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Refrigerant and lubricant charge in air condition heat exchangers: Experimentally validated model

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ABSTRACT

The paper presents a semi-empirical model to predict refrigerant and lubricant inventory in both microchannel condenser and plate-and-fin evaporator of an air conditioning system. Validated against experiments, where mass of refrigerant and lubricant are isolated under steady state and afterwards measured within ±1% and ±2.5% uncertainty, respectively, the model predicts refrigerant mass in both heat exchangers within 20%. As for lubricant, initial application of the model predicts mass well for evaporator but consistently under-predicts for condenser. Analysis shows that the lubricant might be separated in the condenser inlet header. Accumulated in the bottom, the lubricant-rich liquid may start to fill in the microchannel tubes. The temperature profile in the infrared image supports this hypothesis, as the temperature of the bottom channels is much lower. After modifying the model by counting in these liquid filled channels, both refrigerant and lubricant mass in the condenser can be modeled within 15% error.

Charge en frigorigène et en lubrifiant dans des échangeurs de chaleur de conditionneur d’air: Modèle validé expérimentalement

Mots clés : Charge en frigorigène ; Charge en lubrifiant ; Distribution ; Échangeur de chaleur

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Nomenclature

A	area
Bo	boiling number
c	oil concentration
Cp	specific heat
Dh	hydraulic diameter
G	mass flux
h	heat transfer coefficient
j	Colburn-j factor
k	conductivity
KE	kinetic energy
Nu	Nusselt number
OCR	oil circulation ratio
P	pressure
PAG	polyalkylene glycol
Pr	Prandtl number
q	heat flux
Q	capacity
Re	Reynolds number
TXV	thermal expansion valve

Subscripts

air	air side
hom	homogeneous
l	liquid
lo	liquid only
mix	mixture
oil	lubricant, oil
ref	refrigerant side
tp	two-phase
v	vapor

Greek letters

α	void fraction
ε	effectiveness, error
σ	deviation
μ	viscosity
ρ	density
Φ	pressure drop multiplier

1. Introduction

In a vapor compression AC system, refrigerant and lubricant charge is crucial for the reliability of compressor and the performance of heat exchangers. Over the years, researchers have employed experimental or modeling approach to study refrigerant and lubricant.

In the literature, experimental techniques for measuring refrigerant and lubricant mass inventory can be grouped by whether the method is intrusive or not. By using the intrusive method, Hoehne and Hrnjak (2004) 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 (2010) 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 (2005) 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 (1985) 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. (2004) 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 (2010) and Sethi and Hrnjak (2011) employed a similar method to measure oil retention in suction lines. The uncertainties reported by the two authors were 0.5% and 2%, respectively. Besides remove and weigh technique, Peuker and Hrnjak (2010) developed Flushing technique and Mix and Sample technique. Using these three methods, Peuker and Hrnjak (2010) were able to determine oil amount totals within 2%. As for the non-intrusive method, Lee et al. (2011) 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 used to measure oil retention in each part of a CO_2/PAG46 A/C system by Lee (2003) and that of a residential A/C system by Cremaschi (2004). Cremaschi (2004) estimated 12% relative error.

Most of the methods to model refrigerant–lubricant mixture found in open literature can be divided into two categories. One is the "oil contamination approach", where oil is treated as a contaminant in an otherwise pure refrigerant. Pure refrigerant properties and correlations are used and the presence of oil is transformed into an independent contamination parameter. Although simple to implement, this approach is in lack of physical meaning. It precludes the physical properties of lubricant in the calculation and the contamination parameter is solely empirical. The other method, presented by Thome (1995), is the so called "thermodynamic approach" where refrigerant–oil mixture is treated as a zeotropic mixture with a temperature glide. This approach overcomes the negative aspects of the oil contamination but requires additional complexity for determining boiling temperature and enthalpy change. The "thermodynamic approach" is used in this work. Since the lubricant used in this study is essentially oil, the term "lubricant" and "oil" are used interchangeably.