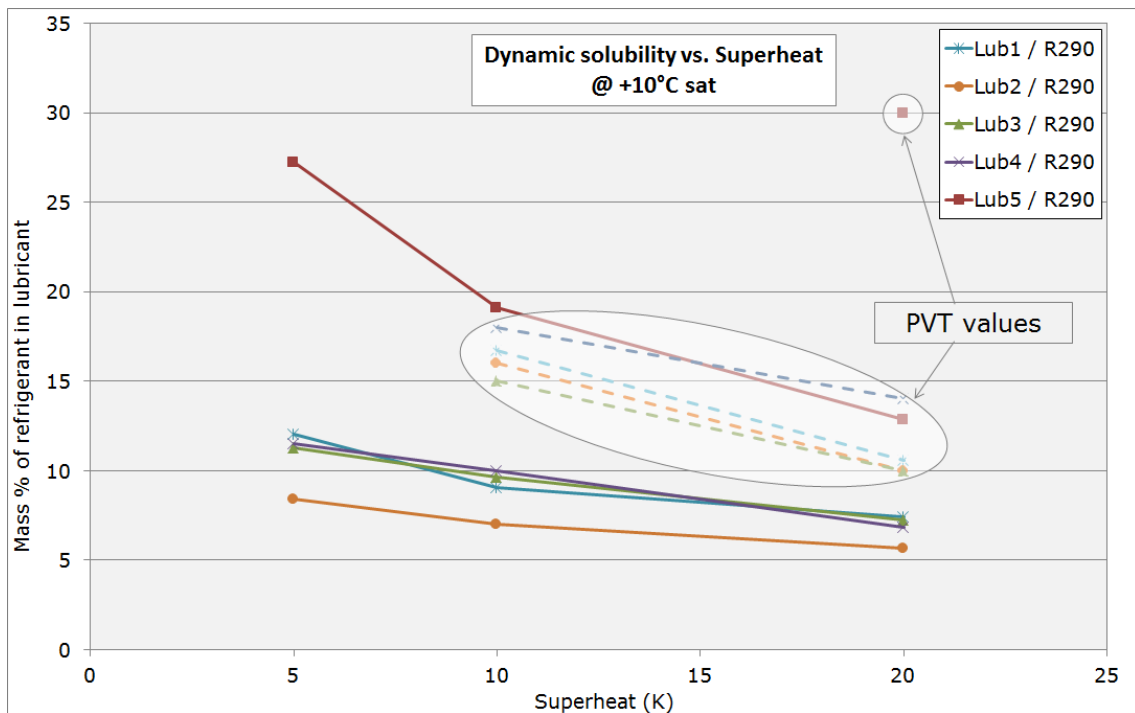


Figure 5 : Comparison of solubility from PVT plots (dotted line) and dynamic solubility tests performed in compressor

A 5% difference between PVT charts and tests performed in compressor values is noticed. In some case this shows that the refrigerant mass is reduce by 70% to 80%. The real solubility (in running conditions) is lower than the steady state solubility provided by PVT plots. P.J. Rubas and C.W. Bullard (1993) already observed a solubility decrease during the startup of compressor.

This solubility difference is also noticeable with both references R407C and R410A (Figure 6).

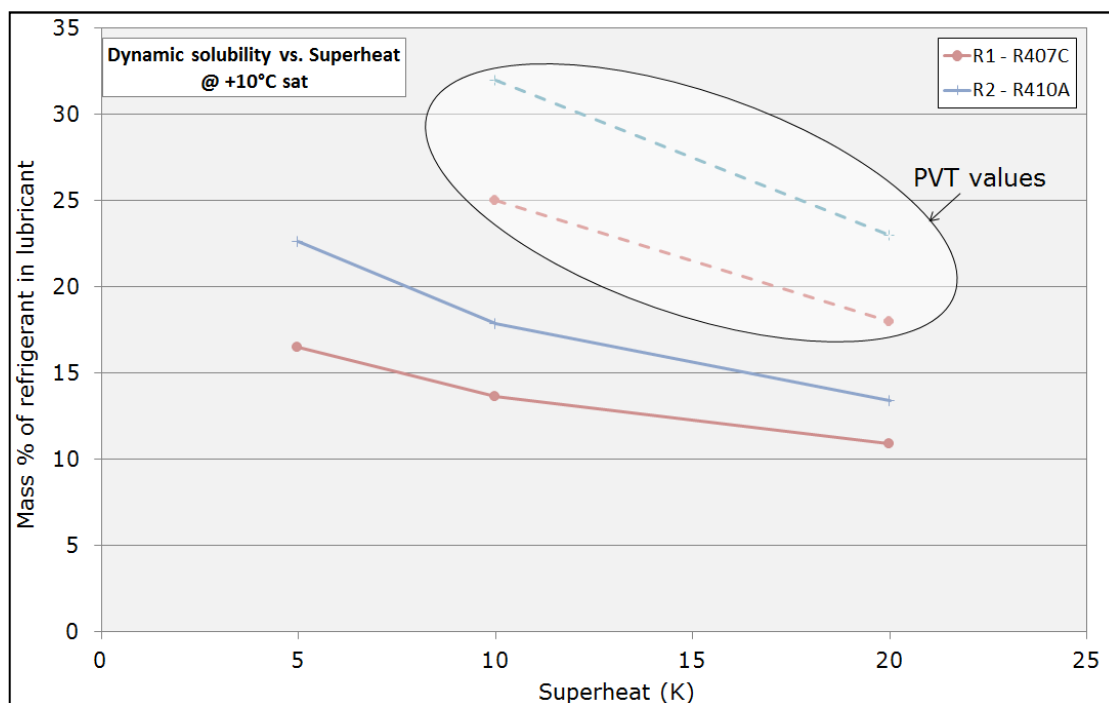


Figure 6 : Comparison of solubility from PVT plots and tests for R407C and R410A with POE oil

This decrease in solubility may be caused by the stirring effect in the oil sump produced by the moving parts, including the crankshaft and the oil pump. Said stirring effect leads to the foaming of the lubricant/refrigerant mixture which brings a decrease in solubility. T. Yanagisawa and T. Shimizu (1985) had early noticed that foaming caused by stirring effect in rolling piston type rotary compressor.

3.2 FGAS: new LGWP refrigerant investigation

On the work for new LGWP refrigerant applications we use similar evaluation method than the one we did for R290. The idea was to see what the existing similarities could be.

Figure 7 shows the results when we compare the Daniel plots solubility data for different POE lubricants with potential replacement LGWP refrigerant candidates versus known applications.

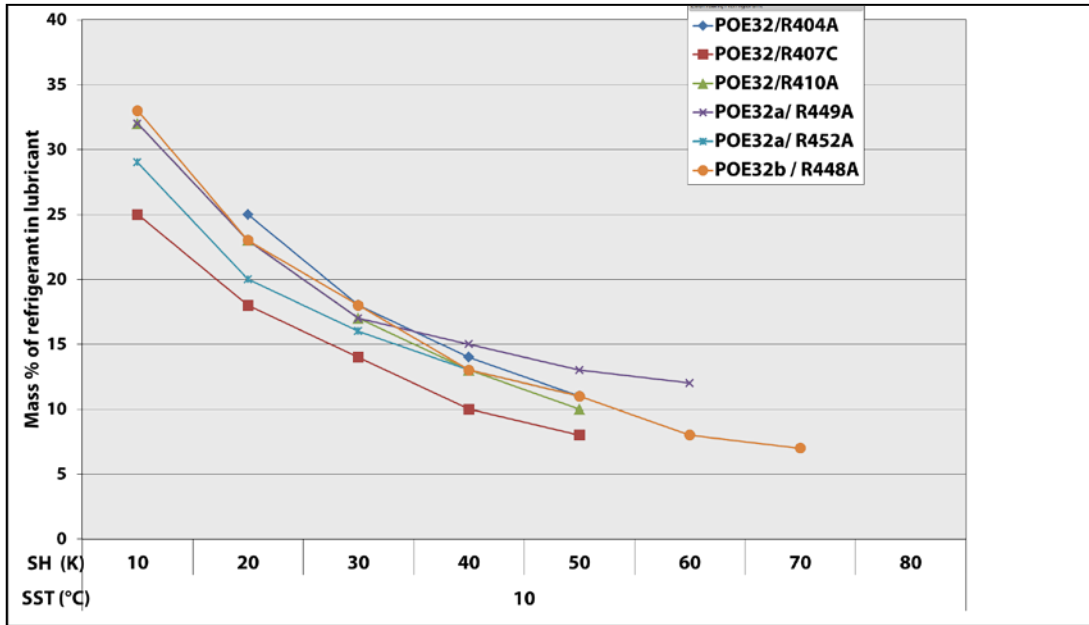


Figure 7 : Steady state solubility provided by PVT plots at 10°C saturated suction temperature and at several superheat conditions

The potential R404A new refrigerant replacement candidates; solubility % on static (Daniel plot) are on the same level than the R404A and R410A.

We can see that the solubility level for R404A and the new refrigerant candidates have a similar percentage value versus SH. We can note that the solubility percentage tends to be higher than the R407C refrigerant solubility in lubricant.

➔ Static solubility: POE32/R407C < POE/R449A ~ POE32/R410A ~ POE32b/R448A

To have a better vision of the behavior on oil sump we need some experimental tests to know the real values on the oil sump.

We perform similar testing process than we carried out for R290 with new LGWP refrigerants comparing the measurements of the refrigerant oil sump solubility % with sampling technique

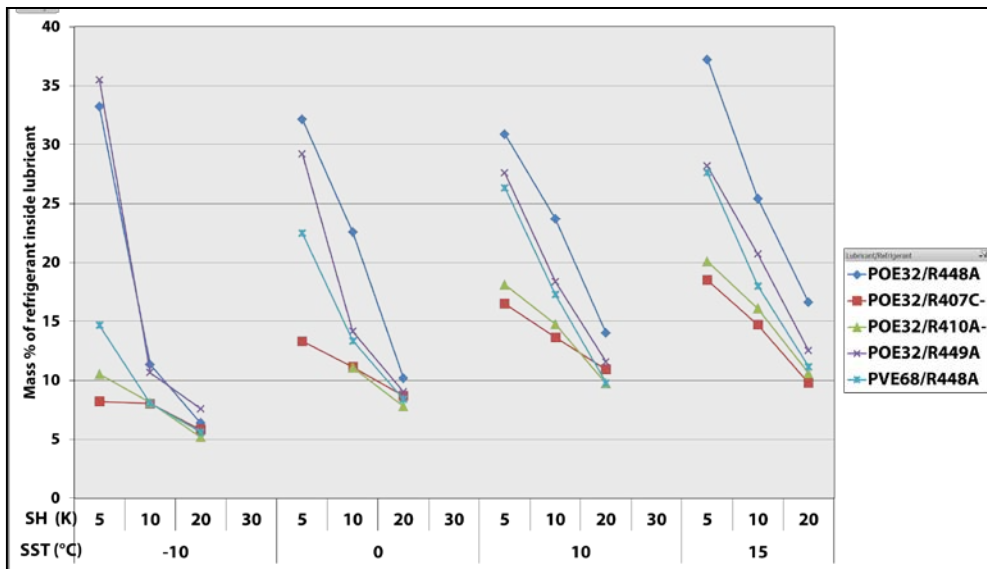


Figure 8 : Dynamic solubility measured in running compressor when the compressor is running with R410A, R407C, R448A and R449A refrigerants

Dynamic solubility with HFO mixtures: can be sorted as followed:

→ POE32/R407C ~ POE32/R410A < POE32/R448A < POE32/R449A < PVE68/R448A

We note on this test, that dynamic conditions when using new HFO blends, R448A and R449A, have a higher solubility with the same oil. So, refrigerant concentration on lubricant is higher than what we have with existing R404A refrigerant at the same operating point.

3.2 Evaluation of potential out gassing process on oil sump for reduction of the solubility percentage.

The idea was to evaluate the potential lubricant outgassing on the oil sump.

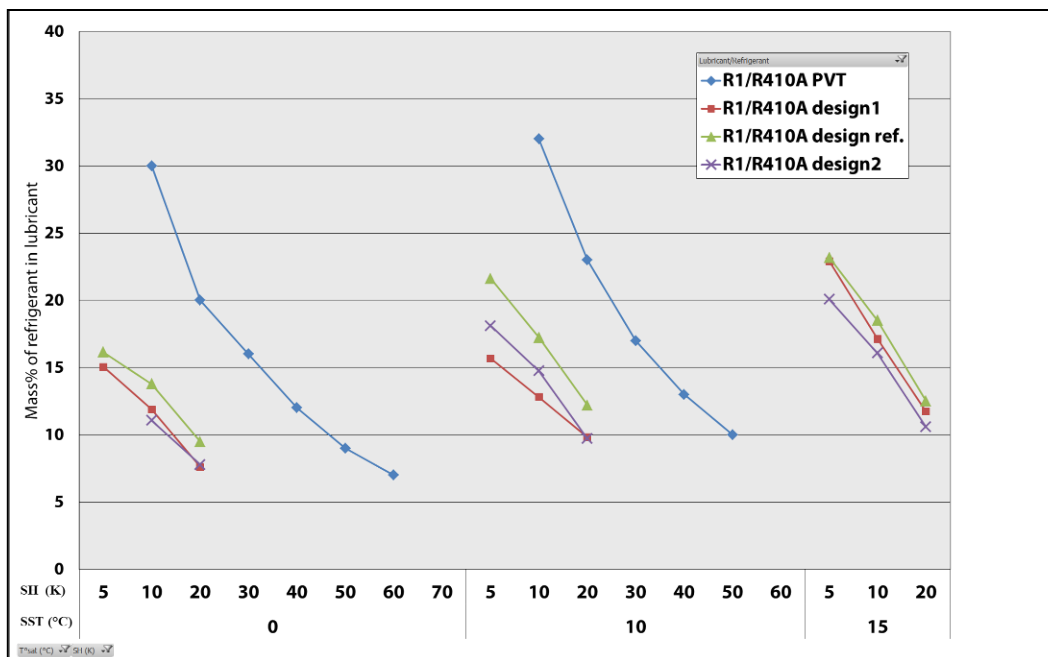


Figure 9 : Comparison of solubility % for Daniel plot, and dynamic measurement for: design 1; design 2 & reference

On Figure 9 we compare the Daniel plot versus sampling measurement on reference compressor and sampling measurement with two oil sump designs to see the changes in steering effect.

The first design has a cage around the oil pump pickup tube. The oil has a slightly lower solubility than in a standard compressor, according to the measures for most of temperatures.

On the second design, we add one stirrer feature on the oil pickup tube. With this design, on the presence of the stirrer, the solubility is higher in each point, whatever the temperature.

Contrary to our expectations, the stirrer increased oil solubility. This result seems to be linked to the stirring action on the oil sump surface level.

However, the oil solubility sampling fitting is placed on the compressor shell at the edge of the housing and is therefore far from the agitation zone. It is possible that the arrangement of the measuring equipment is not adequate with the desired results.

For the next degassing tests it would be wise to place the solubility sampling location as close as possible to the oil pumping area.

3.3 HC/HFO trends

Some of the new LGWP refrigerants are based on HFO. In line with our work done with R290 and some HFO reliability investigations, we want to compare the behavior of HFOs with lubricants in oil sump and compare it to the data measured with R290.

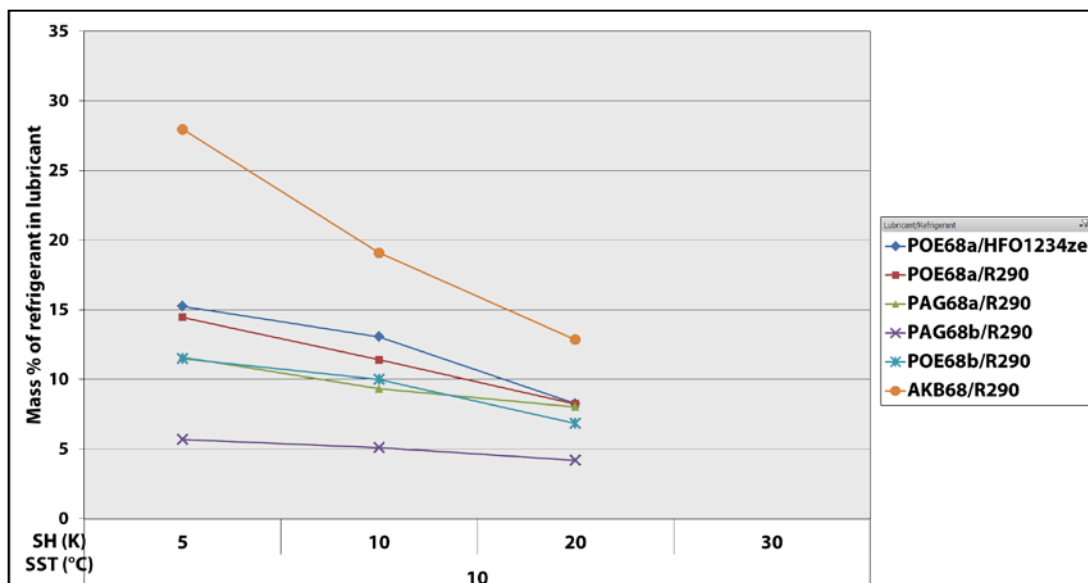


Figure 10 : Solubility % comparison on dynamic oil sump conditions

The results on Figure 10 show that the HFO evaluated behave not that far from R290 on the selected lubricants. This helps us to build up the compressor lubricant selection and qualification program.

4. CONCLUSIONS

R290 solubility tests in running compressor have given lower values than PVT plots. The difference between dynamic and static values reaches 5 to 10 percent of refrigerants in mass of lubricant. This small value brings significant differences. It could be caused by the stirring of the refrigerant/lubricant mixture. Other tests are scheduled in order to study this effect by implementing a stirrer in the oil sump.

The concept of outgassing by steering effect process seems to be promising but the real measurement of lubricant solubility % is not so easy to carry out within the area of the oil pickup tube inlet without disturbing its efficiency.

The solubility test developed for R290 was used on new LGWP refrigerants evaluation and helps to compare properties and this was confirmed during reliability testing.

This measurement principle gives a better knowledge on what happens inside the compressor oil sump. This work will help on the lubricant candidate selection process for compressor on reliability evaluation.

NOMENCLATURE

HFC	hydrofluorocarbon	GWP	global warming potential
POE	polyol ester lubricant	T	temperature
AKB	alkylbenzene lubricant	PAG	polyalkylene glycol lubricant
HFO	Hydro Fluoro Olefin		
SST	saturated suction temperature (°C)		
SH	super heat (K)		
SDT	saturated discharge temperature (°C)		
Daniel plot or PVT pressure temperature viscosity data			

Subscripts

Oil	lubricant	Lub	lubricant
Sat	saturation	R	refrigerant

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