

Effect of Lubricant on Two-phase Refrigerant Distribution in Microchannel Evaporator

Huize Li and Predrag Hrnjak
Univ of Illinois at Urbana-Champaign

ABSTRACT

This paper presents a model analysis of oil effects on the distribution of two phase refrigerant in a parallel flow microchannel evaporator. A microchannel evaporator model developed and presented earlier (SAE paper 2012-01-0321) is enhanced by inclusion of the thermodynamic and transport properties of refrigerant-oil mixture and their impact on boiling heat transfer and pressure drop characteristics. R134a and PAG oil are selected as the working pair. Viscosity effect and OCR effect on refrigerant distribution are investigated using this model, and the results show that 1) High viscosity is detrimental for refrigerant distribution. 2) As OCR increases, distribution becomes worse; but at very high OCR, distribution becomes better. Some initial experimental results show that distribution becomes worse when OCR changes from 0.1% to 3%.

CITATION: Li, H. and Hrnjak, P., "Effect of Lubricant on Two-phase Refrigerant Distribution in Microchannel Evaporator," *SAE Int. J. Mater. Manf.* 6(3):2013, doi:10.4271/2013-01-1508.

INTRODUCTION

Lubricants in a vapor compression refrigeration system are mainly used to reduce friction and minimize wear of the compressor. In automobile air conditioning systems, where an oil separator is less commonly used, oil injected by the compressor is mixed with refrigerant and travels throughout the system. An adverse effect of lubricating oil on capacity and COP has been identified experimentally by many researchers (McMullan et al., 1988; McMullan et al., 1992; Grebner and Crawford, 1993; Lottin et al., 2003; DeAngelis and Hrnjak, 2005). This adverse effect can also be predicted by numerical models (Youbi-Idrissi et al., 2002; Lottin et al., 2003; Wei et al., 2008).

Compared to oil effect on capacity and COP, less is known about oil effect on refrigerant distribution in microchannel evaporators. It has been seen by DeAngelis and Hrnjak (2005) that reducing oil viscosity improved refrigerant distribution, but OCR effect was not clear to them at that time. Typically oil can effect distribution in two ways: 1) Oil addition can change the flow regime in the inlet header thus affecting quality distribution. Bowers and Hrnjak (2009) observed a dramatic change between the developing two-phase flow regime of pure R134a and R134a/PAG oil mixture in horizontal inlet headers. Zou and Hrnjak (2012) investigated oil effect on refrigerant distribution in vertical inlet headers and found that distribution becomes worse with a little amount of oil; Further addition of oil improves

distribution due to the changes of flow pattern. 2) Oil addition can vary the flow resistance of each microchannel tube with different magnitude, thus affect refrigerant mass flow rate distribution among parallel tubes. Oil exerts effect on flow resistance by changing the heat transfer and pressure drop characteristics of the working fluid. A critical review of oil effect on refrigerant heat transfer and pressure drop is given by Shen and Groll (2005). They found that the lubricant tends to increase pressure drop and decrease heat transfer coefficient in most cases, but increase of heat transfer coefficient can happen at low oil concentrations.

In this study, a modeling approach is taken to investigate oil effect on distribution. Tuo et al. (2012) proposed an experimentally validated microchannel evaporator model considering pure refrigerant maldistribution in both conventional direction expansion (DX) and flash gas bypass (FGB) cycles (Tuo and Hrnjak, 2012). This model is enhanced in this study by inclusion of the thermodynamic and transport properties of refrigerant-oil mixture and their impact on boiling heat transfer and pressure drop characteristics. R134a and PAG 46 oil are used in the models unless otherwise stated. First, oil effect on thermodynamic equilibrium between the vapor and liquid phases within one microchannel tube is investigated, as well as the oil effect on heat transfer and pressure drop characteristics. Then, a simplified parallel two-tube model is employed to obtain in-depth understanding of how oil affect the flow resistance of

each tube thus affect distribution. In the end, attempt is made to quantitatively analyze oil effect on refrigerant distribution in a real microchannel evaporator.

SINGLE TUBE MODEL

A 1D steady state numerical model for refrigerant-oil mixture upward flow in a microchannel tube has been built. The following assumptions are made to simplify the model without losing generality: 1) Uniform distribution of refrigerant among parallel ports of each tube. 2) Uniform temperature and velocity profile of the incoming air along the tube. 3) Ideal mixture of refrigerant and oil (for enthalpy calculation).

In this model, a thermodynamic approach proposed by Thome (1995) is used for refrigerant-oil mixture modeling. Refrigerant and a miscible lubricating oil create a zeotropic mixture (immiscible oil will not be discussed here). The vapor pressure of oil is normally 12 orders of magnitude smaller than the vapor pressure of refrigerant, so the composition of oil in the vapor phase is negligible.

1. Mixture Quality, Local Oil Concentration and OCR

In this study, mixture quality, local oil concentration and OCR are defined by (1), (2), (3) respectively.

$$x_{\min} = \frac{m_{\text{ref},\text{vap}}}{m_{\text{ref},\text{vap}} + m_{\text{ref},\text{liq}} + m_{\text{oil}}} \quad (1)$$

$$w_{\text{oil}} = \frac{\dot{m}_{\text{oil},\text{liq}}}{\dot{m}_{\text{ref},\text{liq}} + \dot{m}_{\text{oil}}} \quad (2)$$

$$\text{OCR} = \frac{\dot{m}_{\text{oil},\text{liq}}}{\dot{m}_{\text{ref},\text{liq}} + \dot{m}_{\text{ref},\text{vap}} + \dot{m}_{\text{oil}}} \quad (3)$$

During evaporation process, the liquid phase is gradually enriched with oil. Based on the mass balance of oil in steady state, local oil concentration is related to OCR and mixture quality:

$$w_{\text{oil}} = \frac{\text{OCR}}{1 - x_{\text{mix}}} \quad (4)$$

2. Properties of Oil and Refrigerant-Oil Mixture

The accuracy of the property calculations is essential to the reliability of the numerical model for refrigerant-oil mixture. Most of the properties correlations are from Seeton and Hrnjak (2009). Their experimental data covers a wide range of pressure (0.6-39.3bar), temperature (-15-100 °C)

and local oil concentration (10%-91%) for R134a and PAG46 oil mixture.

Table 1. Property correlations for pure oil and refrigerant-oil mixture

Item	Pure oil	Refrigerant-oil mixture
VLE	N/A	Seeton and Hrnjak (2009)
v	Seeton and Hrnjak (2009)	Seeton and Hrnjak (2009)
ρ	Seeton and Hrnjak (2009)	Seeton and Hrnjak (2009)
σ	Seeton and Hrnjak (2009)	Jensen and Jackman (1984)
c_p	Liley and Gambill (1973)	Jensen and Jackman (1984)
λ	Liley and Gambill (1973)	Filippov and Novoselova(1955)

The rest of the correlations are commonly used general relationships for oil and refrigerant-oil mixtures property calculations.

3. Oil Effect on Bubble Point Temperature

For refrigerant-oil mixture, the temperature moves along the bubble point line during evaporation. Bubble point temperature is a function of local oil concentration and pressure. Fig. 1 shows the temperature development at fixed pressure (370kPa) as a function of quality. For pure refrigerant, the temperature stays constant because it is in saturation condition. For refrigerant-oil mixture, the liquid phase gradually becomes enriched with oil, so the temperature of the mixture keeps increasing, especially in the high quality region. The increase in bubble point temperature will decrease the temperature difference between air-side and refrigerant-side, reducing capacity.

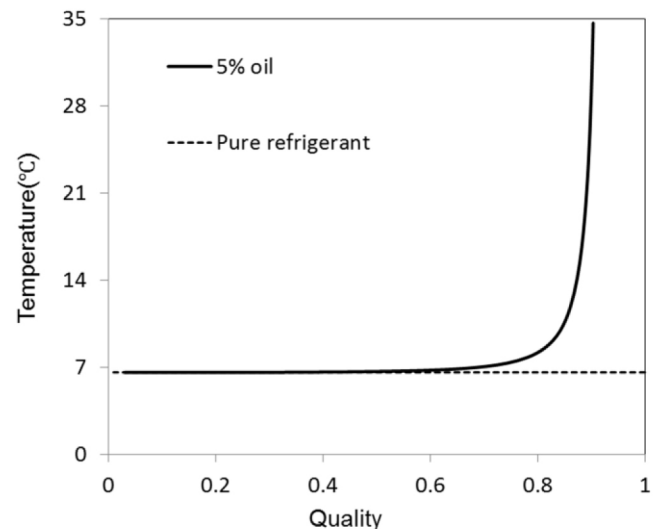


Figure 1. Oil effect on bubble point temperature

4. Oil Effect on Refrigerant-Side Heat Transfer Coefficient

Chen's (1966) heat transfer correlation is inherited in this study from Tuo et al.'s (2012) model but modified with

refrigerant-oil mixture properties. Fig. 2 shows that refrigerant heat transfer coefficient is degraded due to the presence of oil, because convective boiling is suppressed by the increase of viscosity and nucleation boiling is inhibited by the increase of surface tension. This modified version of Chen's correlation does not account for flow regime transition and foaming effect caused by oil addition, so it cannot predict the possible enhancement of heat transfer coefficient due to small concentrations of oil, a phenomenon which is commonly seen in conventional tubes.

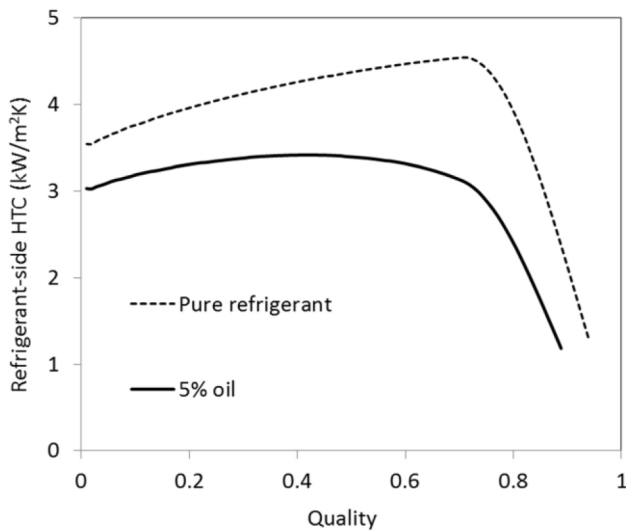


Figure 2. Oil effect on refrigerant-side HTC

5. Oil Effect on Refrigerant-Side Pressure Drop

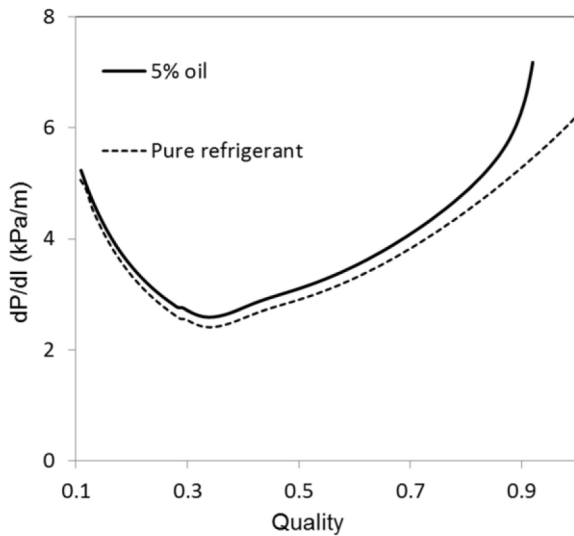


Figure 3. Oil effect on pressure drop

Friedel (1979) correlation which is used in Tuo et al.'s (2012) model has a tendency of overpredicting pressure drop. So the Mishima and Hibiki (1996) correlation modified with

refrigerant-oil mixture properties is used instead in this study. From Fig. 3, it can be seen that oil addition will increase pressure drop, because of the viscosity increase of the liquid mixture.

TWO TUBES MODEL

Using the single tube model, a study of oil effect on distribution is carried out for two tubes in parallel. This study is aimed at demonstrating how oil affects the flow resistance of each tube thus affect distribution. One of the tubes is vapor-rich, the other is liquid-rich. These two tubes are taken from a microchannel heat exchanger with geometric parameters listed in Table 2. Header pressure drop is not considered at this point, so each tube should have the same pressure drop.

Table 2. Heat exchanger Geometry

Total Length	356mm
Louver Angle	27°
Louver Pitch	1.4 mm
Fin Height	7.8 mm
Flow Depth	20.4 mm
Tube Depth	20.4 mm
Tube Thickness	2.1 mm
Louver Length	6.6 mm
Tube Pitch	10 mm
Fin Thickness	0.1 mm
Fin Pitch	3.2 mm
Port Diameter	1.2 mm
Inlet Header Diameter	23.8 mm
Outlet Header Diameter	37.5 mm
Number of Ports	10
Number of Tubes	25
Total Length	356 mm
Louver Angle	27°

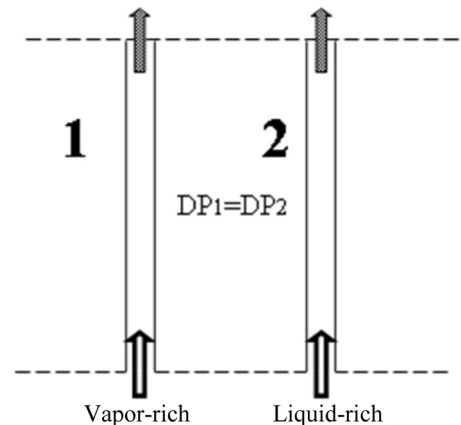


Figure 4. Two tube model illustration