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Flow boiling heat transfer characteristics of nano-refrigerants in a horizontal tube

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ABSTRACT

The flow boiling heat transfer characteristics of four nano-refrigerants with different mass fractions, qualities, and mass velocities in a horizontal tube were studied. The nano-refrigerants were Cu-R141b, Al-R141b, Al_2O_3-R141b, and CuO-R141b. The nanoparticle mass fractions were 0.1 wt%, 0.2 wt%, and 0.3 wt%; the quality ranged within 0.3–0.8; and the mass velocities were 120, 210, and 330 kg m^{-2} s^{-1}. Results showed that the flow boiling heat transfer was enhanced by nanoparticle addition. The heat transfer coefficient of the nano-refrigerant increased with increased mass fraction, quality, and mass velocity. The mass fraction of nanoparticles was the main factor that influenced the heat transfer coefficient. The heat transfer enhancement effects of the different nano-refrigerants differed, with the highest enhancement achieved using Cu-R141b. At $G = 120$ kg m^{-2} s^{-1} and 0.3 wt% mass fraction, the maximum heat transfer coefficient of Cu-R141b increased by 49% (average increase = 27%).

Caractéristiques du transfert de chaleur d'écoulement en ébullition de nano-frigorigènes dans un tube horizontal

Mots clés : Nano-frigorigènes ; Amélioration du transfert de chaleur ; écoulement en ébullition

1. Introduction

According to the Maxwell theory, adding metals, metal oxides, or other solid particles into a liquid can improve the heat transfer coefficient. However, millimeter- or micro meter-sized particles easily precipitate in a liquid, leading to clogging in pipes. In 1995, Choi of the U.S. Argonne National Laboratory proposed the concept of nanofluids (Choi, 1995). He prepared nanofluids by adding nanoparticles to a liquid, and found that the nanoparticles can significantly increase the thermal conductivity of the fluid. Recent research on nanofluids (Masuda et al., 1993; Lee et al., 1999; Putra et al., 2003; Li and Peterson, 2007; Suresh et al., 2012) has shown that adding appropriate volume fractions of nanoparticles can significantly increase the thermal conductivity of a fluid.

Based on the concept of nanofluids, the concept of nano-refrigerants has been proposed. Studies on nano-refri gerants (Kedzierski and Gongb, 2009; Trisaksri and Wongwises, 2009; Kedzierski, 2011; Peng et al., 2011) have

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Nomenclature

q_w	heat flux (W m^{-2})
t_{wi}	inner surface temperature (°C)
t_f	fluid temperature (°C)
t_{in}	inlet temperature (°C)
t_{out}	outlet temperature (°C)
G	mass velocities (kg m^{-2} s^{-1})
x	quality Bo boiling number
k_l	thermal conductivity of liquid (W m^{-1} °C^{-1})
t_{wo}	outer surface temperature (°C)
d_{out}	outer diameter (mm)
d_{in}	inner diameter (mm)
Λ	thermal conductivity of copper (W m^{-2} K^{-1})
L	length of test section (mm)
U	voltage (V)
I	current (A)
Q	heating capacity (W)
P	inlet pressure of preheating section (kPa)
p_c	critical pressure of R141b (MPa)
p_{in}	inlet pressure of test section (kPa)
Pr_l	Prandtl number of liquid
F_{ht}	influencing factors of nanoparticles
H	enthalpy (J)
M	molar mass (g mol^{-1})

Subscripts

in	inlet of test section
out	outlet of test section
pre in	inlet of preheating section
pre out	ontlet of preheating section
test	test section
pre	preheating section

shown that adding nanoparticles to refrigerants can improve the heat transfer coefficient of the base fluid. Simultaneously, energy conservation and emission reduction are achieved.

In this study, Cu, Al, Al_2O_3, and CuO nanoparticles were separately added to a refrigerant at 0.1 wt%, 0.2 wt%, and 0.3 wt% mass fractions. Then, boiling heat transfer tests were performed by simulating evaporation in a horizontal tube. The heat transfer performances of the nano-refrigerants were then compared. Cu, Al, Al_2O_3, and CuO nanoparticles (average particle diameter = 40 nm, purity = 99%) were supplied by Xuzhou Hongwu Nano Materials Co., Ltd. Given that the Montreal Protocol requires the use of CFC-type and HCFC-type working fluids to be eventually terminated, alternatives to CFC refrigerants need to be identified. HCFC141b had an ozone depression potential of 0.089, global warming potential of 0.15, and boiling point (1 atm) of 32.05 °C. In the experiment, nanoparticles were mixed with refrigerants under normal pressure and temperature; thus, R141b was selected.

2. Experimental apparatus and process

2.1. Experimental apparatus

Fig. 1 shows the experimental system, including the main circuit, bypass circuit, cooling water circuits, data acquisition systems, high-speed photographic camera, and nano-refrigerant filling apparatus.

The main circuit includes the preheating, test, and cooling sections. The copper tube specifications were as follows: inner diameter, 10 mm; wall thickness, 1 mm; length of preheating section, 500 mm; and length of test section, 1400 mm. To eliminate entrance effects, a 300 mm-long settling chamber was placed before the preheating section.

The nano-refrigerant filling apparatus was connected with the main circuit through the shut-off valve. The nano-refrigerant passed through the filling apparatus into the experimental system. A magnetic circulation pump was used to provide power so that the nano-refrigerant can pass

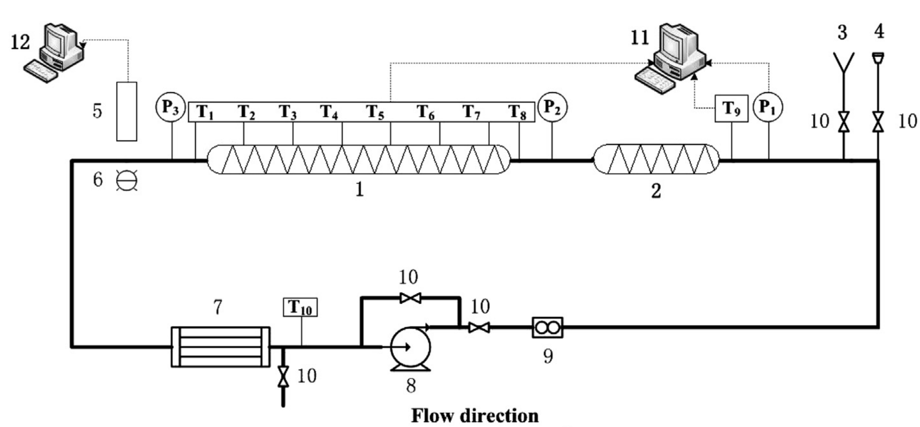

Fig. 1 – Schematic of the experimental system: 1 – test section, 2 – preheating section, 3 – filling apparatus, 4 – exhaust unit, 5 – high-speed camera, 6 – light, 7 – cooler, 8 – magnetic drive pump, 9 – turbine flow transmitter, 10 – valve, 11 – data acquisition system, 12 – computer. T_1–T_{10} are temperature transmitters. P_1–P_3 are pressure transmitters.