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Pool boiling heat transfer characteristics of refrigerant-nanoparticle mixtures☆

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ABSTRACT

The main focus of the present study is to investigate the pool boiling heat transfer characteristics of nanofluids on the cylindrical surface. The nanofluids with suspending TiO_2 nanoparticles in the base fluid refrigerant R141b and ethyl alcohol are used as working fluids. Effects of nanoparticle concentration and boiling pressure on the pool boiling heat transfer coefficient on the cylindrical brass surface and the boiling bubble characteristics are considered. It is found that the nanoparticle concentration and boiling pressure have a significant effect on the pool boiling heat transfer coefficient. In addition, the pool boiling heat transfer coefficients obtained from the experiment are compared with the proposed correlation and reasonable agreement is obtained.

1. Introduction

Fluids are essential for heat transfer processes in many engineering devices. Although various techniques are applied to enhance the heat transfer, the low heat transfer performance of these conventional fluids obstructs the heat transfer enhancement and the heat exchanger compactness. The passive heat transfer enhancement can be done by changing flow geometry, boundary conditions or by improving thermophysical properties for example, increasing fluid thermal conductivity. One way to enhance fluid thermal conductivity of the base fluid is by adding small solid particles. Firstly, the particles with micrometer or millimeter dimensions were used in the solid–liquid mixture. However, they were many problems such as high pressure drop, abrasion, clogging and poor suspension stability. Nowadays, in advance technology, the nanometer-size particles have been made to overcome these problems as mentioned above. The suspending nanoparticle in the base fluid is called "nanofluid". Due to the suspending nanoparticle, the transport and thermal properties of the base fluid are changed. Liu et al. [1,2] experimentally studied the nucleate boiling heat transfer of water–CuO, alcohol-CuO nanoparticles in a miniature flat heat pipe with micro-grooves. Coursey and Kim [3] studied the increasing critical heat flux of nanofluid. Lotfi and Shafii [4] investigated the transient boiling heat transfer characteristics of nanofluids. Peng et al. [5–9] investigated the influence of nanoparticles on the flow boiling heat transfer characteristics of the nanofluid inside a horizontal smooth tube. Trisaksri and Wongwises [10] considered the nucleate pool boiling heat transfer of the nanofluids. The refrigerant R141b with different TiO_2 nanoparticle concentrations were tested. Ahn et al. [11,12] investigated the enhancements of the nucleate boiling heat transfer of nanofluids in a rectangular flow channel. Boudouh et al. [13] experimentally studied the convective boiling heat transfer of nanofluids in a copper plate multichannel. Ontiveros et al. [14] investigated the effects of the nanoparticle concentration on the boiling heat transfer. Kwark et al. [15] investigated the pool boiling behavior of low concentration nanofluids over a flat heater at 1 atm. Henderson et al. [16] considered the flow-boiling of R-134a and R-134a/polyolester mixtures. Soltani et al. [17] reported the investigation of pool boiling heat transfer of Al_2O_3/CMC non-Newtonian nanofluids. Yang and Liu [18] experimentally studied the pool boiling heat transfer characteristics of the nanofluid at atmospheric and sub-atmospheric pressures. Kim et al. [19] described the flow boiling heat transfer of Al_2O_3 nanofluid in the plain tube. White et al. [20] studied the electrophoretic deposition of nanoparticles on boiling performance. Nayak et al. [21] studied the transient and stability behavior of a boiling two-phase. Huang et al. [22] considered the boiling heat transfer enhancement by using coated TiO_2 nanoparticle on the nickel wires with various nanofluid concentrations. Heris [23] experimentally investigated the pool boiling heat transfer characteristics of CuO/ethylene glycol–water nanofluids. Bolukbasi and Ciloglu [24] studied the pool boiling heat transfer characteristics of SiO_2–water nanofluids of vertical cylinder. Wen et al. [25] studied the nucleate boiling heat transfer with alumina nanofluids on two designed surfaces. Sheikhbahai et al. [26] considered the nucleate boiling and critical heat flux of Fe_3O_4/ethylene glycol–water nanofluid on a horizontal thin Ni–Cr wire. Xu and Xu [27] investigated the flow boiling heat transfer in a single microchannel of pure water and nanofluid. Okawa et al. [28,36] carried out to explore boiling heat transfer of nanofluid drops onto a hot stainless steel plate. Yang and Liu [29] studied the flow boiling heat transfer in the evaporator of a loop thermosyphon operating with CuO based aqueous nanofluids. Park et al. [30] studied the pool boiling critical heat flux enhancement by graphene-oxide nanofluid. Aminfar et al. [31]

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numerically investigated the nucleate pool boiling on the horizontal surface for nano-fluid using wall heat flux. Mitra et al. [32] studied the boiling jet heat transfer of TiO_2 nanofluids. Lee et al. [33] described the effects of a magnetite-water nanofluid on the critical heat flux enhancement using an Ni–Cr wire in pool boiling. Kole and Dey [34,35] investigated the variation of thermophysical and pool boiling characteristics of ZnO-ethylene glycol nanofluids. Jung et al. [37] measured the critical heat flux and boiling heat transfer coefficient of water-based Al_2O_3 nanofluids. Ahmed and Hamed [38] experimentally investigated the pool boiling heat transfer coefficient of nanofluid at various concentrations. Lee et al. [39] studied effect of magnetic on the flow boiling critical heat flux characteristics of nanofluid. Abedini et al. [40] numerically investigated the subcooled flow boiling of water and Al_2O_3 nanofluids. Vazquez and Kumar [41] studied the effects of ribbon heaters surface on the pool boiling critical heat flux of nanofluid. Mourgues et al. [42] observed the boiling behaviors and critical heat flux on a horizontal and vertical plate in saturated pool boiling of ZnO nanofluids. Shoghl and Bahrami [43] investigated effect of the surfactant on the pool boiling heat transfer coefficient of ZnO, and CuO water-based nanofluids. Raveshi et al. [44] experimentally investigated the pool boiling heat transfer enhancement of alumina–water–ethylene glycol nanofluids. Cheng and Liu [45] observed the boiling and two-phase flow phenomena of refrigerant-based nanofluids. Ganapathy and Sajith [46] applied the semi-analytical model for predicting the pool boiling characteristics of nanofluids.

As mentioned above, there are many papers presented on the boiling heat transfer characteristics. However, the research on the pool boiling of refrigerant-based nanofluids is little in the literature. In addition, many controversies exist with numerous conflicting experimental results and trends. Therefore, its mechanisms should be further investigated. The inconsistencies between different studies should be clarified. Therefore, the purpose of this study is to present the pool boiling heat transfer characteristics on the cylinder surface of refrigerant-based nanofluids.

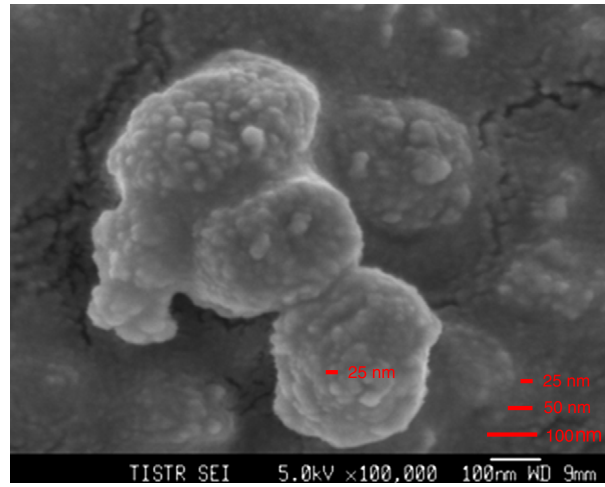

Fig. 2. Photograph of TiO_2 nanoparticles.

2. Experimental apparatus and method

2.1. Test loop

A schematic diagram of the experimental apparatus is shown in Fig. 1. The test loop consists of a set of main test pool, water cooling loop and data acquisition system. The main test pool consists of a 80 mm internal diameter, 300 mm high Pyrex glass vessel and a 10 mm thick Bakelite cover. The brass cylindrical heater is used as boiling surface with a diameter and length of 12.7, 42 mm, respectively. The maximum permitted surface temperature of the brass

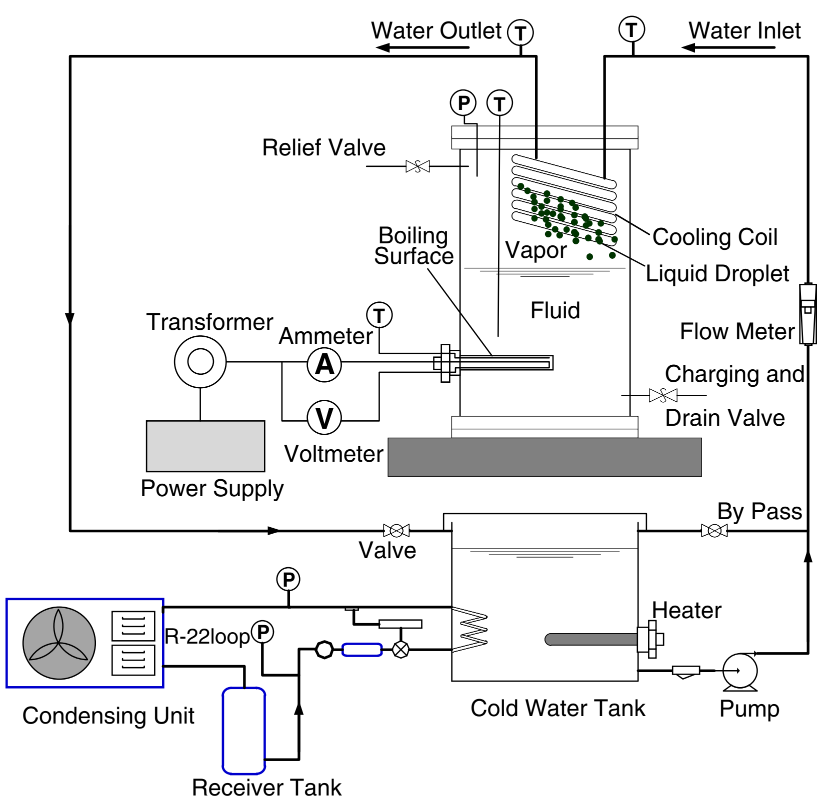

Fig. 1. Schematic diagram of experimental apparatus.