Assessment of pool boiling CHF enhancement using magnetite and alumina water nanofluids at higher pressure

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1. Introduction

One of the key issues in the nuclear safety is a development of critical heat flux (CHF) enhancement which can improve the safety and efficiency of cooling system. As a part of this effort, nanofluids have been considered as a new coolant and experimentally studied to assess the characteristics of CHF using various nanoparticles [1-4]. However, most CHF experiments using nanofluids were performed at atmospheric pressure. To utilize nanofluids as a coolant for nuclear system, CHF performance of nanofluids has to be assessed at higher pressure. Therefore, we investigated the pressure effect on CHF enhancement in water based nanofluids with alumina and magnetite nanoparticles at higher pressure in this study. And, there were several attempts to understand the mechanism of CHF according to the changes of pressure by analyses on the bubble dynamics.

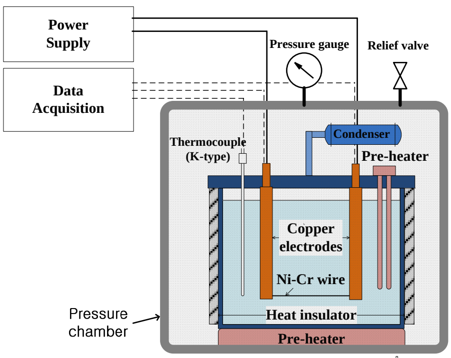

Fig. 1 Schematic of pool boiling CHF experimental apparatus

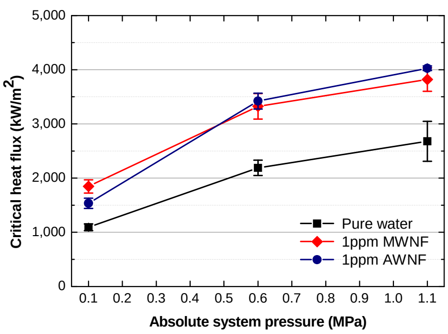

Fig. 2 Comparison of CHF data between distilled water and 1ppm of nanofluids

2. Pool boiling CHF experiments

2.1Experimental apparatus and procedure

Magnetite and alumina nanoparticles, whose averaged size is 25 nm and 20-30 nm respectively, were used for assessing the performance of CHF at higher pressure. Nanofluids were made for using two-step method which is the most economic and widely used method for preparing nanofluids.

A schematic of the experimental apparatus was shown in Fig. 1. The pressure chamber has cylindrical type with an inner diameter of 410 mm, and a height of 500 mm. The top of pressure chamber was comprised of a pressure gauge to measure the system pressure, a relief valve, and injection and venting valves. A rectangular main vessel was assembled on the center of the pressure chamber. A main vessel consists of a pre-heater, thermocouple to measure the pool temperature, copper electrodes, and a condenser. A heating surface is made of Ni-Cr with a wire type using the direct heating method. Visualization windows are installed in both sides of the main vessel and pressure chamber. The experimental data for the pool temperature, current and voltage were obtained with a National Instrument data acquisition system. The CHF was calculated by Eq. (1) using data obtained immediately before the sharp increase of the Ni-Cr wire resistance.

$$q''_{CHF} = \frac{V_{CHF} \times I_{CHF}}{\pi D L} \qquad (1)$$

2.2 CHF results

To understand the characteristics of pressure effect on CHF, pool boiling CHF experiments using distilled water were performed at 0.1, 0.6, and 1.1 MPa of system pressure. All experiments were conducted more than 5 times at each system pressure condition to validate the repeatability of experimental results. The measured data of distilled water were compared with the CHF correlation and well matched by the existed CHF correlations. CHF values for distilled water were increased with increasing the system pressure.

To clarify the pressure effect on the CHF using water-based nanofluids, pool boiling CHF experiments were performed using 1ppm of water-based nanofluids with magnetite and alumina nanoparticles according to the changes of the system pressure. The CHF results are represented in Fig. 2. As the system pressure increased, the CHF using water-based nanofluids can be enhanced. For 1ppm of MWNF, CHF values can be increased from approximately 140% to 170% relative to the CHF with the use of distilled water. And, CHF for 1ppm of AWNF can be also increased from about 140% to 160% of the one for distilled water.

2.3 Analyses on bubble behavior

To understand the pressure effect on CHF improvement using nanofluids, we focused on the bubble behavior of heating surface in the lower range of heat flux. By using high speed camera, all bubble images of nucleate boiling were obtained when heat flux is 200 kW/m^2.

The bubble size between distilled water and nanofluids can't be visually distinguished at the same pressure condition. However, the bubble sizes were smaller as the system pressure was increased in the cases of both distilled water and nanofluids. The nucleate site density was commonly increased for all cases as system pressure increased. We also analyzed the bubble frequency of distilled water and nanofluids. Fig. 3 shows the results for averaged bubble frequency between distilled water and nanofluids. The bubble frequency was not changed with increasing the system pressure. However, the bubble frequency for nanofluids was 2 times higher than that for distilled water at the same heat flux. Because of these characteristics for bubble behavior, the chance to rewet the same area in nanofluids was increased for the same duration in boiling. This means that CHF occurrence can be retarded by the use of nanofluids with higher bubble frequency.

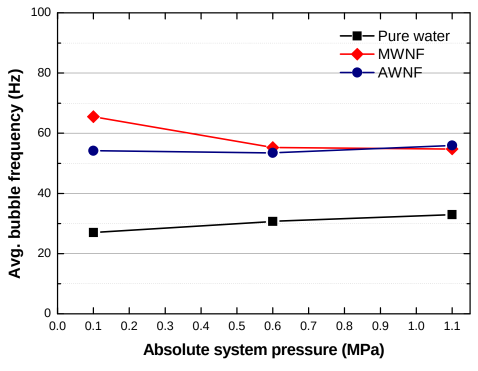

Fig. 3 Results for bubble frequency with increasing the system pressure

3. Conclusions

In this study, the pressure effect on CHF using water-based nanofluids was investigated experimentally. Pool boiling CHF experiments with Ni-Cr wire using magnetite and alumina water nanofluids were performed with several conditions of system pressures. Pool boiling CHF experiments using distilled water were carried out to understand the only pressure effect on CHF. Water based nanofluids with magnetite and alumina nanoparticles can significantly enhance the CHF in a pool at higher pressure.

Based on these, we focused on the mechanism of CHF occurrence by the analysis on the bubble behavior. Bubble frequency for nanofluids was around 2 times higher than that for distilled water. Due to the higher frequency of departing bubbles, the opportunity to rewet the hot spot of the heating surface was increased.

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