Experimental investigation on the CHF enhancement of pool boiling using magnetic fluid

Jong Hyuk Lee, Yong Hoon Jeong *
Dept. of Nuclear and Quantum Eng., Korea Advanced Institute of Science and Technology,
335 Gwahak-ro, Yuseong-gu, Daejeon,305-701, Republic of Korea.
**Corresponding author:yhjeong@kaist.ac.kr*

1. Introduction

One of the key research areas in the cooling systems of nuclear reactors, nuclear fusion reactors, thermal power plants, and others is the removal of high heat flux to guarantee the efficiency, performance, and safety. In the process of removing high heat flux, nucleate boiling is a very effective heat transfer mechanism. However, it is well known that 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].

The objectives of this paper are CHF enhancement by using magnetite-water nanofluid, and to obtain a higher CHF value than general nanofluids. A number of pool boiling experiments were conducted using magnetite-water nanofluids and alumina-water nanofluids with volumetric concentration from 10^{-4} to 10^{-3} % to compare the degree of CHF enhancement. In order to check the effect of the deposited nanoparticles after the pool boiling experiment, SEM images were obtained. Finally, the comparison of CHF enhancement between alumina-water nanofluid and magnetite-water nanofluid was discussed.

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 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.

Two kinds of nanofluids were prepared using magnetite and alumina nanoparticles which were manufactured by Nanostructured & Amorphous Materials Inc. (NanoAmor). A two-step method was used to produce nanofluids with low concentrations of nanoparticles. The first stage is to mix nanoparticles with a nominal particle size of 30±5nm in DI water. The next stage is to homogenize the mixture using ultrasonic vibration at sound frequencies of 40 kHz, since ultrasonic vibration breaks down agglomerates in the mixture. 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.

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].

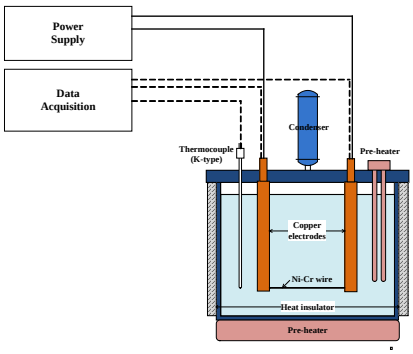

Fig. 1. Schematic of the pool boiling apparatus

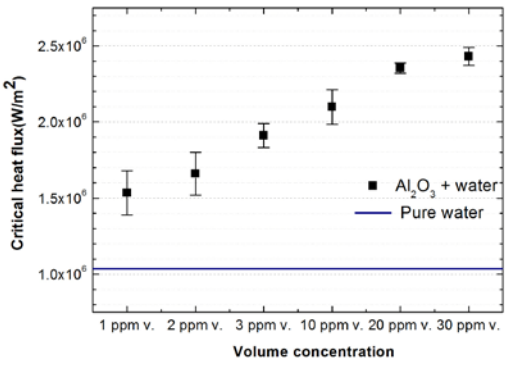

Fig. 2. CHF data for alumina-water nanofluid

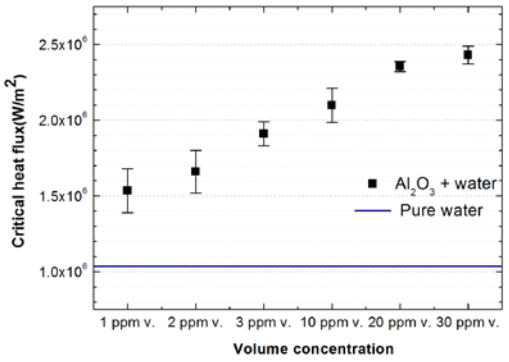

Fig. 3. Comparison of CHF data between alumina-water nanofluid and magnetite-water nanofluid

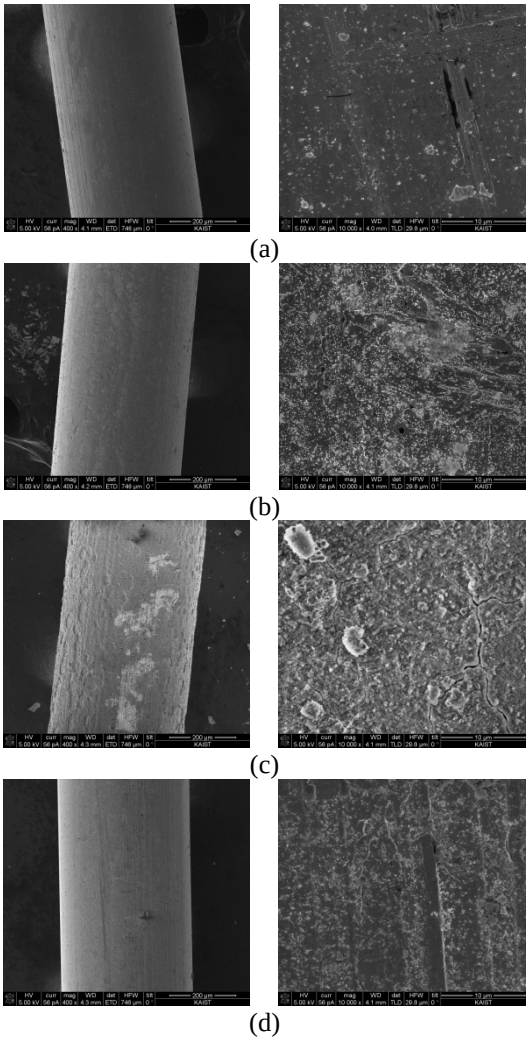

Fig. 4. SEM images of wire surface after pool boiling (a) Pure water (b) 1ppm of Alumina-water (c) 10ppm of Alumina-water (d) 1ppm of magnetite-water (left $\times 400$, right $\times 1000$)

Secondly, the pool boiling experiments with alumina-water nanofluids were performed to compare the CHF enhancement with magnetite-water nanofluids. Alumina-water nanofluid included nominal 20-30 nm diameter particles at volume concentrations between 1ppm (0.0001% v.) and 30ppm (0.003% v.). All of the data for the alumina-water nanofluid is shown in Fig. 2. The CHF values of alumina-water nanofluid increased from about 150% to 230% of the value for pure water with increasing nanoparticle concentration. Fig. 3 shows the comparison data for pool boiling CHF values with the alumina- 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 1-3ppm volume concentration.

3.2 SEM

Fig. 4 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.

4. Conclusions

The main findings of this study are as follows:

(1) Nanofluids with low concentration of alumina 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 CHF enhancement with alumina-water nanofluid in the range of 1-3ppm volume concentration.

REFERENCES

[1] S.M. You, J.H. Kim, K.H. Kim, Effect of nanoparticles on critical heat flux of water in pool boiling heat transfer, Appl. phys. Lett. 83, pp. 3374-3376, 2003.
[2] P. Vassallo, R. Kumar, S. D'Amico, Pool boiling heat transfer experiments in silica-water nanofluids, Int. J. of Mass Transfer 47, pp. 407-411, 2004.
[3] I. C. Bang, S. H. Boiling heat transfer performance and phenomena of Al_2O_3-water nanofluids from a plain surface in a pool, Int. J. Heat Mass Transfer 48, pp. 2407-2419, 2005.
[4] H. D. Kim, M. H. Kim, Experimental study of the characteristics and mechanism of pool boiling CHF enhancement using nanofluids, Int. J. Heat Mass Transfer 45, pp. 991-998, 2009.
[5] N. Zuber, Hydrodynamic aspects of boiling heat transfer, AEC Rep. AECU-4439, 1959.