Sorption and agglutination phenomenon of nanofluids on a plain heating surface during pool boiling

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Abstract

The pool nucleate boiling heat transfer experiments of water (H_2O) based and alcohol (C_2H_5OH) based nanofluids and nanoparticles-suspensions on the plain heated copper surface were carried out. The study was focused on the sorption and agglutination phenomenon of nanofluids on a heated surface. The nanofluids consisted of the base liquid, the nanoparticles and the surfactant. The nanoparticles-suspensions consisted of the base liquid and nanoparticles. The both liquids of water and alcohol and both nanoparticles of CuO and SiO_2 were used. The surfactant was sodium dodecyl benzene sulphate (SDBS). The experimental results show that for nanofluids, the agglutination phenomenon occurred on the heated surface when the wall temperature was over 112 °C and steady nucleated boiling experiment could not be carried out. The reason was that an unsteady porous agglutination layer was formed on the heated surface. However, for nanoparticles-suspensions, no agglutination phenomenon occurred on the heating surface and the steady boiling could be carried out in the whole nucleate boiling region. For the both of alcohol based nanofluids and nano-suspensions, no agglutination phenomenon occurred on the heating surface and steady nucleate boiling experiment could be carried out in the whole nucleate boiling region whose wall temperature did not exceed 112 °C. The boiling heat transfer characteristics of the nanofluids and nanoparticles-suspensions are somewhat poor compared with that of the base fluids, since the decrease of the active nucleate cavities on the heating surface with a very thin nanoparticles sorption layer. The very thin nanoparticles sorption layer also caused a decrease in the solid–liquid contact angle on the heating surface which leaded to an increase of the critical heat flux (CHF).
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1. Introduction

Nanofluid technology has emerged as a new enhanced heat transfer technique in recent years. Choi [1] firstly proposed the concept of ''nanofluid'', which is actually nanoparticles-suspension. A number of studies have been carried out to understand and describe the larruping behaviors of nanofluid, such as its effective thermal conductivity under the static conditions [2–6], the convective heat transfer associated with fluid flow and transfer phenomena [7–14] and phase-change heat transfer [15–20]. Most investigations indicated that the addition of nanoparticles could greatly increase the effective thermal conductivity with increasing the nanoparticles concentration. Therefore, so far, the studies concerning nanofluids focused mainly on the single phase convective heat transfer of nanofluids flowing in tubes to enhance the forced convective heat transfer by use of the increased thermal conductivity.

Compared with the research effort in thermal conductivity and forced convective heat transfer, relatively few studies have been carried out on pool boiling heat transfer.

Das et al. [15] conducted an investigation on the pool boiling of water–Al_2O_3 nanoparticles-suspension on horizontal tubular heater having diameter of 20 mm with different surface roughness at atmospheric pressure. The heat flux ranged from 2×10^4 W/m^2 to 1.2×10^5 W/m^2. No surfactant was added into suspensions. It was found that the nanoparticles-suspensions have poor heat transfer compared with pure water. Surface roughness could also

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Nomenclature

$c_{p,1}$ specific heat (J/kg K)
D diameter of heat transfer surface (m)
h heat transfer coefficient, (W/K m^2)
h_{fg} latent heat of evaporation (J/kg)
p pressure (Pa)
q_w wall hat flux (W/m^2)
$q_{c,0}$ CHF of saturated water (W/m^2)
Ra mean roughness, $\mathrm{Ra} = \frac{1}{L}\int_0^L |Z(x)|\,\mathrm{d}x$
Rq standard roughness, $\mathrm{Rq} = \sqrt{\frac{1}{L}\int_0^L Z(x)^2\,\mathrm{d}x}$
x axial position (m)
Z orthogonal position (m)
ΔT_{sat} wall superheat (K)

Greek symbols
λ thermal conductivity (q/m^2 K)
v kinematics viscosity (m^2/s)
σ surface tension (N/m)
ρ density (kg/m^3)

Subscripts
l liquid
v vapor

greatly affect the nucleation superheat. The required superheat for a smooth surface was usually higher than that for a rough surface. When the volume concentration of nanoparticles was higher than 0.1%, the effect was well-regulated in their experimental conditions, and the superheat for high concentration nanoparticles-suspensions was higher than that for low concentration nanoparticles-suspensions at a specified heat flux. The subsidence of nanoparticles was considered as the main reason for the increase of superheat.

Vassallo et al. [16] carried out a pool experiment of silica–water nanoparticles-suspensions on a horizontal NiCr wire at atmospheric pressure. No surfactant was added into suspensions. An increase in critical heat flux (CHF) was observed compared with pure water. But, no appreciable differences in the boiling heat transfer were found for the heat flux less than the CHF.

Bang and Cheng [17] conducted an investigation on the pool boiling of water–Al$_2$O$_3$ nanoparticles-suspensions on a plain heated plate at atmospheric pressure. The test surface is a 4×100 mm^2 rectangle with a depth of 1.9 mm. As the cases of the two studies above mentioned, no surfactant was added into suspensions in their experiment. It was found that the boiling heat transfer characteristics of the nanoparticles-suspensions were poor compared with pure water in nucleate boiling region. For the horizontal test surface, however, the CHF increased 32% compared with the pure water case. These were related to a change of the surface characteristics by the deposition of nanoparticles on the heating surface.

You et al. [19] carried out an investigation on the CHF of water–Al$_2$O$_3$ nanoparticles-suspensions in a pool boiling experiment with a flat square heater at the pressure of 2.89 Psia ($T_{\mathrm{sat}} = 60$ °C). The experimental results demonstrated that the CHF increases dramatically two times compared with pure water. However, the nucleate boiling heat transfer coefficients appeared to be about the same.

The above review of literature indicates that relatively few studies have been reported on the pool boiling of nanoparticles-suspensions or nanofluids on a plate surface and

there exist some deficiencies in these studies. Firstly, in the most of the experiments, no surfactant was added into the suspensions. In fact, these kinds of suspensions have poor stability and uniformity because of great aggregate structures. These kinds of suspensions cannot be applied for actual engineering. Secondly, even in these few studies, there are some controversial results for boiling heat transfer and the CHF. Thirdly, the kinds of nanofluids used in the literature are few. Fourthly, although the most researchers guessed that the changes of the heating surface characteristics were main reasons which affected the boiling heat transfer of nanofluids, no visual microphotographs on the surface characteristics were shown to support their guesswork.

In order to understand the boiling heat transfer characteristics of nanofluids more extensively, the poor boiling behavior of both nanofluids and nano-suspensions are studied on a horizontal flat surface. The key objective of this experiment is to understand the sorption and agglutination phenomenon of nanofluids and nanoparticles-suspensions and their effects on pool boiling heat transfer. The visual microphotographs on the surface characteristics were shown to recover the mechanism of the boiling heat transfer of the nanofluids on a flat heating surface.

2. Experimental apparatus and procedures

Fig. 1 shows the schematic diagram of the experimental apparatus. The apparatus mainly consisted of a main vessel, an outer isothermal vessel, a heated copper block, an electronic supply and a digital data connecting system. The main vessel made of stainless steel had a diameter of 250 mm and a height of 400 mm. The upper part of the main vessel was a water tank to contain the working liquid and the lower part of the vessel was a closed heating box to mount the heater component. The heater component was a vertical copper bar having 80 mm diameter and 120 mm height. The copper bar was inserted into a vertical Teflon bar and the Teflon bar was mounted in the heating box. The space inside the outer isothermal vessel was filled by