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Experimental research on wetting behavior of refrigerant–oil mixture on micro/nanostructured surface

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ABSTRACT

The wettability of micro/nanostructured surface is a key property for its application in enhancing the boiling heat transfer of refrigerant–oil mixture. The objective of this research is to experimentally investigate the wetting behavior of refrigerant–oil mixture on micro/nanostructured surface. Three types of surfaces including plain copper surface (PS), micro/nanostructured surface (MNS) and micro/nanostructured surface with fluorinated self-assembled monolayer (MNFS) were fabricated; and the wetting behavior of pure R141b as well as R141b-NM56 mixtures with different oil concentrations on three types of surfaces was measured. The experimental results show that the protuberant liquid film is formed during the wetting of refrigerant–oil mixture on MNS or PS, but does not exist on MNFS; the presence of F-SAM or micro/nanostructure modified by F-SAM reduces the surface wettability, while the presence of micro/nanostructure increases the surface wettability; oil increases the wettability of refrigerant on MNS, while it reduces the wettability of refrigerant on MNFS.

Recherche expérimentale sur le comportement de mouillage d'un mélange frigorigène-huile sur une surface micro/nano-structurée

Mots clés : Micro/nano structure ; Huile

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Nomenclature

EF_F	F-SAM effect factor
EF_{MN}	micro/nanostructure effect factor
EF_{MNF}	micro/nanostructure combined F-SAM effect factor
EF_{oil}	oil effect factor
H	rising liquid height [mm]
h	vertical distance between contact line and horizontal liquid level in CCD image [pixel]
L	liquid film length [mm]
l	vertical distance between contact line and top of meniscus in CCD image [pixel]
Ma	magnification of image [mm pixel^{-1}]
Ra	arithmetic mean roughness [μm]
v_{CL}	contact line velocity [mm s^{-1}]
y_{CL}	vertical coordinate of contact line in CCD image [pixel]

Greek symbols

Δt	time interval between two frames [s]
θ	contact angle [°]
ω	oil concentration [wt%]

Subscripts

a	time-averaged
r	pure refrigerant
ro	refrigerant–oil mixture

Abbreviations

CCD	charge-coupled device
FESEM	field emission scanning electron microscopy
fps	frames per second
F-SAM	fluorinated self-assembled monolayer
FTIR	Fourier transform infrared
LED	light-emitting diode
MNFS	micro/nanostructured surface with F-SAM
MNS	micro/nanostructured surface
PFOTS	1H, 1H, 2H, 2H – perfluorooctyltrichlro silane
PS	plain copper surface
UV	ultraviolet

1. Introduction

Micro/nanostructured surface, formed by fabricating micro/nanostructures on a conventional surface, has shown great potential for enhancing the boiling heat transfer (Dong et al., 2014; Kim et al., 2015; Kruse et al., 2015; Launay et al., 2006; Shojaeian and Kosar, 2015). Application of this type of surface for enhancing the boiling heat transfer of refrigerant–oil mixture might become a new method for improving the energy efficiency of vapor compression refrigeration systems. In order to realize the application of micro/nanostructured surface in vapor compression refrigeration systems, the influence mechanism of micro/nanostructured surface on the boiling heat transfer of refrigerant–oil mixture should be known.

A micro/nanostructured surface affects boiling heat transfer performance through changing the heating surface properties. The surface wettability is an important surface property (Attinger et al., 2013, 2014), and has significant influences on active nucleation site density and bubble departure frequency (Gong and Cheng, 2015; Jo et al., 2011; Li et al., 2013, 2014). In order to understand the influence mechanism of micro/nanostructured surface on the boiling heat transfer of refrigerant–oil mixture, the wetting behavior of refrigerant–oil mixture on micro/nanostructured surface needs to be known.

The effect of surface modification should be considered during the investigation of the wetting behavior of refrigerant–oil mixture on micro/nanostructured surface based on the following reasons. The micro/nanostructure itself modifies the surface morphology of plain surface, and causes the increase of surface roughness. For the fluids with high surface wettability, the increase of surface roughness will increase the surface wettability; the increase of surface roughness enhances the boiling heat transfer, while the increase of surface wettability deteriorates the boiling heat transfer (Li et al., 2015). The negative effect of surface wettability on the boiling heat transfer enhancement could be eliminated by the control of surface wettability (Zhang et al., 2012), and the surface modification is usually used to control the surface wettability (Li et al., 2015). In order to develop the surface wettability control method for refrigerant–oil mixture on micro/nanostructured surface, the effect of surface modification should be evaluated.

The effect of oil concentration should also be considered during the investigation of wetting behavior of refrigerant–oil mixture on micro/nanostructured surface due to the following reasons. Firstly, the saturation vapor pressure of oil is much less than that of pure refrigerant (Ermolaev et al., 1972), causing the negligible evaporation of oil during the boiling process of refrigerant–oil mixture, which leads to the non-uniform mass transfer and the dynamic wetting (Sefiane et al., 2008). Secondly, the thermophysical properties of refrigerant–oil mixtures are changed with the oil concentration, and the variations of thermophysical properties will change the wetting behavior.

The existing studies on the wetting behavior on micro/nanostructured surfaces are mainly focused on water, in which the surfaces were fabricated by thermal oxidation (Nam and Ju, 2013), chemical oxidation (Kim et al., 2011; Köroglu et al., 2013; Nam and Ju, 2013; Zhu et al., 2012), chemical oxidation combining UV-photolithography (Kim et al., 2009), chemical oxidation combining self-assembled monolayer (SAM) (Chen et al., 2009), SAM (Lee et al., 2008, 2012, 2013), etching (Lee et al., 2013), coating materials (Lee et al., 2013; Zhang et al., 2015), electro-deposition (Khorsand et al., 2015), photolithography (Zhong et al., 2006), colloidal lithography combining plasma etching (Park et al., 2011) or ultraviolet nanoimprint lithography (Jo et al., 2014). The existing literatures have also reported