

Refrigerant and Lubricant Distribution in MAC System

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ABSTRACT

This paper presents experimental results for refrigerant and lubricant mass distribution in a typical automotive A/C (MAC) system.

Experiments were conducted by closing valves located at the inlet and outlet of each component after reaching steady state, isolating the refrigerant and lubricant in each component. Refrigerant mass is recovered in a separate vessel using liquid nitrogen to reduce refrigerant vapor pressure to near vacuum. The overall weight is determined within $\pm 1\%$ after the separation of refrigerant and lubricant. The mass of lubricant is determined by using three different techniques: Remove and Weigh, Mix and Sample, and Flushing. The total mass of lubricant in the system is determined with $\pm 2.5\%$ uncertainty on average. R134a and R1234yf are used with PAG 46 oil as working fluid at different Oil Circulation Ratio (OCR), ranging from 2% to 4%. Experiments are conducted in two standard testing conditions: I35 and L35 (SAE Standard J2765) [11].

R134a and R1234yf exhibit similar results in terms of refrigerant and lubricant retention. Higher mass flow rate does not significantly change the refrigerant distribution, but a lower lubricant retention in the evaporator is observed. It is found that only about a quarter of the total mass of lubricant resides in the compressor.

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INTRODUCTION

In a vapor compression refrigeration system oil is crucial to provide sealing and lubricating for the compressor. In an automotive A/C system where an oil separator is integrated into the compressor if at all present, oil is inevitably mixed with refrigerant and travels throughout the system due to a separation efficiency of less than 1. The circulating oil appears in the form of mist, droplets, a thin oil rich film, or a fairly homogeneous liquid mixture with refrigerant depending on its location and the system configuration. The presence of oil can significantly change the properties of the working fluid, degrade heat transfer, and increase pressure drop. A large amount of oil retention outside the compressor can cause compressor failure due to insufficient lubrication. As a result, the amount of oil in circulation and oil retention has a direct influence on the system performance and compressor reliability [14].

In the literature, experimental techniques used to measure a refrigerant and lubricant mass inventory can be grouped by whether the method is intrusive or not. By using the intrusive method, Hoehne and Hrnjak [1] were able to measure refrigerant mass in less than 0.1 g uncertainty in each section of a low charge (<150g) hydrocarbon (propane) refrigerant

system. Peuker and Hrnjak [2] measured refrigerant mass distribution in an automotive A/C system with orifice tube (OT) and low side accumulator in transient and steady state. A measurement uncertainty of 0.4% regarding total refrigerant mass was achieved by using liquid nitrogen as the recovery coolant. Björk [3] used an expansion tank where refrigerant can reach a superheat thermodynamic equilibrium. Using the p-v-T relationship and internal volume, refrigerant mass can be calculated. According to the comparison, the difference between Peuker's and Björk's procedures is small, ranging from 1% to 5%. The non-intrusive measuring technique, also known as On-Line Measuring Technique, weighs a section directly while the system is still running. According to Miller's [4] result on a 3-ton R22 split-system air-to-air heat pump, the accuracy for the weighing system is about 0.05 kg.

Various authors have reported lubricant retention results using intrusive measuring technique. Crompton et al [5] employed a Remove and Weigh technique to investigate oil retention in smooth and micro-fin tubes. Similar to the intrusive method mentioned previously for refrigerant, valves at both ends of the section of interest were closed simultaneously. After refrigerant was slowly released, the section was removed from the test loop and weighed so that

oil retention is determined. The average uncertainty was 4.9%. Zoellick and Hrnjak [6] and Sethi and Hrnjak [7] employed a similar method to measure oil retention in suction lines. The uncertainties reported by the two authors were 0.5% and 2%, respectively. Except for remove and weigh technique, Peuker and Hrnjak [2] developed Flushing technique and Mix and Sample technique. Using these three methods, Peuker and Hrnjak [2] were able to determine oil amount totals within 2%. As for the non-intrusive method, Lee [8] used an injection-extraction method to investigate oil retention in a vertical suction line. Oil was injected at the bottom of a pure refrigerant suction line and was separated at the top by using oil separators. The oil retention was the difference between mass of oil injected and that of oil extracted. This method was later used to measure oil retention in each part of a CO₂/PAG 46 A/C system by Lee [9] in 2003 and that of a residential A/C system by Cremaschi [10] in 2004. Cremaschi [10] estimated 12% relative error.

EXPERIMENT SETUP

In the facility the system components are located at the same relative heights as they are in the original vehicle. The compressor is a piston-cylinder reciprocating compressor with fixed displacement. No oil separator is installed. A micro-channel condenser with 48 tubes and a plate and fin evaporator with 19 plates are used in the facility, as shown in Figure 3 and 4. The condenser does not have a separate pass for subcooling. An external receiver is installed after the condenser, with an internal diameter of 13.08 mm and a length of 560 mm. A thermal expansion valve (TXV) is used as throttling device. The schematic of the facility and details of the system and components is shown in Figure 1 and 2. Due to the large size of the environment chambers, longer tubes than in the real system are used to connect the components. As a result, the experimental system volume is larger than original system and the largest difference in tubing length is from condenser to evaporator, or liquid line.

Two methods are used to measure the system volume: one is based on combining the volume calculated from tube geometry with the internal volumes of components provided by manufacturers; the second is to charge a known amount of gas and calculate volume based on density, also referred to as the isothermal gas method.

To avoid the diffusion of gas, lubricant is removed from the system by flushing with soluble refrigerant before using the isothermal gas method. Each section is then evacuated and charged with a certain amount of the designated gas, the weight of which is measured by the scale. Gas with higher density is preferred since the scale will have better accuracy if the charged mass is larger. Carbon dioxide, with a stated purity of 99.9% as supplied, is selected. Equilibrium temperature and pressure are measured to calculate density and the saturation temperature is also calculated to make sure the gas is superheated.

The internal volumes calculated using two methods agree with each other, as shown in Table 1. The isothermal gas method has a consistent but slightly larger value than geometrical method as expected, due to the “inactive volume” such as pressure taps and charge ports. Since the inactive volume can hold refrigerant mass as well, the values of isothermal gas method are used.

The operation condition is mainly focused on idle condition, i.e. minimum compressor speed. So the I35-dry condition from SAE J2765 [11] is investigated as the design condition. Charge tests are performed at this condition to determine the refrigerant charge for maximized COP for both R134a and R1234yf. The same type of lubricant (PAG 46) is used in all tests but varying charge amounts are employed to change the OCR. Since the lubricant used in this study is essentially oil, the term “lubricant” and “oil” are used interchangeably. The system is also operated at higher compressor speeds (L35) to investigate the effect of higher mass flux.

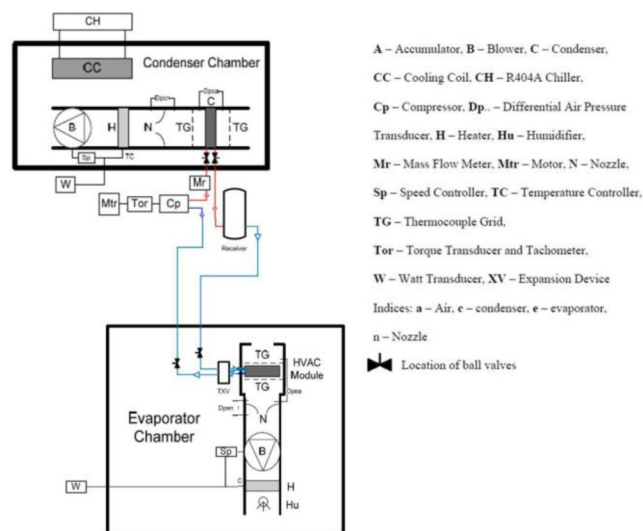


Figure 1. Schematic of test facility

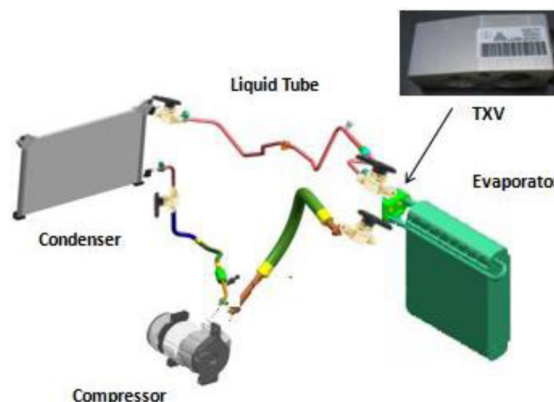


Figure 2. Schematic of TXV-Receiver system

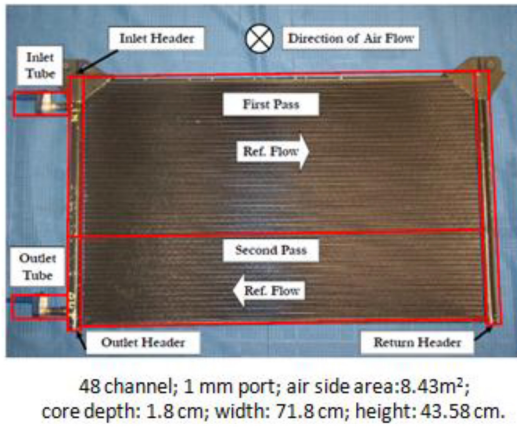


Figure 3. Micro-channel condenser

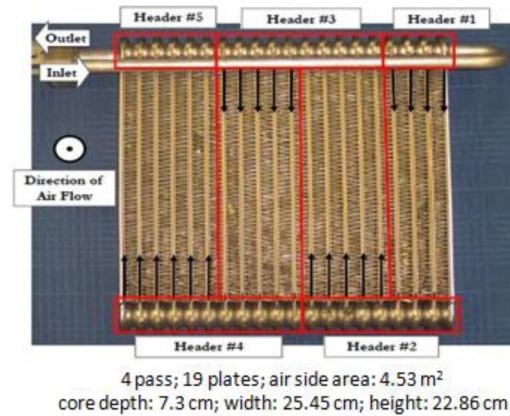


Figure 4. Plate and fin evaporator

Table 1. Internal volume of TXV system

Component	Comp.	Cond.	Liq. line	Evap.
M _{CO2} g	14.1	29.7	21.9	22.7
P kPa	562	1916	1863	1054
T °C	22.4	22.6	24.9	23.4
T _{sat} °C	-54.7	-20.9	-21.8	-38.7
ρ kg/m³	10.37	38.34	36.74	19.91
V _{iso} cm³	1360±48	775±13	596±14	1140±25
V _{geo} cm³	N/A	725±9	558±15	1038±24

UNCERTAINTY ANALYSIS

Applicable standards require at least two independent energy balances to experimentally determine steady-state system performances. The test facility for this system has a refrigerant-side energy balance (Q_{ref}) and an air-side energy balance (Q_{air}) for both indoor and outdoor chambers, according to SAE J2765 [11] and ASHRAE 41.2 [12]. The two energy balances are measured and calculated as following:

$$Q_{ref} = \dot{m}_{ref} \cdot (h_{ref,out} - h_{ref,in}) \quad (1)$$

$$Q_{air} = \dot{m}_{air} \cdot (h_{air,out} - h_{air,in}) \quad (2)$$

The enthalpies are calculated based on temperature and pressure measurements. However, refrigerant is usually two phase at the exit of the TXV so the enthalpy at the inlet of the evaporator is calculated assuming an isenthalpic throttling process. The air side and refrigerant side heat balance are within $\pm 5\%$ error with their average, respectively, as shown in Figure 5 and Figure 6.

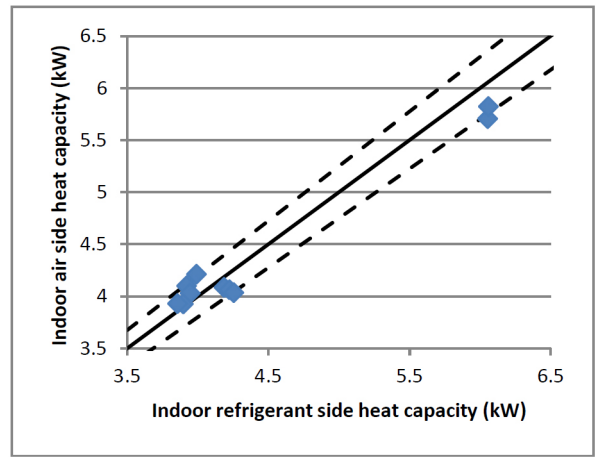


Figure 5. Comparison of indoor heat balance

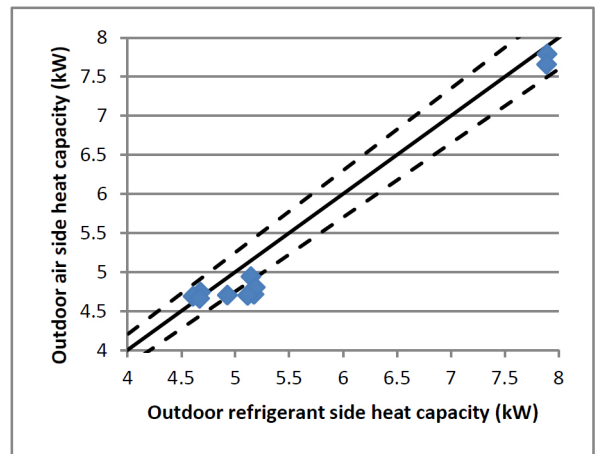


Figure 6. Comparison of outdoor heat balance

Two uncertainties are involved in measuring oil distribution. One is the uncertainty from the instrumentation as listed in the Appendix. Both the accuracy of property data and the mass flow measurement affect the uncertainty of the system performance. In addition, the accuracy of the scale can directly influence the results of measured mass retention.

Another uncertainty lies on the time lag of closing the valves simultaneously. The valves are operated manually by