INTERNATIONAL JOURNAL OF REFRIGERATION 34 (2011) 1823–1832

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Influences of refrigerant-based nanofluid composition and heating condition on the migration of nanoparticles during pool boiling. Part I: Experimental measurement

Hao Peng [a,b], *Guoliang Ding* [a,*], *Haitao Hu* [a]

[a] *Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University, 800 Dongchuan Road, Shanghai 200240, PR China*
[b] *Key Laboratory of Microgravity (National Microgravity Laboratory)/CAS, Institute of Mechanics, Chinese Academy of Sciences (CAS), 15 Beisihuan Xilu, Beijing 100190, PR China*

ARTICLE INFO

Article history:
Received 8 February 2011
Received in revised form
8 July 2011
Accepted 28 July 2011
Available online 4 August 2011

Keywords:
Heat flux
Oil
Particle
Pool boiling
Refrigerant

ABSTRACT

Influences of refrigerant-based nanofluid composition and heating condition on the migration of nanoparticles during pool boiling were investigated experimentally. The nanoparticles include Cu (average diameters of 20, 50 and 80 nm), Al and Al_2O_3 (average diameters of 20 nm), and CuO (average diameter of 40 nm). The refrigerants include R113, R141b and n-pentane. The mass fraction of lubricating oil RB68EP is from 0 to 10 wt%, the heat flux is from 10 to 100 kW m^{-2}, and the initial liquid-level height is from 1.3 to 3.4 cm. The experimental results show that the migration ratio of nanoparticles during the pool boiling of refrigerant-based nanofluid increases with the decrease of nanoparticle density, nanoparticle size, dynamic viscosity of refrigerant, mass fraction of lubricating oil or heat flux; while increases with the increase of liquid-phase density of refrigerant or initial liquid-level height.

Influences de la composition et le chauffage d'un nanofluide sur la migration des nanoparticules lors de l'ébullition libre. Partie I : mesures expérimentales

Mots clés : Flux thermique ; Huile ; Particule ; Ébullition libre ; Frigorigène

1. Introduction

Refrigerant-based nanofluid is a new type of heat transfer working fluid by dispersing nanoparticles in conventional pure refrigerant, and is also called as nanorefrigerant by some researchers (Ding et al., 2009; Jiang et al., 2009). The existing researches show that substituting refrigerant-based nanofluid for conventional refrigerant is an effective method for

* *Corresponding author*. Tel.: +86 21 34206378; fax: +86 21 34206814.
E-mail address: glding@sjtu.edu.cn (G. Ding).

doi:10.1016/j.ijrefrig.2011.07.010

Nomenclature

d	diameter of single nanoparticle (m)
k_B	Boltzmann constant, $k_B = 1.381 \times 10^{-23}\ J\ K^{-1}$
L	initial liquid-level height (m)
m	mass (kg)
m_b	mass of bubbles (kg)
q	heat flux ($W\ m^{-2}$)
$R(u > u_{0,min})$	ratio of number of nanoparticles with velocity larger than $u_{0,min}$ to the total number of nanoparticles
T	temperature (K)
u	velocity of single nanoparticle ($m\ s^{-1}$)
$u_{0,min}$	minimum escaping velocity ($m\ s^{-1}$)
$\bar{u}$	average velocity of bubbles
x	mass fraction of lubricating oil
Greek symbols	
γ	surface tension of liquid ($N\ m^{-1}$)
ζ	migration ratio of nanoparticles
φ	initial nanoparticle concentration
ρ	density ($kg\ m^{-3}$)
Subscripts	
L	liquid-phase
n	nanoparticle
o	lubricating oil
r	refrigerant

improving the energy efficiency of refrigeration system (Wang et al., 2003; Wang et al., 2007; Bi et al., 2008). In order to apply the refrigerant-based nanofluid in the refrigeration system, the phase-change heat transfer characteristics of refrigerant-based nanofluid should be quantitatively evaluated, and the cycle behavior of nanoparticles in the refrigeration system should be known. The phase-change heat transfer characteristics of refrigerant-based nanofluid is affected by the distribution of nanoparticle concentration in the liquid-phase and vapor-phase refrigerant because the distribution of nanoparticle concentration has significant effect on the thermophysical properties of the liquid-phase and vapor-phase refrigerant. Meanwhile, the cycle behavior of nanoparticles in the refrigeration system is also affected by the distribution of nanoparticle concentration. Therefore, the migration characteristics of nanoparticles between liquid-phase and vapor-phase need be known to determine the distribution of nanoparticle concentration in the liquid-phase and vapor-phase refrigerant. As the pool boiling heat transfer is the basic type of phase-change heat transfer, the migration characteristics of nanoparticles from liquid-phase to vapor-phase during the pool boiling process of refrigerant-based nanofluid should be firstly investigated.

In recent years, some researchers have experimentally investigated the pool boiling heat transfer characteristics of refrigerant-based nanofluids (Kedzierski, 2009; Kedzierski and Gong, 2009; Trisaksri and Wongwises, 2009; Peng et al., 2010) and flow boiling heat transfer characteristics of refrigerant-based nanofluids (Peng et al., 2009; Henderson et al., 2010). Some of the researches indicate that the presence of nanoparticles can enhance the boiling heat transfer (Kedzierski, 2009; Kedzierski and Gong, 2009; Peng et al., 2009; Peng et al., 2010), while the other researches indicate that the presence of nanoparticles deteriorates the boiling heat transfer (Trisaksri and Wongwises, 2009; Henderson et al., 2010). From these researches, it can be seen that the nanoparticle type, the nanoparticle size, the refrigerant type, the mass fraction of lubricating oil and the heat flux have influences on the pool boiling heat transfer of refrigerant-based nanofluid. Therefore, the influences of the above factors on the migration characteristics of nanoparticles during the pool boiling process of refrigerant-based nanofluid should be investigated. In addition, the initial liquid-level height affects the pool boiling heat transfer, so the influence of initial liquid-level height on the migration characteristics of nanoparticles also needs to be investigated.

Compared with the researches on the boiling heat transfer of refrigerant-based nanofluid, there are much fewer researches on the migration characteristics of nanoparticles. A literature survey shows that the migration characteristics of nanoparticles during the pool boiling process of refrigerant-based nanofluid is only reported by Ding et al. (2009). In that paper, the relationship between the migration ratio and the volume fraction of nanoparticles was investigated. However, only one type of nanoparticle and one type of refrigerant were used in the experiments at a fixed heat flux. In order to well understand the migration characteristics of nanoparticles, more experiments concerning the influences of nanoparticle type, nanoparticle size, refrigerant type, mass fraction of lubricating oil, heat flux and initial liquid-level height on the migration characteristics of nanoparticles are needed.

The objective of this study is to experimentally investigate the influences of refrigerant-based nanofluid composition (including nanoparticle type, nanoparticle size, refrigerant type and mass fraction of lubricating oil) and heating condition (including heat flux and initial liquid-level height) on the migration characteristics of nanoparticles, and to propose a model to predict the migration ratio of nanoparticles. Part I of the present study focuses on the experimental measurement, and part II focuses on the model development.

2. Experimental facility and method

2.1. *Experimental facility*

The experimental facility used for testing the migration characteristics of nanoparticles in the refrigerant-based nanofluid pool boiling consists of three parts (i.e., a pool boiling apparatus, a migrated mass measurement apparatus and a capture cover), as schematically shown in Fig. 1. The pool boiling apparatus mainly consists of a boiling vessel and an electric heating membrane. The boiling vessel is a cylindrical glass container with the inside diameter of 50 mm and the height of 95 mm. The vessel is insulated with glass fibers to reduce heat loss to the surroundings. The electric heating