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Influence of oil concentration on wetting behavior during evaporation of refrigerant–oil mixture on copper surface

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ABSTRACT

As wetting behavior is a key factor affecting boiling heat transfer performance of refrigerant–oil mixture, the influence of oil concentration on wetting behavior during evaporation of refrigerant–oil mixture on copper surface was experimentally investigated. The wetting behavior was analyzed by capillary rise method, and the test conditions covered oil concentrations of 1, 3, 5 and 10 wt%, and surface roughness of 0.028, 0.079, 0.144, 0.419 and 1.166 μm. The experimental results show that protuberant liquid film occurs in front of meniscus during evaporation of refrigerant–oil mixture; and contact line velocity, contact angle, liquid film length and rising liquid height increase as oil concentration increases. It is also found that the ratio of the rising liquid height of refrigerant–oil mixture to that of pure refrigerant is larger than 1, and ranges between 1.42 and 2.18 under present test conditions, indicating that the presence of oil significantly enhances the surface wettability of refrigerant.

Influence de la concentration d'huile sur la mouillabilité pendant l'évaporation d'un mélange frigorigène-huile sur une surface de cuivre

Mots clés : Méthode de la remontée capillaire ; Film liquide ; Huile ; Frigorigène ; Mouillabilité

1. Introduction

In vapor compression refrigeration systems, the lubricating oil usually circulates with the refrigerant, and the oil concentration has significant influence on the boiling heat transfer performance (Bandarra Filho et al., 2009; Wang et al., 2012). During the design and optimization of vapor compression refrigeration systems, the influence of oil concentration on the boiling heat transfer of refrigerant–oil mixture needs to be accurately

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Nomenclature

E	evaporation rate
H	rising liquid height
h	vertical distance between contact line and liquid level in the captured image
L	liquid film length
M	mass of the liquid
Ma	magnification of image
r	roughness ratio
Ra	arithmetic average roughness
t	time
v_{CL}	contact line velocity
y	vertical coordinates of the contact line in the captured image

Greek symbols

θ	contact angle
ω	oil concentration
η	oil influence factor
ρ	liquid density

Subscripts

CL	contact line
r	pure refrigerant
ro	refrigerant–oil mixture

predicted. In order to understand the physical mechanism of refrigerant–oil mixture and develop the accurate prediction model, the researchers have paid great attention to the influence of oil concentration on the factors affecting the boiling heat transfer, such as the thermophysical properties of refrigerant–oil mixture (Assaela et al., 2003; Zheleznу et al., 2014) and the lubricant excess layer (Kedzierski, 2002, 2003).

The wetting behavior of fluid reflects the interaction between liquid, vapor and solid surface, and it is another key factor that affects the boiling heat transfer (Gong and Cheng, 2015; Jo et al., 2011; Li et al., 2014a, 2014b, 2014c; Phan et al., 2009). The existing results have shown that for pure fluids such as water, the decrease of surface wettability can lead to the increase of nucleate active nucleation site density as well as bubble departure frequency, and then result in the enhancement of nucleate boiling heat transfer coefficient (Choi et al., 2011; Zhang and Kim, 2014; Zhang et al., 2012, 2013). For refrigerant–oil mixture, oil concentration affects the boiling heat transfer, thus the research on the wetting behavior of pure fluids should be extended to cover the influence of oil concentration.

During the investigation of the influence of oil concentration on the wetting behavior of refrigerant–oil mixture, the effects of evaporation and surface roughness should be considered based on the following reasons. Firstly, the liquid micro-layer evaporation is the key mechanism of boiling heat transfer (Cooper and Lloyd, 1969), and the evaporation has significant effects on the contact line motion, contact angle and shape of wetting interface (Bourges-Monnier and Shanahan, 1995; Gokhale et al., 2003; Kandlikar and Steinke, 2002; Sefiane et al., 2008; Zhang and Chao, 2000). Secondly, the surface of heat exchange tube in actual refrigeration system has certain roughness level (Hubner and Kunstler, 1997), and the surface roughness results in the contact angle hysteresis (Bracke et al., 1988).

The wetting behavior of pure refrigerant has been investigated by the existing researches, in which the effects of evaporation (Zhang and Chao, 2000), temperature (Reale, 1973; Vadgama and Harris, 2007), surface oxidation (Hong et al., 1994), surface roughness (Hong et al., 1994) and surface material (Hong et al., 1994; Vadgama and Harris, 2007) on the wetting behavior have been considered. These researches indicated that the contact angles of pure refrigerant on copper and aluminum surfaces are small, and this high wettability is caused by the low surface tension of refrigerants. In addition, the effects of evaporation on spreading and contact angle of refrigerant droplet are related to the evaporation rate, while the surface material, surface oxidation and surface roughness have slight effect on the contact angle of refrigerant.

During the evaporation of refrigerant–oil mixture, the oil is considered to be non-phase change component for the reason that its saturated vapor pressure is much lower than that of refrigerant (Ermolaev et al., 1972). The thermophysical properties (e.g. surface tension and viscosity) of refrigerant–oil mixture change with the variation of oil concentration, and are different from those of pure refrigerant. The surface tension has influence on the surface wettability, while the viscosity affects the contact line motion. Therefore, the wetting behavior during evaporation of refrigerant–oil mixture may change with the oil concentration, and is different from those of pure refrigerants.

The existing researches on the wetting behavior during evaporation of binary mixtures mainly focus on the water–alcohol mixtures (Fournier and Cazabat, 1992; Loewenthal, 1931; Neogi, 1985; Thomson, 1855; Vuilleumier et al., 1995). These researches have shown that during the evaporation of water–alcohol mixture, the liquid near the surface is driven upward in the form of thin film, and then downward in the form of regular rows of drops known as “tears of wine” (Loewenthal, 1931; Neogi, 1985; Thomson, 1855). This phenomenon has been attributed to the Marangoni convection effect, which is caused by the faster evaporation of alcohol and the difference of surface tension between alcohol and water (Fournier and Cazabat, 1992; Vuilleumier et al., 1995). For refrigerant–oil mixture, the evaporation rate of refrigerant is much larger than that of oil, and the surface tension of refrigerant is different from that of oil, which may cause the occurrence of Marangoni convection similar to water–alcohol mixtures. However, the physicochemical properties of refrigerant and oil are different from those of alcohol and water, so the wetting behavior during evaporation of water–alcohol mixtures cannot be directly extended to the refrigerant–oil mixture.

In order to know the influence of oil concentration on wetting behavior during evaporation of refrigerant–oil mixture, the experiments on copper surface are performed in the present study, considering the different surface roughness.