2014

# Refrigerant and Lubricant Mass Distribution in a Convertible Split System Residential Air-Conditioner

Scott S. Wujek
*Creative Thermal Solutions*, scott.wujek@creativethermalsolutions.com

Chad D. Bowers
*Creative Thermal Solutions*, bowers.cd@gmail.com

Joshua W. Powell
*Creative Thermal Solutions*, josh.powell@creativethermalsolutions.com

Roberto A. Urrego
*Chemtura Corporation*, roberto.urrego@chemtura.com

Edward T. Hessell
*Chemtura Corporation*, ed.hessell@chemtura.com

***See next page for additional authors***

Wujek, Scott S.; Bowers, Chad D.; Powell, Joshua W.; Urrego, Roberto A.; Hessell, Edward T.; and Benanti, Travis L., "Refrigerant and Lubricant Mass Distribution in a Convertible Split System Residential Air-Conditioner" (2014). *International Refrigeration and Air Conditioning Conference.* Paper 1511.
http://docs.lib.purdue.edu/iracc/1511

**Authors**
Scott S. Wujek, Chad D. Bowers, Joshua W. Powell, Roberto A. Urrego, Edward T. Hessell, and Travis L. Benanti

# Refrigerant and Lubricant Mass Distribution in a Convertible Split System Residential Air-Conditioner

Scott S. WUJEK[1]*, Chad D. BOWERS[1], Joshua W. POWELL[1],
Roberto A. URREGO[2], Edward T. HESSELL[2], Travis L. BENANTI[2]

[1]Creative Thermal Solutions, Inc.
Urbana, Illinois, United States of America
scott.wujek@creativethermalsolutions.com

[2]Chemtura Corporation,
Naugatuck, Connecticut, United States of America
roberto.urrego@chemtura.com

* Corresponding Author

## ABSTRACT

Lubricants are utilized in air-conditioning systems for the purpose of decreasing friction and wear within the compressor. While ideally the lubricant remains in the compressor, some lubricant is entrained and transported by the refrigerant to the other system components. During operational transients, the lubricant is redistributed throughout the various system components. The equilibrium distribution of lubricant depends among other things on fluid properties, phase change processes, flow rates, geometries, and operating conditions. Experiments were conducted in a commercially available, split-system, residential, air-conditioning system with a nominal 3-ton capacity that could be operated both as an air-conditioner and a heat-pump. While the system was designed to operate with R410A, most of the testing was conducted with pure R32, which is a leading candidate for R410A replacement pending regulatory discontinuation of its other constituent: R125. The lubricants used in this study were traditional and advanced polyol ester (POE) lubricants. Advanced polyol ester lubricants promise to improve lubricity and wear protection compared to current lubricants. The lubricants had nominal viscosities ranging from 32 to 80 cSt. To inventory the distribution of refrigerant and lubricant, the system was modified by the installation of ball valves which could be utilized to separate the system into its constituents: compressor, condenser, liquid line, evaporator, suction line, and accumulator. The system was brought to equilibrium at conditions A, B, C, H1, and H2 which are defined in AHRI Standard 210/240. After maintaining equilibrium, simultaneously the compressor being shut off and the ball valves were closed which isolated refrigerant and lubricant within each component. The components were subsequently removed and weighed in a manner which allowed the mass of refrigerant and lubricant in each component to be determined. Analysis of the results focuses on the change in mass distribution due to refrigerant-lubricant mixture properties and due to changes in operating conditions. The implications of the net migration of lubricant from the compressor to the remainder of the system will also be discussed.

## 1. INTRODUCTION

In recent years, several researchers have looked into how refrigerant and oil are distributed throughout the system. This research is important because lubricant is placed into the system to lubricate the moving parts of the compressors, and serves little purpose at other locations, other than having some role in lubricating valves. Knowing how much oil gets shifted to each component from the compressor would allow the system designer to specify a more optimal quantity of oil. There is a tradeoff between the benefit of decreasing lubricant charge for the sake of reducing cost and that of increasing oil charge which is viewed as a method for ensuring system longevity.

Most recent research related to lubricant and refrigerant inventory has been focused on systems where charge is well controlled or there is a very strong desire to minimize charge. Some examples of this are automotive systems, system utilizing toxic or explosive refrigerants, or packaged systems. Litch and Hrnjak (1999), for example, determined the ammonia mass contained in a microchannel condenser. Peuker and Hrnjak (2009) measured the distribution of lubricant and refrigerant in an automotive air-conditioning system. Their experiments showed that the accumulator contained more lubricant than any other component. As this experiment was done with an automotive compressor, there was no oil sump. Jin (2012) furthered this work for additional refrigerants and created a model which matched refrigerant and lubricant distribution to approximately 20% using various void fraction models.

To determine the quantity inside each component several different experimental techniques have been suggested. While some online measurements of void fraction have been made using capacitive measurements, in nearly all cases where real system components are used, the methodologies rely on simultaneously and quickly closing valves at the inlet and outlet of every component of interest. The methodology of simultaneously closing valves with a variety of measurement techniques was shown by Peuker (2010) to determine the quantity of lubricant to accuracies better than 0.61g.

Several different methods have been presented in literature to detail how refrigerant and lubricant mass can be determined once the fluids are trapped within a component. Typically refrigerant mass is determined by transfering as much refrigerant as possible into a vessel held and a low temperature and weighing the amount of refrigerant collected in the vessel. Attempting to remove all refrigerant was the methodology employed by Litch and Hrnjak (1999) and subsequently improved by Traeger and Hrnjak (2005). An alternative, which is more practical when components can be easily removed from the system, is to weigh the combined mass of the component, refrigerant, and lubricant and then remove as much refrigerant as possible from the component. This methodology allows for the bulk of refrigerant to be collected, with the small remaining quantity in the component to be easily removed with a vacuum pump.

Once refrigerant mass is removed there are several techniques mentioned in the literature to determine the amount of lubricant, these were discussed in Peuker and Hrnjak (2010). Of the several techniques listed, that described in Wujek *et al* (2010) was shown to give the best results for heat exchangers and tubing, especially when these components were difficult to remove due to mounting within the laboratory facility. For systems where components can be easily removed, or for components such as the compressor where it is not possible to circulate a solvent, the technique from Sheth and Newell (2005) was preferable due to quicker experiments and less manual intervention. Due to the good accuracy mentioned by Peuker, and ability to quickly measurement oil content in multiple components, the technique utilized by Sheth was used for these experiments.

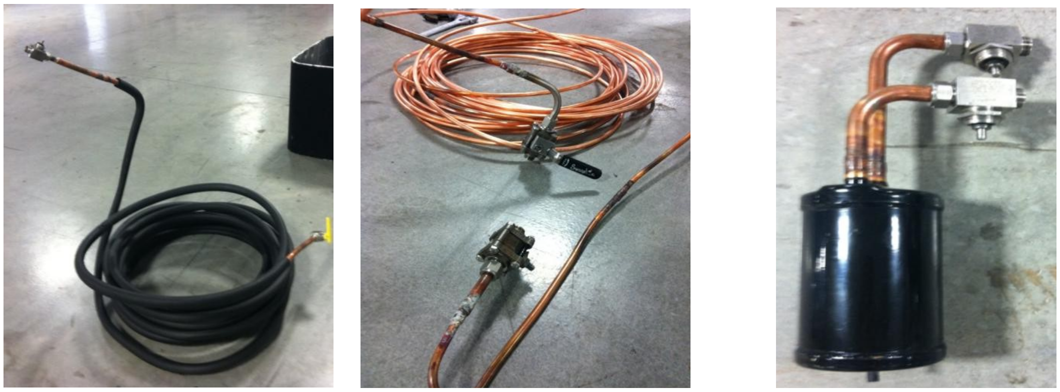
## 2. EXPERIMENTAL SETUP

To understand where oil charge is located researchers often take the approach of simply measure the quantity of oil in the compressor. While this may give insight as to whether there is sufficient lubricant to ensure longevity, it does not give much information on how to design systems to have less oil out, in the system. To best understand where lubricant is retained in the system, it is preferable to measure the quantity of lubricant in each major system component. By measuring retention in each component, a great deal can be learned regarding the physics of oil retention. Because lubricant retention is truly a system problem, very limited understanding will be gained by only measuring the quantity of oil in the compressor. To get a better understanding of how oil behaves in the system, it is important to perform measurements at locations other than the compressor. For example, Cremaschi (2004) and Zoellick and Hrnjak (2010) did fundamental research and found that increasing mass flux in the suction line will cause less lubricant retention to occur there, thus allowing more lubricant to be available in the sump.

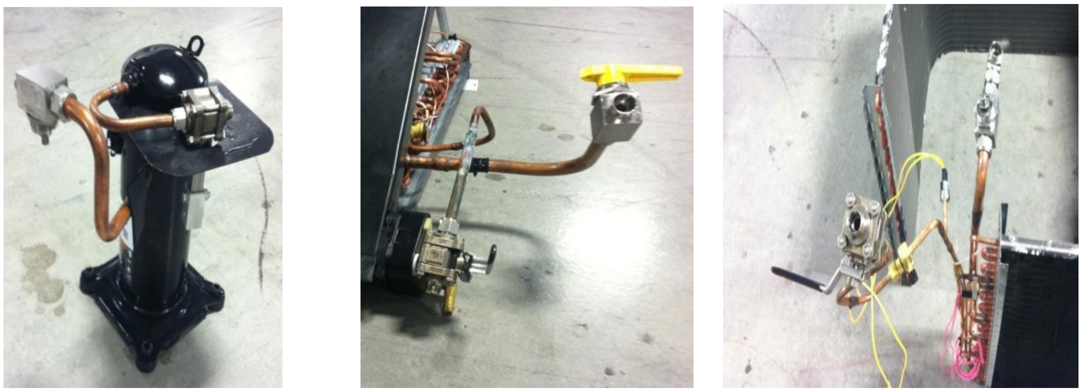
Due to the rising costs of energy and due to governmental and utility supported programs, systems which are convertible between air-conditioning and heat pump modes are gaining market share in the residential sector. Due to the size difference between the interior and exterior heat exchangers and piping, there is concern regarding the proper charging of these systems. When these convertible cycles switch from operating as air-conditioners to heat pumps, less charge is needed in the heat exchangers. This migration of refrigerant charge was expected to affect the location of lubricant in the system. Because oil tends to be located coincidentally with liquid refrigerant, convertible heat pumps systems will most likely have far greater chances for oil retention problems. For this reason a commercially available, residential, split system, convertible air-conditioner/heat pump was selected as the basis for this study.

To determine the lubricant content in each major system component, it was necessary to outfit the system with a series of valves which can be simultaneously closed. The components of interest in the experiment can be seen in Figure 1. Throughout this paper, the components are referred to according to their use in the air-conditioning configuration. Therefore, in heat pump application, the evaporator functions as the condenser and vice versa. Ball valves suitable for low temperature operation were selected to isolate each component due to their low pressure drop while in the open position and their tight sealing while in the closed position. Valves for the suction line, liquid line, and evaporator were readily accessible. Those valves used for components found in the condensing unit were fitted with extended handles. A team was utilized to simultaneously close all valves. Not all refrigerant and lubricant was able to be measured: short lengths of tubing between sequential components, near the 4-way valve, and where pressure transducers were connected. For this reason, the mass of measured refrigerant and lubricant mass was less than the charged mass.

To determine the refrigerant and oil charge, each component and its contents were weighed. The tare weight of cleaned components with valves was measured before testing. After testing, each component was carefully removed and placed on a scale having a capacity of 30 kg and an accuracy of 0.1 g. The refrigerant was slowly recovered into vessels placed in liquid nitrogen. The refrigerant evacuation was slowed by metering valves so as to leave oil in each component. The mass of the lubricant plus component was measured. From the 3 different weights, it was possible to calculate the refrigerant and lubricant charge in each component.



a) Suction line b) Liquid line c) Low pressure receiver



d) Compressor e) Evaporator f) Condenser

Figure 1. System components for which oil and refrigerant mass is measured

The compressor, heat exchangers, and accumulator were all standard components from the baseline system. Because two different refrigerants were used for this testing, R410A and R32, the thermostatic expansion valve was replaced with an electronic valve. Using property data for both refrigerants allowed evaporator exit superheat to be calculated from temperature and pressure measurements. For each test, the valve was adjusted to the static position which created the appropriate superheat. Instead of using the standard line set, a 30.5 m (100 ft) line set was used, this increased the accuracy of lubricant retention by giving more area on which lubricant could collect. The base of the condensing unit was located approximately 2.4 m (8 ft) above the base of the indoor unit to simulate the conditions found where the indoor unit is placed in a basement and the condenser at ground level.

To make testing more easily connected to other experiments done in the air conditioning equipment industry, oil inventory was determined at operating conditions prescribed by AHRI 210/240. The air temperatures for the tests are shown in Table 1. Condenser air flow rate was not measured; the stock fan was utilized. As a nominally 10.4 kW (3 ton) system, evaporator air flow rate was measured and controlled to be 425 L/s (900 cfm). Refrigerant charge was added according to match those specified in the OEM's subcooling specifications. Lubricant charge equaled that specified by the manufacturer. Conditions A, B, C, H1, and H2 are steady state tests. For these tests valves were closed simultaneously with the compressor being turned off in order to trap refrigerant and lubricant for later measurement. Condition D is a condition meant to relate to compressor cycling. A simplified version of the cycling test was used for this oil retention study. The system was allowed to reach equilibrium at the C condition, the compressor was stopped, the evaporator fan was allowed to run for an additional 90 seconds (which is a standard feature for this unit), and the valves were simultaneously closed 3.5 minutes after the fans were stopped. While other heat pump test conditions are mandated by AHRI 210/240, they were not utilized in this study because frost formation on the outdoor coil creates less repeatable results.

Table 1. Air temperature and humidity conditions.

| Condition | Indoor Air | | Outdoor Air | |
|---|---|---|---|---|
| | Dry Bulb [°C] | Wet Bulb [°C] | Dry Bulb [°C] | Wet Bulb [°C] |
| A | 26.7 | 19.4 | 35 | - |
| B | 26.7 | 19.4 | 27.8 | - |
| C & D | 26.7 | - | 27.8 | - |
| H1 | 21.1 | <15.6 | 8.33 | 6.11 |
| H2 | 21.1 | <15.6 | 1.67 | 0.56 |

While experiments were conducted with 6 different combinations of refrigerants and POE lubricants, this paper will focus on 3 refrigerant-lubricant combinations: R410 with 32 cSt POE, R32 with a 32 cSt POE lubricant, and R32 with 80 cSt POE. This particular system is sold for use R410 and is supplied with 32 cSt POE lubricant. R410 is a mixture of R32 and R125, due to environmental legislature, R410A equipment may be phased out at some future date due to the high GWP value assigned to R125. R32 was used in other tests, as it is one of the main contenders for next generation residential system. The 80 cSt POE was included in this report to show the effect mass distribution due to a nominally higher viscosity lubricant.

## 3. EXPERIMENTAL RESULTS

Experimental results for three different refrigerant lubricant mixtures are given in this section. Figures 2 and 3 show the refrigerant and lubricant mass distribution respectively for the baseline R410 with 32 cSt POE lubricant. The refrigerant and lubricant mass distribution for R32 with 32 cSt POE lubricant are shown in Figures 4 and 5, respectively. The results for the final combination, R32 with 80 cSt POE, are given in Figures 5 and 6. In each graph, the x-axis tells which of the conditions described in Section 2 was measured. The various colors are used to show the fraction of the total mass of either the refrigerant or lubricant which is contained in each component.

For each steady state test, oil circulation ratio is measured based on the relative concentration of lubricant in the liquid line. This is based on the assumption that the refrigerant and lubricant flow homogenously in the liquid line either because the lubricant-refrigerant mixture is single phase, or there is no slip between liquid phases. The oil circulation ratio (OCR) for each condition is shown in Table 2. Generally, the measured OCR was higher for the heat pump systems, this result may be artificially high due to insufficient subcooling creating some void fraction and accompanying slip within the tube.

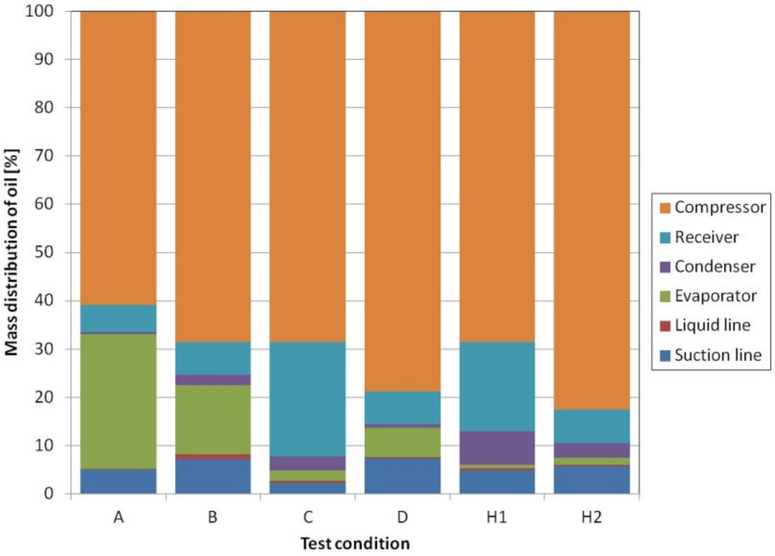


Figure 2. Oil distribution for R410A with 32 cSt POE

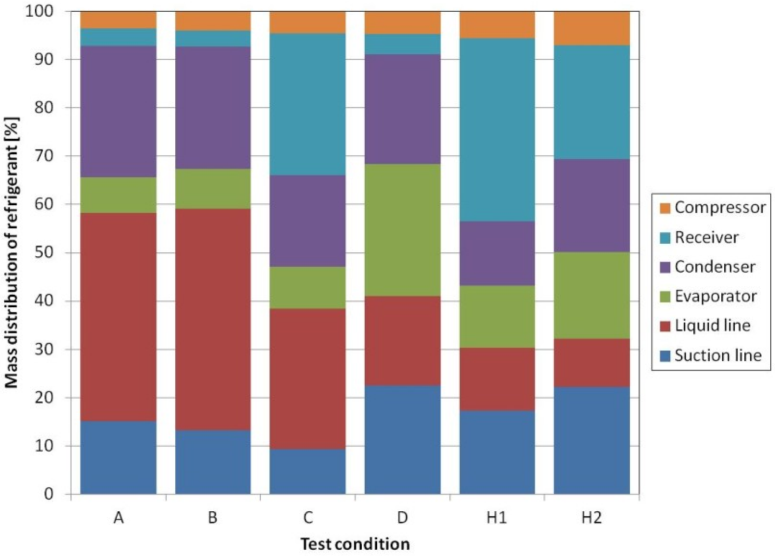


Figure 3.  Refrigerant distribution for R410A with 32 cSt POE

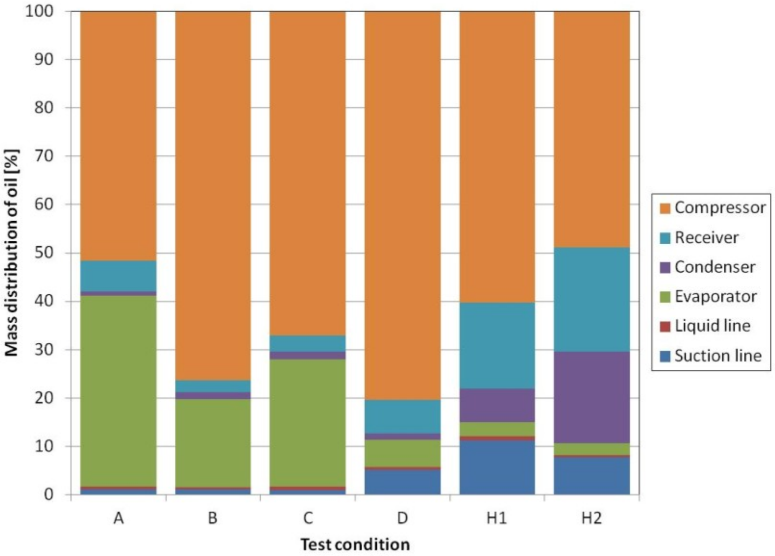


Figure 4. Oil distribution for R32 with 32 cSt POE

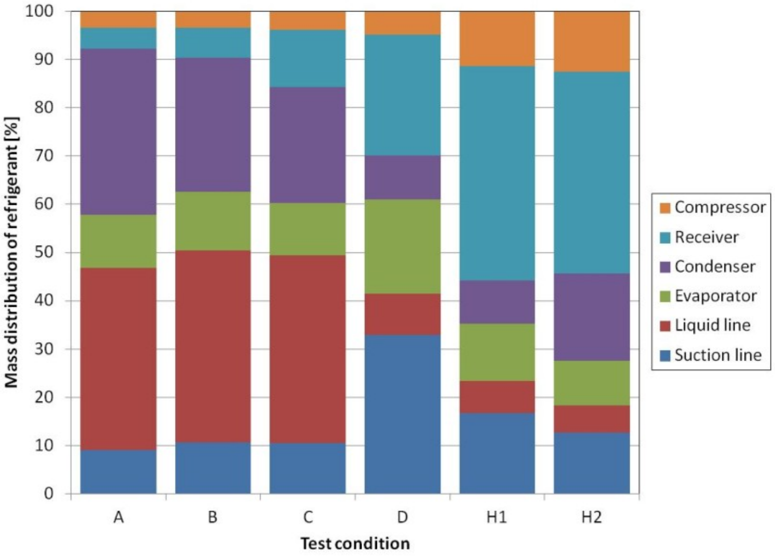


Figure 5. Refrigerant distribution for R32 with 32 cSt POE

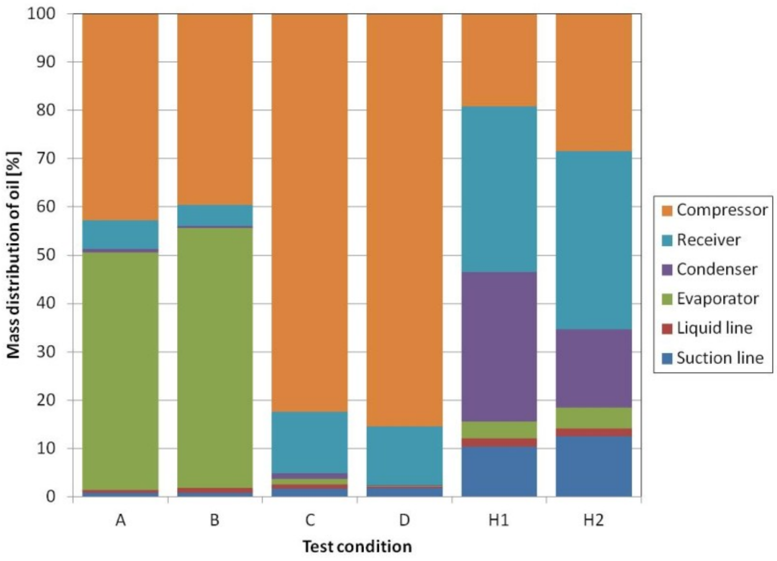


Figure 6. Oil distribution for R32 with 80 cSt POE

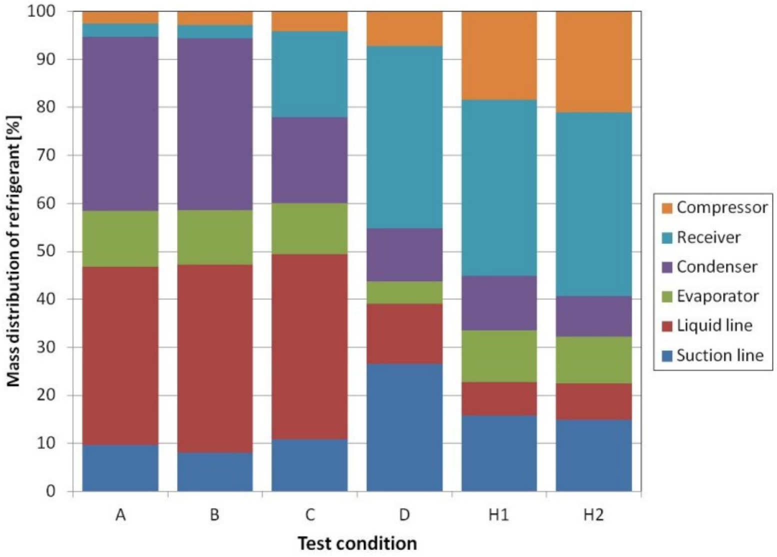


Figure 7. Refrigerant distribution for R32 with 80 cSt POE

Table 2. Measured OCR

| Combination | A | B | C | H1 | H2 |
|---|---|---|---|---|---|
| R410A w 32 cSt | 0.17% | 0.37% | 0.28% | 1.15% | 1.29% |
| R32 w 32 cSt | 0.43% | 0.23% | 0.53% | 3.61% | 1.26% |
| R32 w 80 cSt | 0.49% | 0.47% | 0.42% | 4.66% | 4.47% |

## 4. DISCUSSION

Since the same system was used with a variety or lubricants at very closely replicated conditions, this discussion is a comparison between the results acquired with the 3 refrigerant-lubricant combinations mentioned previously.

The most readily apparent trend in the oil retention results, Figures 2, 4, and 6, is that more of the lubricant is found in the compressor than in any other component. This is in direct contrast to the results for automotive systems, such as those found in Peuker and Hrnjak (2009) and Jin (2012). The major reason for this discrepancy comes from the fact that the hermetic scroll compressor found in the system under investigations has an oil sump and a low OCR. Not only does the sump make it is possible to have a large reservoir of liquid, but due to the pressure-temperature-concentration relationships discussed in Urrego *et al* (2014), the liquid in the sump is predominantly lubricant. The low OCR of the compressor means that there is a relatively higher flow rate of refrigerant to oil, thus helping to thin wall films and return lubricant to the compressor.

After the compressor, most lubricant charge is located in the other low pressure components: the suction line, the evaporator (shown as condenser for heat pump mode), and the low pressure receiver. Lubricant tends to collect in these components because the lubricant is more viscous, thus allowing thicker wall films. With its relatively large internal volume, it is no surprise that oil is able to accumulate in the low pressure receiver. Because of the strong impact of low side pressure drop on system performance, the suction line is sized larger than the liquid line in order to decrease low side pressure drop. This larger diameter of the pipe increases oil retention in two ways: by giving more wall area to wet and by allowing a thicker wall film to develop. Many papers have been written about the subject of lubricants in suction lines precisely for the reason that the ability of this line to build up large quantities of lubricant. Taking a different view from most previous authors, Zoellick and Hrnjak (2010) pointed out if there is sufficient lubricant in the system it is bound to return. It is hopeful, that studies such as this one in conjunction with suction line literature may help designers optimize oil charges based on a combination of geometric parameters, operating conditions, and fluid properties.

On the other hand, refrigerant charge is predominantly in those components which have more liquid or that have large volumes. Therefore suction and liquid lines typically contain about 40% of the total charge. The liquid line while being smaller is almost completely full of liquid refrigerant, with the exception of the oil being circulated. The suction line and accumulator are volumetrically much larger components, so charge is found there simply because of their large size. Due to the lower density in most of the system in heat pump mode, more refrigerant is shifted to the accumulator for these conditions. It is because of this refrigerant surplus that convertible systems typically have bigger accumulators than air-conditioning only systems.

Comparing results from condition C and D is interesting, because the conditions were identical, other than the timing used to close the valves. Because the evaporator fan continued to run and the compressor was stopped, refrigerant and lubricant redistributed to a different locations for condition D compared to where they were measured for the C test. This is primarily because refrigerant and oil migrated from the high pressure liquid line into the evaporator. Once in the evaporator, there was little motivation for the refrigerant to leave the evaporator because this coil was colder than other regions of the system. In a real system, this migration would have been substantially slowed by with the hard-closing TXV which is supplied by the system. Therefore the results of the cycling tests may be more similar to the results that would be measured in systems with capillary tubes or orifice tubes. Given sufficient time, and a path for flow, refrigerant would migrate to the coldest area of the system.

Comparing the results with the same lubricant but with different refrigerants, it can generally be seen that R32 has higher oil retention in the evaporator (or condenser in heat pump mode). This is due primarily to R410A having higher solubility than R32. The trend is most strongly noticeable when using the system as a heat pump. The 32cSt used in this comparison is a traditional POE, which has a larger immiscibility gap with R32 than R410A. Next generation POEs, which were also utilized in this studies, had smaller retentions on the low side of the system. This trend points to the possibility that next generation refrigerants, such as R32, may require more advanced lubricants, or necessitate design changes, in order to have acceptably small oil retention in the system.

Similar comparisons can be made between results with the same refrigerant, R32, but with different lubricants. Not surprisingly, refrigerant distribution was not strongly effect by the relatively small quantities of lubricant. However, once again higher viscosities led to greater retention on the low temperature side of the system. While viscosity differences of the lubricant in the system are not as large as suggested by their nominal viscosities (Urrego *et al*, 2014), there is still a substantial difference, especially on a percentage basis. With traditional POEs the shift in viscosities is exacerbated to some extent by the higher viscosity index (viscosity change per change in temperature). Next generation POE lubricants may not present quite as much difficulty going between air-conditioning and heat pump modes because of their lower viscosity index.

The general trends with regard to mass distribution can also be seen by looking into relative proportion of lubricant mass to the total mass inside each component. The mass fraction from tests with R410A with the 32 cSt POE lubricant is shown in Figure 8, to give an example of general trends in the data. As may be expected from discussions of holdup, and reinforced by pressure-temperature-concentration charts, those components on the low pressure side of the system, including the compressor with its low pressure sump, are the areas which have relatively high percentage of fluid mass coming from lubricant. In no case did a component on the high pressure side of the system have more than 10% of its mass content come from lubricant. In contrast, almost 80% of the fluid mass inside the compressor comes from the lubricant. Another item to note is that the liquid line, where OCRs are typically measured and therefore the most commonly cited number related to oil outside the compressor, is the location with the lowest proportion of fluid mass coming from the lubricant. The concentration the liquid line is often different from the concentration in other components by an order of magnitude. For this reason, OCR should not be seen as a good surrogate for oil retention.

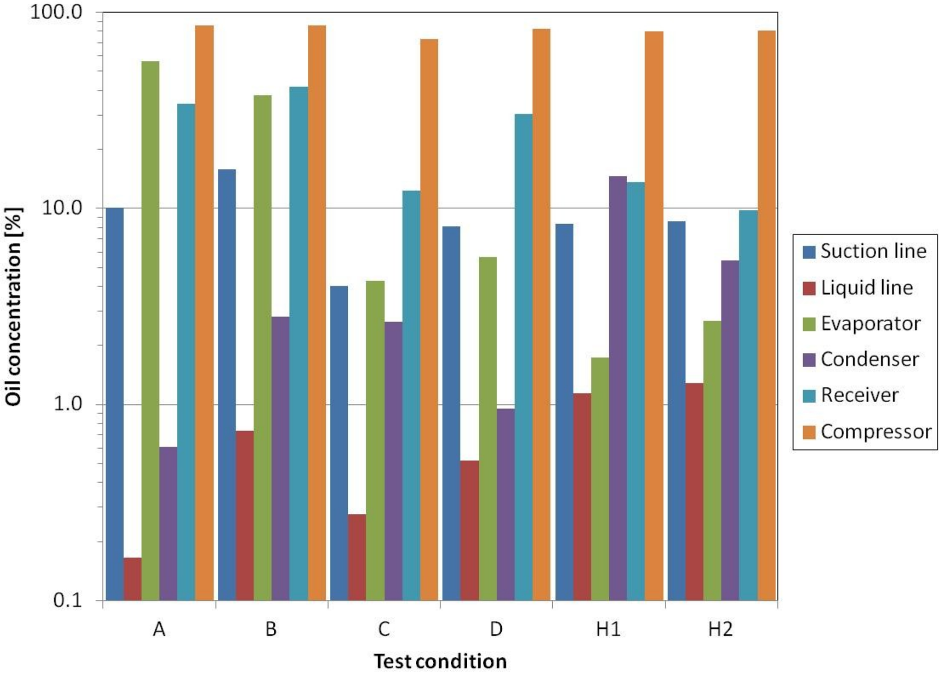


Figure 8. Mass fraction due to lubricant

## 6. CONCLUSIONS

Experiments were conducted in order to determine how refrigerant and lubricant mass distributed between the various components in a residential convertible split-system air-conditioner/heat pump unit. Results showed that the compressor contained more lubricant than any other component. The POE lubricant tended to accumulate in the low pressure components of the system due to higher liquid viscosity and due to the geometry of the components. Refrigerant on the other hand was typically found in areas where there was liquid refrigerant. It was shown that after the system is turned off; refrigerant and lubricant charge migrated from the high pressure to the low pressure components. All else being similar, R32 was shown to have more lubricant retention than R410A due to differences in mixture properties. Similar results were found for higher viscosity lubricants. The relative concentration of lubricant within a component was shown to range from less than 1% in the liquid line to roughly 80% in the compressor.

## REFERENCES

Air-Conditioning Heating and Refrigeration Institute, 2008, *ANSI/AHRI 201/240 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment*, AHRI, Arlington, pp 126.

Cremashi, L. 2004, *Experimental and theoretical investigation of oil retention in vapor compression systems*, University of Maryland, College Park.

Jin, S. 2012, *Distribution of Refrigerant and Lubricant in Automotive Air Conditioning Systems*, University of Illinois at Urbana-Champaign, Urbana.

Litch, A.D., and Hrnjak, P.S., 1999, *Condensation of Ammonia in Microchannel Heat Exchangers,* ACRC CR-22, University of Illinois at Urbana-Champaign, Urbana.

Peuker, S., Hrnjak, P. S., 2009, Transient Refrigerant and Oil Migration of an R134a Automotive A/C System, SAE Int. J. Passeng. Cars – Mech. Syst., v. 2, i. 1,pp.714-724.

Peuker, S., Hrnjak, P.S., 2010, Experimental Techniques to Determine Oil Distribution in Automotive A/C Systems, *Int. Refrigeration and Air Conditioning Conf. at Purdue,* Purdue University, pp 8.

Sheth, V.P., Newell, T.A., 2005, Refrigerant and Oil Migration an dRetention in Air Conditioning and Refrigeration Systems, ACRC TR-240, University of Illinois at Urbana-Champaign, Urbana.

Traeger, K.M., Hrnjak, P.S., 1999, *Charge Minimization of Microchannel Heat Excangers,* ACRC TR-251, University of Illinois at Urbana-Champaign, Urbana.

Urrego, R.A.L., Benanti, T., Hessell, E., 2014, *Solution Properties of Poly Ester Lubricants Designed for Use with R-32 and Related Low GWP Refrigerant Blends*, *Int. Refrigeration and Air Conditioning Conf. at Purdue*, Purdue University.

Wujek, S.S., Peuker, S., Mai, H., Bower, J., Koffler, M., Hrnjak, P.S., 2010, Method for Measuring Oil Contained in Air-Conditioning Components, *Int. Refrigeration and Air Conditioning Conf. at Purdue*, Purdue University, pp 11.

Zoellick, K.F., Hrnjak, P., 2010, Oil Retention and Pressure Drop in Horizontal and Vertical Suction lines with R410A/POE, *Int. Refrigeration and Air Conditioning Conf. at Purdue*, Purdue University, pp 8.

## ACKNOWLEDGEMENT

Financial support for this work was generously provided by the Department of Energy (grant DOE-EE0003986) for which the authors are most grateful. Components were provided by Carrier Corporation and Emerson Climate Technologies. The authors would like to acknowledge Sebastian Decker for his diligent work in the laboratory.