CHF enhancement of a forced convective flow boiling in nanofluid

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1. Introduction

You *et al*. [1] showed that nanofluids containing only 0.005 g/L of Al_2O_3 nanoparticles cause a dramatic increase (on the order of 200%) in the critical heat flux (CFH) during pool boiling. There has been much research effort directed at CHF enhancement using nanofluids. The mechanism of CHF enhancement in nanofluid pool boiling is the result of nanoparticle deposition on the heating surface, which changes the surface characteristics [2–5]. This study focuses on the possible CHF enhancement caused by nanofluids during forced convective flow boiling because of the importance of flow boiling conditions in various practical heat transfer applications. The nanofluid used in this study was a very low concentration of Al_2O_3 (0.01 % vol) dispersed ultrasonically in water.

2. Experimental and discussion

The general consensus of recent studies is that the CHF enhancement in nanofluids under pool boiling conditions is due predominantly to the deposition of nanoparticles on the heater surface. In this regard, the present experimental apparatus was designed to have an ability of investigating the heating surface under the flow boiling condition.

2.1 Preparation of nanofluid

Nanofluid was prepared by two-step method. Dry nano-sized particles (Al_2O_3) were dispersed in ultrasonically pure water (the distilled water) during 3 hours without any additive.

2.2 Experimental Apparatus

Figure 1 shows the experimental forced convective flow boiling apparatus. A detailed explanation of this experimental apparatus has been given by Ahn *et al*. [6], although this specific setup had some differences. The rectangular channel made of transparent strengthened acryl was 10 × 5mm and 1.2m long.[7] A specimen used the boiling surface was prepared for the experiment with a surface roughness of about 400nm(R_a) achieved by polishing. After the test section was set up, working fluids (deionized distilled water or nanofluid) were introduced into the pool chamber by the magnetic pump. Degassing was performed while the bulk temperature was raised to 100°C, and then the pump, heat exchanger, and circulation heater were operated until steady-state conditions were reached. Steady state was defined as the point where the bulk temperature was same as the outlet temperature of the circulation heater (99.5 ± 0.3°C). Once the experiment reached steady state, the main heater was set to power control mode.

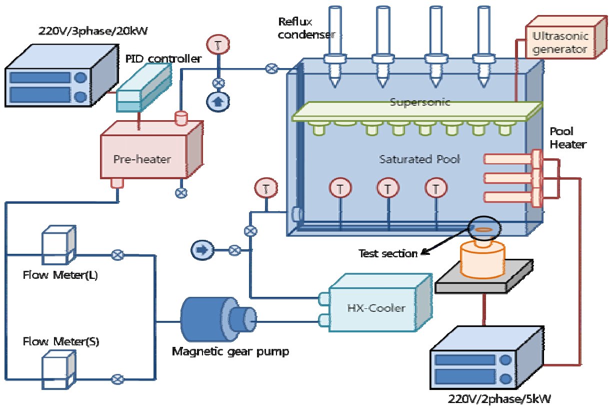

Fig. 1. The flow boiling CHF experimental apparatus

2.3 Flow boiling CHF

Prior to the nanofluid experiment, a set of flow boiling tests was carried out in pure water at the same flow velocity that would be tested with the nanofluid. The tests provided pure water data for comparison, and they were also used to verify the procedure and the repeatability of the experiments. Katto and Kurata [8] described the CHF of saturated convective boiling on uniformly heated plates in a parallel flow. They performed experiments such as changing the short heater size, nozzle size, and flow velocity. They also developed a correlation between the CHF-related short heater length and the mass flux:

$$\frac{q_c}{GH_{fg}} = 0.186\left(\frac{\rho_v}{\rho_l}\right)^{0.559}\left(\frac{\sigma\rho_l}{G^2 l}\right)^{0.264} \qquad (1)$$

Figure 3 shows that the CHF value with the nanofluid increased as the flow velocity increased. The mean value of the CHF in the nanofluid for a given velocity was higher than that in pure water. An explanation of the CHF enhancement in nanofluids under flow boiling conditions requires identification of the enhancement mechanism (e.g., roughness, wettability, or capillary wicking) under pool boiling, because only nucleate boiling was considered in this study.

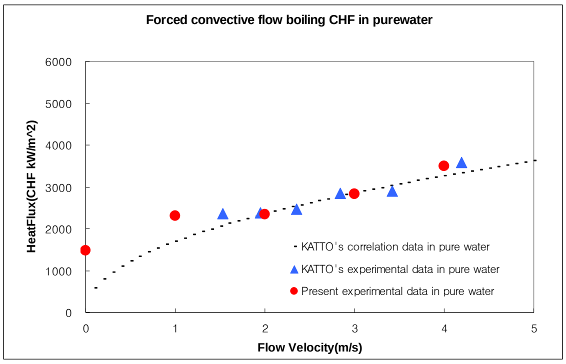

Fig. 2. Experimental CHF data in pure water

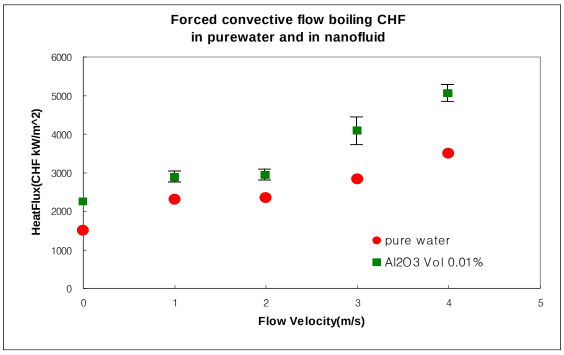

Fig. 3. Experimental CHF data in nanofluid

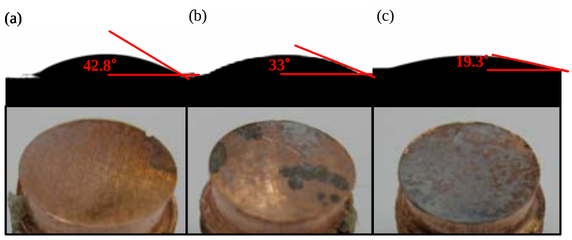

Fig. 4. Contact angle of the nanoparticles fouled surface at a flow velocity 3m/s
(a) : 3638 kW/m^2 (b) : 4147 kW/m^2 (c) : 4435 kW/m^2

2.4 CHF enhancement in nanofluid and wettability

The presence of nanoparticles deposited on the heated surface is a possible cause of the wettability change. Kim *et al.* [5] reported that the surface wettability change caused by nanoparticle deposition should affect the CHF enhancement under pool boiling conditions. The nanoparticle deposition on the heated surface found in this study was corroborated Ahn *et al.* [6] using scanning electron microscopy. Figure 4 shows that the test samples with different amounts of deposition had different contact angles for a fixed flow velocity. The CHF value increased as the contact angle decreased. The different contact angles influenced the CHF enhancement for the same flow velocity in the nanofluid. This shows that the dominant influence of the CHF enhancement in the nanofluid was the surface wettability, a function of the contact angle.

3. Conclusions

An experimental CHF apparatus for testing forced convective flow boiling in pure water and nanofluids was developed and validated. The CHF value increased as the flow increased in pure water; the CHF enhancement was due to the flow velocity. As the flow increased in nanofluid, the CHF value increased more than it did in pure water for the same flow velocity. The CHF enhancement ratio in the low-velocity region was 26%, while it was 43% in the high-velocity region. Since the CHF increased in the nanofluid along with the flow velocity, this could explain the CHF enhancement phenomena using the mechanism of the CHF enhancement under pool boiling. The wettability change of the nanoparticle-fouled surface was confirmed by measuring the contact angle. The change of wettability also was a key influence on the CHF enhancement during forced convective nanofluid flow boiling.

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