



Effects of magnetic field on the pool boiling heat transfer of water-based α -Fe₂O₃ and γ -Fe₂O₃ nanofluids

Shi-Yan Li, Wen-Tao Ji^{*}, Chuang-Yao Zhao, Hu Zhang, Wen-Quan Tao

Key Laboratory of Thermo-Fluid Science and Engineering of MOE, Xi'an Jiaotong University, Xi'an 710049, China

ARTICLE INFO

Article history:

Received 18 March 2018

Received in revised form 2 September 2018

Accepted 6 September 2018

Keywords:

Pool boiling

Magnetic field

Ferric oxide nanoparticles

Heat transfer enhancement

ABSTRACT

Pool boiling experiments of water-based α -Fe₂O₃ and γ -Fe₂O₃ nanofluids with different concentrations (0.005–0.100 g/L) were conducted at atmospheric pressure. Two kinds of magnetic field induced by two neodymium magnets were also applied to investigate the effects of magnetic field on the pool boiling of nanofluids. It demonstrated that the magnetic field could change the local concentration of nanofluids and produce an extra pressure on the bubble boundary. The extent of the effects was not only dependent on the intensity and distribution of magnetic field, but also the magnetism and concentration of nanoparticles. For the 0.050 g/L γ -Fe₂O₃ nanofluid in the presence of magnetic field induced by two mutually exclusive magnets, an enhancement in boiling heat transfer coefficient up to 28% was obtained. The results of the experiments indicated the feasibility to control the pool boiling performance of magnetic nanofluids by external magnetic field.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

With the development of products with higher heat flux, the heat dissipation requirement is more prominent. As one of the most effective heat transfer methods, boiling has been widely used in industry. In recent decades, many studies have focused on the improvement of boiling heat transfer coefficient and critical heat flux from different aspects [1,2]. Among them, adding nanoparticles is more attractive because the nanofluids might exhibit superior properties in pool boiling heat transfer.

Various nanoparticles were used to investigate the effects of nanoparticles on pool boiling, such as Al₂O₃ [3–5], TiO₂ [6,7], SiO₂ [8,9] and carbon nanotubes [10,11]. However, these experimental results varied from one to another. Many factors are correlated with the results of nanofluids pool boiling experiments, including the size, type, wettability and concentration of the nanoparticles [4,7,8,12,13,14], the roughness of heat surface and heat flux [15,16].

Investigations on the boiling of magnetic nanofluids were also performed in recent years. Magnetic nanofluids are suspensions which are comprised of a non-magnetic base fluid and magnetic nanoparticles. Table 1 shows the previous pool boiling experiments on magnetic nanofluids [13–15,17–20]. Although the results of magnetic nanofluids were similar to those of conventional

nanofluids, they could exhibit some special features in the presence of magnetic field. Ishimoto et al. [21] investigated the behavior of single bubble in magnetic nanofluid under nonuniform magnetic field. They found that the velocity of single bubble in magnetic nanofluid could be influenced by external magnetic field due to the magnetic body force. The fundamental study on bubble behavior indicated that it was possible to control the boiling process of magnetic nanofluid by external magnetic field. Lee et al. [22] studied the effects of nanoparticles on the CHF enhancement using a Ni-Cr wire in pool boiling. It indicated that the CHF of Fe₃O₄/water nanofluid showed the highest value compared with Al₂O₃ and TiO₂ nanofluids. The Biot-Savart law was applied to analyze the effects of magnetic field induced by electrical current on CHF. They speculated that more Fe₃O₄ nanoparticles would deposit on the wire and the local concentration could be changed by the effect of magnetic field. Khoshmehr et al. [23] tested the quenching process of Fe₃O₄/water nanofluid with the implementation of magnetic field. The directional movement of nanoparticles in nanofluid was validated by Particle Image Velocimetry technique, which could provide supporting evidence for the assumption proposed by Lee et al. [22].

There were relatively few studies available on the effect of magnetic field on boiling heat transfer of nanofluid [20,24,25,26,27]. Liu et al. [24] placed a ring permanent magnet at the bottom of boiling vessel to investigate the mechanism of boiling heat transfer enhancement of water-based magnetic fluid with and without magnetic field. They explained the enhancement on boiling heat

^{*} Corresponding author.

E-mail address: wentaoji@xjtu.edu.cn (W.-T. Ji).

Nomenclature

List of symbols

B	magnetic flux density, T (1 T = 10^4 G)
c_p	specific heat capacity, J/kg·K
C_{wl}	an empirical constant in Rohsenow correlation [32]
F_m	magnetic force, N
g	gravitational acceleration, m/s ²
h	heat transfer coefficient, W/m ² ·K
H	magnetic field intensity, A/m
M	magnetization, A/m
p	pressure, Pa
Pr	Prandtl number
q	heat flux, W/m ²
r	Latent heat, J/kg
Ra	average roughness of heat surface, μ m
s	an empirical constant in Rohsenow correlation [32]
T	temperature, °C
ΔT	superheat temperature
x	distance, m

Greek alphabet

η	dynamic viscosity, Pa·s
λ	thermal conductivity, W/m·K
μ	vacuum permeability
ρ	density, kg/m ³
σ	surface tension, N/m
ϕ	heat loss rate
χ	volume susceptibility

Subscript

l	liquid
n	nanoparticle
sat	saturation
v	vapor
w	wall

transfer coefficient by analyzing the magnetic levitation force acting on a single bubble. Sesen et al. [25] studied the pool boiling of Fe₃O₄/water nanofluid with the magnetic field provided by magnetic stirrers. An enhancement on boiling heat transfer coefficient of 17% was achieved by magnetic actuation, they reported that the magnetic field intensified the circulations and mixing in nanofluid. Abdollahi et al. [20] investigated the influence of magnetic field induced by two magnets on Fe₃O₄/water nanofluid, they found that the diminution or increment of boiling heat transfer coefficient was dependent on the simultaneous effect of magnetic field on both the base fluid and the nanoparticles. The effect of magnetic field on the base fluid was due to the magnetic body force on the bubbles, the direction of which was opposite to that of magnetic field gradient. Shojaeian et al. [26] studied the pool boiling of Fe₃O₄ nanofluids under a rotating magnetic field. It was reported that the magnetic actuation could prevent the sedimentation of nanoparticles and assist the circulation of magnetic nanoparticles in nanofluids. Ozdemir et al. [27] investigated the pool boiling of Fe₃O₄ nanofluids with magnetic actuation experimentally. They found that the magnetic actuation could enhance the boiling heat transfer significantly. In addition, it was reported that the effect of concentration was insignificant when the magnetic actuation was adopted.

Although many researchers have mentioned the effects of magnetic field on pool boiling of magnetic fluids, it is still far from being adequate to the facts. Especially when a magnetic field exists, the effect of nanoparticle concentration on boiling heat transfer needs further research. In addition, many magnetic nanofluids used in previous research contain surfactant or the nanoparticles are coated with other materials, it will change the force between nanoparticles and make the analysis more complicated. Considering that the Fe₃O₄ nanoparticle was highly susceptible to oxidation when exposed to atmosphere [28], α -Fe₂O₃ and γ -Fe₂O₃/water nanofluids with rather low concentrations were used to investigate the effects of magnetic field on pool boiling heat transfer. The joint effect of external magnetic field and nanoparticles on pool boiling was analyzed. Moreover, the study evaluated the feasibility of controlling the pool boiling process of magnetic nanofluids by external magnetic field.

2. Experimental apparatus and procedure

2.1. Experimental setup

A schematic diagram of the pool boiling test setup is shown in Fig. 1. The setup consisted of four main parts. It includes boiling

Table 1
Summary of the pool boiling experiments on magnetic nanofluids.

Reference (year)	Heating surface	Nanofluids and concentration	Nanoparticle size	Results of boiling heat transfer coefficient
Stutz et al. [17]	100 μ m diameter platinum wire	γ -Fe ₂ O ₃ /water 0.1 wt%	10 nm	Deterioration or enhancement based on coating duration
Sheikhhbahai et al. [18]	Ni-Cr wire	Fe ₃ O ₄ /EG-water 0.01–0.1 vol%	50 nm	Deterioration
Souza et al. [13]	Copper disc of 12mm diameter	γ -Fe ₂ O ₃ /HFE7100 0.29 g/L	10, 80 nm	Deterioration or enhancement based on nanoparticle size
Salari et al. [19]	Copper disc of 11 mm diameter	Fe ₃ O ₄ /water 0.1–0.3 wt%	20 nm	Enhancement
Kiyomura et al. [14]	Copper block of 20 mm diameter	γ -Fe ₂ O ₃ /water 0.029, 0.29 g/L	10 nm	Deterioration or enhancement based on surface roughness and concentration
Abdollahi et al. [20]	Copper block of 45 mm diameter	Fe ₃ O ₄ /water 0.01–0.4 vol%	25 nm	Enhanced at low concentration, deteriorated at high concentration
Salimpour et al. [15]	Copper block of 45 mm diameter	Fe ₃ O ₄ /water 0.5 vol%	25 nm	Deterioration or enhancement based on surface roughness and heat flux

Download English Version:

<https://daneshyari.com/en/article/10139958>

Download Persian Version:

<https://daneshyari.com/article/10139958>

[Daneshyari.com](https://daneshyari.com)