Investigation of liquid-gas surface tension and boiling bubble size of alumina nanofluids

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Abstract

Boiling occurs in various engineering applications including nuclear power plants, chemical reactors, electronic devices, and heat exchangers of HVAC (heating, ventilation, and air conditioning) systems for an effective heat transfer method. Therefore, the enhancement of boiling heat transfer have been widely investigated. In order to improve heat transfer performance, the heat transfer using nanofluids which are liquid suspensions containing nanoparticles have been extensively studied. In nucleate boiling, the heat transfer is strongly affected by the size of vapor bubble. In addition, the surface tension is one of the most important properties on the determination of created bubble size. In this study, surface tension and boiling bubble size of pure water and aqueous nanofluids containing Al_2O_3 nanoparticles are compared. The gas–liquid surface tension is obtained by solving the Laplace–Young equation under experimentally measured boundary conditions and droplet parameters. The boiling bubble size is measured using synchrotron X-ray imaging technique. Compared with water, additive of nanoparticles increases both surface tension and size of boiling bubbles.

1 Introduction

Boiling occurs in various engineering applications such as electronic devices, power plants and heat exchangers for an effective heat transfer. Many researches have widely conducted for investigating the enhancement of a boiling heat transfer (Rohsenow, 1951; Salari et al., 2016). To improve the efficiency of the heat transfer, the heat transfer with nanofluids, liquid suspensions containing nanoparticles, have been extensively studied since the work by Choi and Eastman (1995). Boiling heat transfer is a complicated process and it is affected by various parameters including a heating surface characteristic and thermo-physical properties of working fluids such as surface tension.

In general, the nucleate boiling process is strongly related with characteristics of boiling bubbles. The boiling bubble diameter, departure frequency, and bubble growth rate are commonly used for describing bubble behaviors (Pioro et al., 2004). It is known that the surface tension of working fluids significantly influences the boiling bubble diameter and an effect of a nanoparticle addition into base fluids on the surface tension has been also investigated (Vafaei et al., 2009).

Synchrotron X-ray imaging technique has been utilized to measure two-phase bubbly flow characteristics such as void fraction, size and velocity of rising bubbles with high spatial and temporal resolution (Jung et al., 2014). Due to the high coherence of the synchrotron X-ray source, the spatial distributions of the size and velocity of individual microbubbles can be measured with edge enhancement based on the X-ray beam diffraction.

In the present work, the surface tension and the boiling bubble diameter of water and aqueous Al_2O_3 nanofluids were compared. The surface tension was calculated with the Laplace–Young equation and the boiling bubble diameter was measured using synchrotron X-ray imaging technique.

2 Methods

In this study, a two-step method was employed to prepare Al_2O_3 nanofluid solutions as shown in Fig. 1. Al_2O_3 nanofluids were prepared by dispersing 20 % Al_2O_3 nanofluid solutions in 50 mL of deionized water and the ultra-sonication process was performed for preparing the nanofludis. Concentration of Al_2O_3 nanofluid was 0.01 wt% and it was compared with water.
Figure 2 shows the experimental set-up for synchrotron X-ray imaging system. The experiments were conducted at the 6C Biomedical Imaging Beamline (6C BMI) of Pohang Light Source II (PLS-II). The test model was positioned at approximately 30 m downstream from the X-ray source. A CsI scintillator of 450 μm in thickness was utilized as the scintillator crystal. The distance between the scintillator and the test model was fixed at 50 cm. The 500 consecutive X-ray images were recorded with the high-speed camera at 1000 fps for 0.5 s. The diameter of boiling bubbles was obtained by analyzing Fresnel diffraction patterns induced at the liquid and gas interface.

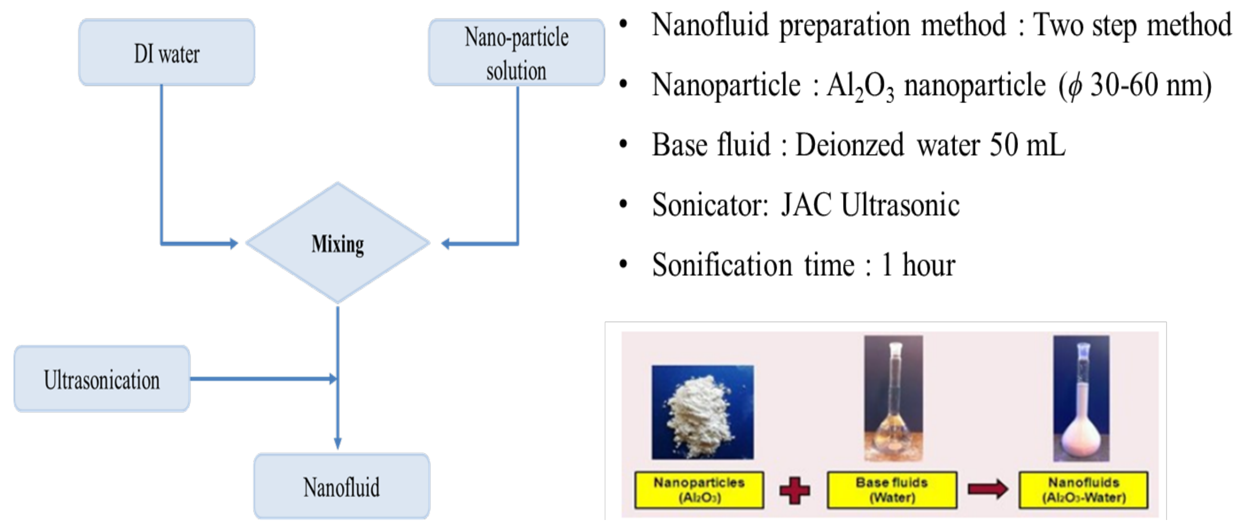

Figure 1 A two-step method for the synthesis of Al_2O_3 nanofluids.

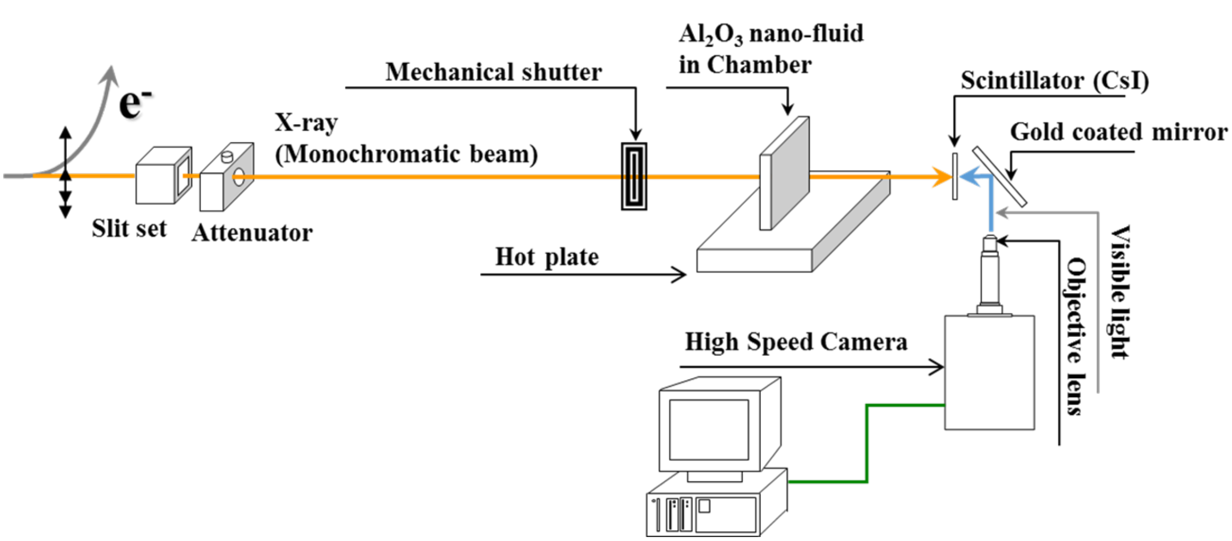

Figure 2 Schematic diagram of synchrotron X-ray imaging experiment set-up

To calculate the gas–liquid surface tension (σ), the Laplace–Young equation with the definition of curvature was solved using measured droplet parameters including the apex location and contact line radius. The equation was solved using the Runge–Kutta method. The gas-liquid surface tension was finally obtained by comparing the calculated profiles of droplets from the Laplace–Young equation with the experimentally measured profiles.

3 Results

The gas-liquid surface tensions of Al_2O_3 nanofluids and water are represented in Fig. 3(a). The result shows that the addition of nanoparticles into water causes the increase of the surface tension. The surface tensions of water and nanofluids are 0.072 and 0.086 N/m, respectively.
Figure 3(b) shows the bubble diameters, and it has a same trend with the surface tension. In general, the departure diameter (D_b) of vapor bubbles for pool boiling process was expressed as following Frits formula (Pioro et al., 2004):

$$D_b \sim \theta \sqrt{\frac{\sigma}{g(\rho - \rho_g)}} \tag{1}$$

where θ is the contact angles, ρ and ρ_g are densities of liquid and gas, respectively. Even though the contact angle is influenced by various parameters, Eq. (1) implies that the bubble diameter is proportional to the surface tension and this represents the same tendency with the present result.

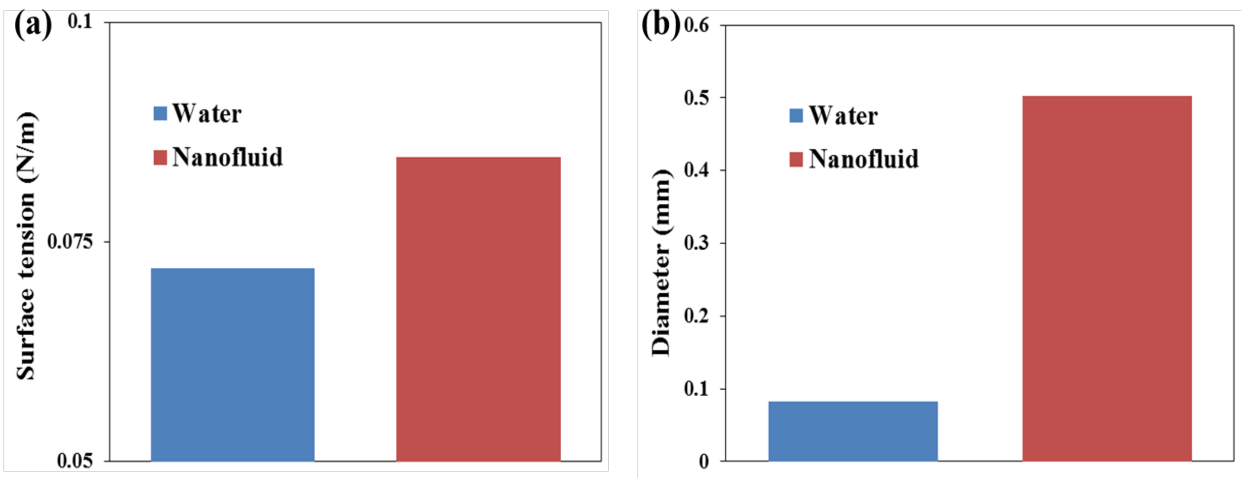

Figure 3 Comparison of (a) the surface tension and (b) the size of boiling bubbles for water and Al_2O_3 nanofluids.

4 Conclusion

The gas-liquid surface tension and vapor bubble diameter of Al_2O_3 nanofluids and water were experimentally compared. The surface tension was calculated by solving the Laplace–Young equation. The diameter of boiling bubbles was measured using synchrotron X-ray imaging. Compared with pure water, the addition of nanoparticles leads to the increase in both surface tension and average bubble size.

Acknowledgements

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