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Measurement and correlation of frictional pressure drop of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube

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ABSTRACT

The objective of this paper is to investigate the effect of nanoparticle on the frictional pressure drop characteristics of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube, and to present a correlation for predicting the frictional pressure drop of refrigerant-based nanofluid. R113 refrigerant and CuO nanoparticle were used for preparing refrigerant-based nanofluid. Experimental conditions include mass fluxes from 100 to 200 $kg\,m^{-2}\,s^{-1}$, heat fluxes from 3.08 to 6.16 $kW\,m^{-2}$, inlet vapor qualities from 0.2 to 0.7, and mass fractions of nanoparticles from 0 to 0.5 wt%. The experimental results show that the frictional pressured drop of refrigerant-based nanofluid increases with the increase of the mass fraction of nanoparticles, and the maximum enhancement of frictional pressure drop is 20.8% under above conditions. A frictional pressure drop correlation for refrigerant-based nanofluid is proposed, and the predictions agree with 92% of the experimental data within the deviation of ±15%.

Chute de pression due au frottement d'un nanofluide fondé sur un frigorigène en ébullition en écoulement à l'intérieur d'un tube lisse horizontal : mesures et corrélation

Mots clés : Échangeur de chaleur ; Tube lisse ; Tube horizontal ; Expérimentation ; Mesure ; Coefficient ; Frottement ; Écoulement ; Ébullition ; Frigorigène ; Additif ; Particule

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Nomenclature

d	diameter of nanoparticle (m)
D	diameter of tube (m)
F_{PD}	nanoparticle impact factor
G	mass flux (kg m^{-2} s^{-1})
m	mass flow rate (kg s^{-1})
P	pressure (Pa)
ΔP	pressure drop (Pa)
q	heat flux (W m^{-2})
T	temperature (°C)
x	vapor quality

Greek symbols

ϵ	void fraction
ρ	density (kg m^{-3})
σ	surface tension (N m^{-1})
φ	volume fraction of nanoparticles
ω	mass fraction of nanoparticles

Subscripts

frict	frictional
i	inside
L	liquid
mom	momentum
n	nanoparticles
r	refrigerant
static	static
total	total
V	vapor

1. Introduction

In recent years, refrigerant-based nanofluids formed by suspending nanoparticles in pure refrigerants have been used as a new kind of working fluid to improve the performance of refrigeration systems (Wang et al., 2003, 2007; Bi et al., 2008). The presence of nanoparticles may have effects on the pressure drop characteristics of refrigerants flow boiling inside tubes, and then have impacts on the overall performance of the heat exchangers of refrigeration systems. Therefore, the pressure drop characteristics of refrigerant-based nanofluids must be known for the design and optimization of the heat exchangers in refrigeration systems using refrigerant-based nanofluids.

The researches on the pressure drop characteristics of nanofluids can be divided into two categories. One is to investigate the single-phase pressure drop characteristics of nanofluids, and the other is to investigate the phase-change pressure drop characteristics of nanofluids.

For the single-phase pressure drop characteristics of nanofluids, experimental studies (Chein and Chuang, 2007; He et al., 2007; Lee and Mudawar, 2007) and simulation study (Li and Kleinstreuer, 2008) have been reported in literatures. Experiments on the single-phase pressure drop of CuO/H_2O nanofluid in micro-channel heat sink showed that the presence of nanoparticle causes a slight increase in pressure drop (Chein and Chuang, 2007). Experiments on the single-phase pressure drop of TiO_2/H_2O nanofluid flowing upward through a vertical pipe showed that the pressure drop of nanofluid is a little larger than that of the host fluid at a given Reynolds number (He et al., 2007). Experiments on the single-phase pressure drop of Al_2O_3/H_2O nanofluid in micro-channel showed that the pressure drop of nanofluid is larger than that of the host fluid, and increases with the increase of nanoparticle concentration at the same Reynolds number (Lee and Mudawar, 2007). Li and Kleinstreuer (2008) simulated the fully developed pressure gradient of CuO/H_2O nanofluid flow inside micro-channels. The simulation results show that: (i) comparing to the host fluid at a given Reynolds number, the pressure gradient enhancements are less than 2% and 5% at nanoparticle volume fractions of 1% and 4%, respectively; (ii) comparing to the host fluid at a given mean velocity, the pressure gradient enhancements are less than 5% and 15% at nanoparticle volume fractions of 1% and 4%, respectively. All these researches show that the single-phase pressure drop of nanofluid is larger than that of the host fluid, and the enhancement of the pressure drop is related to the nanoparticle concentration.

Comparing to the researches on the single-phase pressure drop characteristics of nanofluids, there are much fewer researches on the phase-change pressure drop characteristics of nanofluids. A literature survey shows that the phase-change pressure drop of nanofluid is mentioned only by the paper of Bartelt et al. (2008). In the paper, the authors found that the presence of nanoparticle has an insignificant effect on the pressure drop of refrigerant/nanolubricant mixture (R-134a/POE/CuO nanofluid) flow boiling inside a horizontal tube, but no experimental data of the pressure drop were provided. The reason for such insignificant effect might be that the presence of lubricant oil can significantly enhance the pressure drop of refrigerant flow boiling inside tube (Zurcher et al., 1997; Hu et al., 2008) and conceal the effect of nanoparticle on the pressure drop. A definite conclusion of the nanoparticle effect on the pressure drop characteristics of nanofluid may not be obtained by the only report on the pressure drop characteristics of refrigerant/nanolubricant mixture (Bartelt et al., 2008), and more experiments on the effect of nanoparticle on the phase-change pressure drop of nanofluid are needed.

The purpose of this study is to investigate the frictional pressure drop characteristics of refrigerant-based nanofluid flow boiling inside a smooth tube at different nanoparticle concentrations, mass fluxes, heat fluxes and inlet vapor qualities, to analyze the effect of nanoparticle on the frictional pressure drop characteristics of refrigerant-based nanofluid, and to present a correlation for predicting the frictional pressure drop of refrigerant-based nanofluid flow boiling inside the smooth tube.