Experimental study of the characteristics of pool boiling CHF enhancement using water-based magnetic fluid

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1. Introduction

Nucleate boiling is a very effective heat transfer mechanism. However, there exists a critical value of heat flux at which nucleate boiling transitions to film boiling shows very poor heat transfer behavior. Critical heat flux(CHF) is a main constraint to the design process because it can generate damages or deformations of material. There have been many efforts to improve the CHF by using nanofluids by researchers [1-4]. This paper will describe the effects of magnetic fluid on CHF enhancement of pool boiling. We compared the CHF values of pool boiling experiment between magnetic fluid and other nanofluids with several volume concentrations to evaluate the degree of CHF enhancement. SEM(Scanning Electron Microscope) images were obtained to explain CHF enhancement through the effect of the deposited nanoparticles, which can change the surface wettability, during the pool boiling experiment. Lastly, Finally, in order to investigate the effect of magnetic field in the water-based magnetic fluid, magnetic field was analytically calculated by using Biot-Savart law. Using these results, we discussed the CHF enhancement of magnetite-water nanofluids in detailed.

2. Experimental apparatus and procedure

Fig. 1 shows a schematic of the experimental apparatus. The pool boiling test facility consists of a 250 x 100 x 230 mm rectangular main vessel with visualization windows, a pre-heater, copper electrodes, a thermocouple (K-type) to measure pool temperature, and a condenser. The condenser maintains atmospheric pressure inside the chamber and prevents the loss of vapor from the test vessel. A Ni-Cr wire with a diameter of 0.4mm was used as boiling surface and was heated by resistance heating with a DC power supply. Voltage and current were measured with a National Instruments data acquisition system.

The experiment was performed by gradually increasing the electric power supplied to the wire with a regular pattern. The power was initially increased in large steps and then, near the expected CHF value, the power was increased in small steps. When the expected CHF value was reached, the resistance of the Ni-Cr wire sharply increased and the wire became red-hot or broke suddenly. The CHF was calculated using data obtained right before sharp increase of Ni-Cr wire resistance.

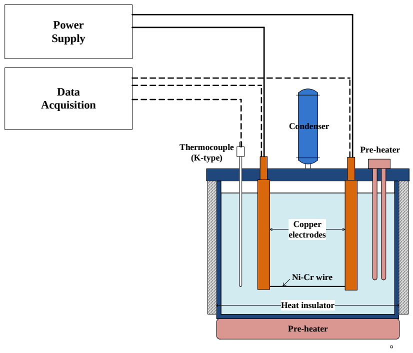


Fig. 1. Schematic of the pool boiling apparatus

3. Experimental results

3.1 Pool boiling CHF

In order to investigate the characteristic of pool boiling CHF enhancement using magnetite-water nanofluid, the pool boiling experiments were performed with pure water as the reference case. Measured CHF average value of pure water was about 5% of the value predicted using Zuber's correlation[5].

Fig. 2 shows the comparison data for pool boiling CHF values with the alumina-, titania-, and magnetite-water nanofluids. The CHF enhancement with magnetite-water nanofluid is higher than the CHF enhancement with alumina-water nanofluid in the range of 1-100ppm volume concentration. The CHF values of magnetite-water nanofluid were increased from about 170% to 240% of the value for pure water with increasing nanoparticle concentration.

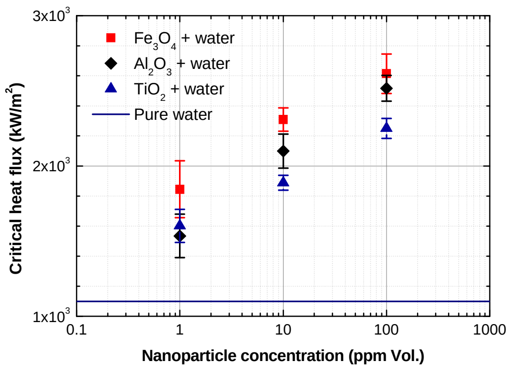
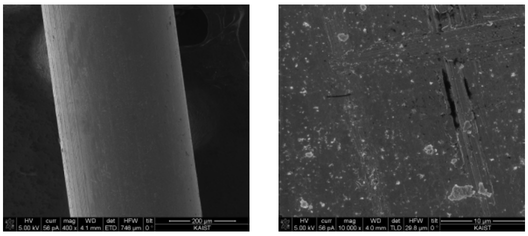


Fig. 2. Comparison of CHF data between mangnetite-water nanofluid and other water-based nanofluids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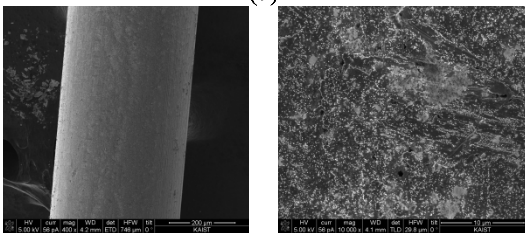
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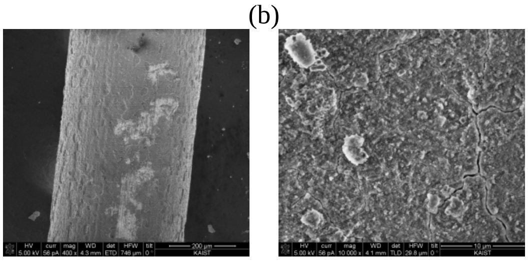
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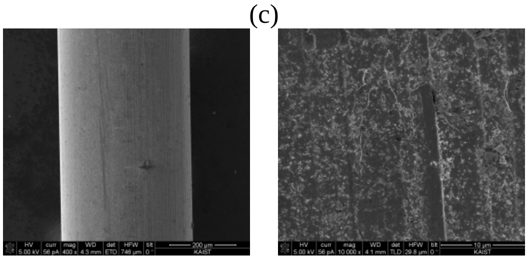
(d)

Fig. 3. SEM images of wire surface after pool boiling (a) Pure water (b) 1ppm of Alumina-water (c) 10ppm of Alumina-water (d) 1ppm of magnetite-water (left $\times 400$, right $\times 1000$)

3.2 SEM

Fig. 3 shows SEM photographs of the Ni-Cr wire surfaces after the pool boiling CHF experiments with alumina-water nanofluid. Considerable amounts of nanoparticles were deposited on the wire. Qualitatively, the higher the concentration of nanoparticles, the larger the amount of nanoparticles was deposited on the wire. The surface wettability and roughness that influences the critical heat flux were changed by the deposited nanoparticles on the wire.

3.3 Effect of magnetic field

Fig. 4. shows analytic solutions using Biot-Savart law for magnetic field which was induced by the current around Ni-Cr wire according to the distance from the center of Ni-Cr wire. As the distance from the wire was decreased, the magnetic field intensity became more-stronger. Because of stronger magnetic field near the wire, magnetite nanoparticles in magnetite-water nanofluids were more congregated. Therefore, it is expected that the magnetite nanoparticles can be deposited on the wire more than other nanoparticles due to more chance to magnetite nanoparticle on the wire and the mechanism of bubble growth can be changed by gathering magnetite nanoparticles around wire. Thus, the degree of CHF enhancement can be also increased due to these effects of magnetic field.

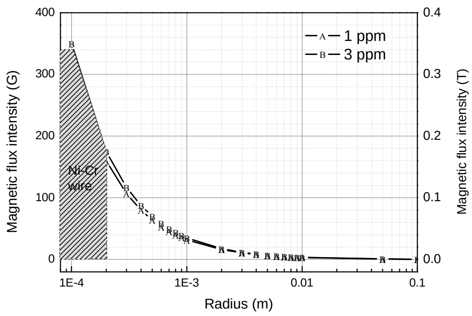

Fig. 4. Analytic calculation results of magnetic field around Ni-Cr wire

4. Conclusions

The main findings of this study are as follows:

(1) Nanofluids with low concentration of alumina, titania and magnetite nanoparticles can significantly enhance the pool boiling CHF.
(2) After pool boiling experiments, considerable amount of nanoparticles were deposited on the wire. Because of this, surface wettability and surface tension, which are related to the important parameter CHF enhancement, are changed.
(3) CHF enhancement with magnetite-water nanofluid is higher than the one with other nanofluids because of the magnetic field effect.

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