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Experimental investigation of oil retention in air conditioning systems

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Abstract

In air conditioning and refrigeration systems a small amount of oil is carried with the refrigerant and is retained in the system components. Oil retention characteristics in the condenser, evaporator, liquid and suction lines were measured and are presented and discussed here. Refrigerants R22, R410A, and R134a with miscible and non-miscible lubricants were considered to investigate oil retention physics in the widest possible range of transport properties. A parametric analysis in the suction line showed that oil retention depends on the oil mass fraction, vapor refrigerant mass flux, mixture viscosity ratio and orientation of the pipe. In the suction line, an increase in mixture viscosity of about 55% caused a rise in oil retention in the range of 50%, depending on the oil mass fraction. Oil retention in the upward vertical suction line is about 50% higher than in the horizontal line at similar conditions.

Keywords: Air conditioning; Refrigerating system; Compression system; Oil; Measurement; Oil return; Compressor

Etude expérimentale sur la retention d'huile dans les systèmes de conditionnement d'air

Mots clés : Conditionnement d'air ; Système à frigorifique ; Système à compression ; Huile ; Mesure ; Retour d'huile ; Compresseur

1. Introduction

Lubricant is necessary in air conditioning and refrigeration systems only because the compressor required it to prevent surface-to-surface contact between its moving parts. While lubricant is needed inside the compressor crankcase it represents an undesired effect in any other component, because it increases the pressure drops and penalizes the heat transfer coefficient in the heat exchangers. Some oil leaves the compressor by forming an equilibrium mixture with the refrigerant; some is simply dragged as a result of very high refrigerant vapor velocity at the compressor discharge. In time the oil forms a layer on all surfaces—an undesirable action because it creates additional resistance.

In 1972, Ridle, Macken, and Gouse [1] were among the first researchers to systematically characterize the flow of oil–refrigerant mixtures. Their analytical model, based on minimum gas velocities, introduced the concepts of void

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Nomenclature

BWMO	blended white mineral oil
COP	coefficient of performance [–]
D	diameter [m]
F	force [N]
f	friction factor [–]
g	gravity [m/s^2]
G	mass flux [kg/(m^2 s)]
HFC	hydrofluorocarbon
m	mass [kg]
MO	mineral oil
$\dot{m}$	mass flow rate [kg/s]
NMO	naphthenic mineral oil
OMF	oil mass fraction [wt%]
OR	oil retention [ml]
PAG	polyalkylene glycole oil
POE	polyol ester oil
R	radius [m]
t	time [min]
u	velocity [m/s]
vrf	viscosity ratio factor [–]
VG	viscosity grade
y	radial distance from the pipe wall
Greek letter	
$\bar{\varepsilon}_{pipe}$	surface roughness [μm]
ε	efficiency [–]
δ	oil film thickness [m]
ρ	density [kg/m^3]
μ	dynamic viscosity [Pa s]
σ	surface tension [N/m]
γ_{misc}	degree of miscibility
ν	kinetic viscosity [cSt]
$\tilde{\nu}$	kinetic viscosity ratio
Subscripts	
Liq	liquid
Ref	refrigerant
Vap	vapor
I	inertia, interface
C	core
G	gas, gravity

fraction, oil entrainment, and liquid film thickness for oil–refrigerant mixtures. Schlager et al. [2] conducted experiments in order to determine the quantity of oil in smooth and micro-fin tubes during evaporation and condensation of refrigerant–oil mixtures. They showed that the parameters that affect oil retention were mass flux, oil mass fraction, mixture viscosity, evaporator exit conditions (i.e. vapor quality at the evaporator outlet), and evaporation pressure. Biancardi et al. [3] conducted experimental and analytical efforts to determine the lubricant circulation characteristics of HFC/POE and HFC/MO pairs in a residential heat pump system and compared the behavior with a R22/MO mixture. Visual observations determined the minimum flow rate for 'the worst-case,' in which the velocities occurred in the vertical upward vapor line.

Shedd and Newell [4] proposed a non-intrusive, automated, optical film thickness measurement technique to be used with a wide range of fluids and flow configurations. Bai and Newell [5] described the characteristics of two-phase, viscous flow of air and 300 SUS AB oil. Using extensive experimental flow visualization in horizontal and vertical pipes, the oil film thickness versus oil mass flow rate was plotted, with vapor velocity and pipe diameter as parameters.

Oil return characteristics in vertical upward flows were experimentally and theoretically investigated by Mehendale [6]. The critical mass flow rates for preventing oil film reversal in a vertical pipe were estimated. Vapor refrigerant of R22, R407C, and R410A with MO and POE oils were compared with the results obtained by Jacobs et al. [7]. If the refrigerant mass flow rates were reduced below the critical values, the stable upward moving oil film became unstable, started oscillating, and reversed its direction of motion. The critical refrigerant mass flow rates for oil transport by superheated vapor in vertical pipes were found to be higher than that predicted from the correlation of Jacobs et al.

In 2002, Lee [8] proposed a model on oil retention in CO_2 air conditioning systems. The lubricant used was PAG oil, which is partially miscible with CO_2. Lee experimentally measured oil retention in microchannel gas cooler, evaporator, and in the suction line of the system. The solubility of CO_2 in PAG oil was ranged from 10 to 40 wt%. The liquid film viscosity ranged from 9.2 to 43 cSt, while refrigerant vapor core Reynolds number in the suction line ranged from 16×10^4 to 32×10^4. Lee also showed the effect of oil retention on pressure drops in the suction line, evaporator, and gas cooler. Pressure drops can easily double when the oil mass fraction increases up to 5 wt%. Cremaschi et al. [9] measured oil retention in the evaporator, condenser, liquid and suction lines of R22 and R410A air conditioning systems. He plotted the cumulative oil retention in each component and measured the increase in pressure drop due to oil retention.

This paper presents further experimental results of oil retention in air conditioning systems with various combinations of refrigerant and oil pairs. It also discusses a parametric analysis of oil retention in the suction line. It finally represents an extension of Lee's research to conventional refrigerant and tube-and-fin heat exchangers.