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An experimental study and empirical correlations to describe the effect of lubricant oil on the nucleate boiling heat transfer performance for R-1234ze and R-134a

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ABSTRACT

In the present work, nucleate boiling heat transfer characteristics of R-134a and R-1234ze refrigerants subject to the influence of lubricant oil on a plate surface were experimentally examined. Eight types of lubricants, including POEA68, POEA120, POEA170, POEB68, POEB120, POEB170, POEC170, and POED 150, were used for investigations; the experiments were carried out at saturated temperatures of 0 °C and 10 °C, respectively. The oil concentrations range from 0% to 10% and heat fluxes vary from 10 kW/m^2 to 70 kW/m^2. The test results for pure refrigerants are in line with the existing data and correlations. With the presence of lubricant, the heat transfer coefficient may be slightly higher or lower than those of pure refrigerants, depending on the lubricant and operating pressure. However, all the heat transfer coefficients deteriorate appreciably as compared to the pure refrigerants when the oil concentration exceeds 5%. A correlation is developed that is capable of describing the influence of lubricant oil. The proposed correlation not only can predict the influence of the lubricants of this study but also can extend to predict existing data with a good accuracy.

1. Introduction

In a typical vapor compression refrigeration system, a small amount of lubricant oil is needed for lubricating the compressor. However, the thermophysical properties of lubricants are virtually different from those of refrigerants; thereby, it may impose a significant influence on heat transfer performance especially in the evaporator. For instance, the viscosity of lubricant may be two orders higher than those of refrigerants while the surface tension may be an order in difference. In this regard, the associated heat transfer performance may be jeopardized even for a tiny amount of lubricants. There had been a considerable amount of studies concerning the effects of lubricant on heat transfer performance of pool boiling, flow boiling in associations with conventional refrigerants or natural refrigerants. Interested readers may consult the reviewed articles summarized by Shen and Groll [1] and Wang et al. [2, 3]. Shen and Groll [1] pointed out that the gigantic viscosity difference may incur mass transfer resistance near the boiling surface, and in most cases especially at high oil concentrations, the lubricant tends to decrease the heat transfer and to increase the pressure drop of the working fluid. The effects of vapor quality, geometric configuration, heat flux, saturation temperature, thermodynamic and transport properties on thermal performance of the working fluid subject to oil concentrations were summarized by Wang et al. [2, 3]. Based on the reviewed articles, significant differences in heat transfer coefficient may prevail at the low oil concentrations (e.g. $x_b < 0.04$) where most literatures reported a consistent degradation of heat transfer coefficient while some revealed augmentation with the presence of lubricant oils. Yet almost all types of lubricants decreased the heat transfer coefficient when the oil concentrations, x_b, exceeded 0.05. Some hypotheses were given to explain the effects of the oil on the thermal performance of the working fluids. In which, Jensen and Jackman [4], and Mitrovic [5] hypothesized that the refrigerant will be preferentially evaporated; therefore, an oil-rich layer and a steep oil concentration gradient will be formed around the bubble, thereby increasing the liquid-gas surface tension. They also argued that a positive influence on heat transfer performance may occur with the rise of surface tension and foaming. However, in addition to the influence of the foaming or the surface additive component, Kedzierski [6] depicted that the heat transfer characteristics were also affected by the bubble size and bubble density. There were numerous studies seeking the fundamental mechanisms of the influence of lubricant on nucleate boiling; however, only relatively few quantitative correlations for predicting the effects of lubricants on the thermal performance had been reported. Among the few, the correlations were proposed by

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Nomenclature

A	effective area (m^2)
h	heat transfer coefficient ($W/m^2 \cdot K$)
M	molecular weight (kg/kmol)
P	pressure (Pa)
Q_t	total heat transfer rate (W)
q	heat flux (W/m^2)
T	temperature (°C)
V	voltage (V)
xb	oil concentration (kg/kg)

Greek symbols

σ	surface tension ($\mu N/m$)
ρ	density (kg/m^3)
ν	kinematic viscosity (m^2/s)

Subscripts

Cu	copper
f	fluid
g	given

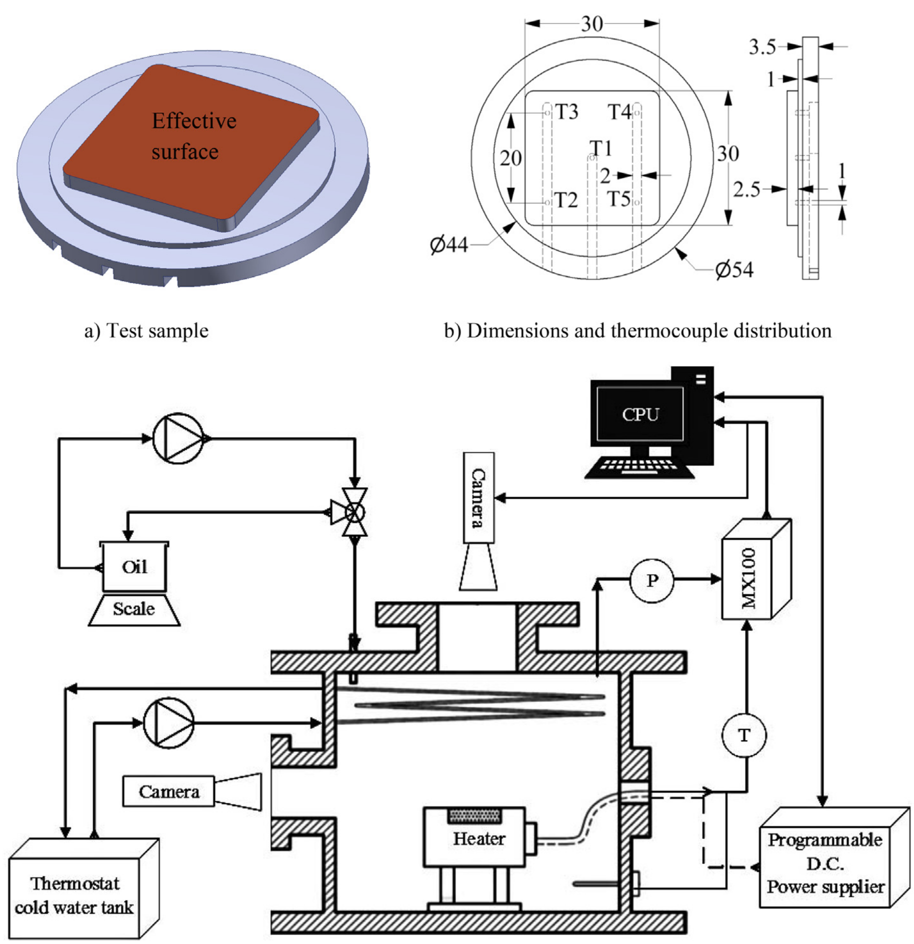
Chongrungreong and Sauer [7], Jensen and Jackman [4], and Kedzierski [8], respectively, as follows:

$$h = 0.05253\left[\frac{qD}{\mu_f i_{fg}}\right]^{0.569}\left[\frac{\mu_f C_{pf}}{k_f}\right]^{0.395}[P]^{1.659}\left[\frac{D}{0.01588}\right]^{-0.444}\left[\phi_r\frac{\rho_f}{\rho_g}\right]^{1.579} \quad (1)$$

$$\frac{h_m}{h_r} = e^{-4.095xb(1+0.0317\Delta T_w{}^{0.753})-55.11xb(1+0.0317\Delta T_w{}^{0.753})^2} \quad (2)$$

$$h_m = \frac{5.9\times10^{(-7)}(1-xb)\rho_o i_{fg}\Delta T_w k_o(1-e^{(-\lambda l_e/r_b)})}{xbT_s\sigma} \quad (3)$$

With the aforementioned correlations, only the Kedzierski correlation [8] was built based on the flat plate while the others were developed with respect to round tube surfaces. However, the Kedzierski correlation [8] is quite difficult to use in practice because it requires some further information. Furthermore, the thermophysical properties as well as correlations for predicting the oil thermophysical properties were limited in the published literature as also mentioned by Zhu et al. [9]. In this regard, it is the purpose of this to provide some new data for the environmentally benign working fluid, R-1234ze, and to encompass the dataset into a correlation that not only can predict the quantitative influence of lubricant oils on the nucleate boiling heat transfer coefficient of the present dataset but also gives fair predictions against some existing data.



a) Test sample

b) Dimensions and thermocouple distribution

c) A schematic diagram of the experimental system

Fig. 1. Test sample and schematic diagram of the experimental system.