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Pool boiling experiments for critical heat flux using Fe_3O_4, SiO_2 nanoparticles on a flat-type upward surface

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1. Introduction

Demands for measures to cope with accidents in nuclear power plants have been increased as interests in safety has been continuously highlighted in recent years. In particular, concepts such as core catcher and IVR-ERVC have been suggested and adopted so as to mitigate a severe accident progression. When designing these equipment, the most significant idea is to secure sufficient time and thermal margins during the severe accident. One of the crucial criteria to guarantee the safety is critical heat flux (CHF) where a nucleate boiling region is transformed into a film boiling region, which can cause a dramatic temperature change. On this basis, several studies have been conducted to enhance thermal margins using nanofluids.

Lee et al. [1] conducted pool boiling experiments on the enhancement of CHF using magnetite, alumina and titania nanofluids. According to their results, the CHF values were enhanced for each nanofluid depending on concentrations from 1 to 100ppmv. This paper involved the SEM images of nanoparticles being deposited on the surface of a Ni-Cr wire. It showed that the particles accumulated on the surface could enhance the surface wettability, resulting in the efficient removal of hot spots.

Bang et al. [2] conducted experiments using alumina, zirconia and silica nanofluids with Ni-Cr wire at relatively high concentrations in % volume units. In this experiment, contact angles of droplets on the surfaces were measured where the increment of wettability with concentrations was found.

Other studies have also reported results of CHF values using Ni-Cr wires. They have been mainly focused on relatively high concentrations of SiO_2 nanoparticles with wire geometries. In this study, pool boiling tests were performed at relatively low concentrations with plate geometry which has larger thermal characteristic size compared with the wire geometry. In addition, magnetite nanoparticles were used for the experiments at the same concentration levels as silica.

2. Experiment

2.1 Pool boiling test

The overview of the experimental equipment including a pool, a rectifier, and a condenser is shown in Fig. 1. The experiment used a direct heating method, and the heat flux was obtained by measuring a voltage at the end locations of main heaters and current through the DAQ. K-type thermocouples were located on the specimen to check overall trends of temperature up to the CHF, and a condenser was installed on the upper side of the pool to minimize the loss of water by evaporation.

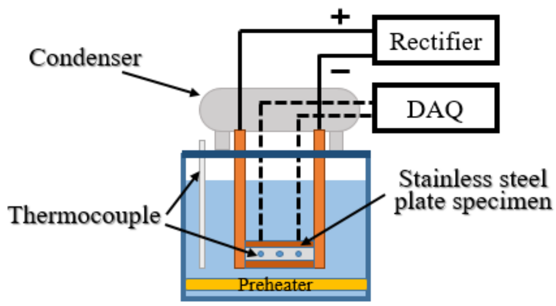

Fig. 1. Illustration of CHF experimental apparatus

For the test section, a stainless steel plate (Fig. 2) was used, and heat was released into the upward side only by insulating the bottom surface with a silicon rubber.

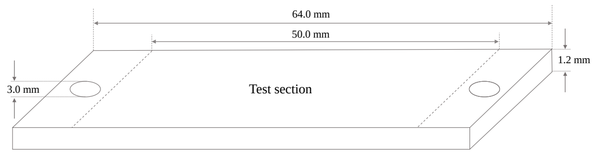

Fig 2. The dimension of plate specimen used in the experiment

2.2 Nanofluids

Zeta potential has been a well-known criterion to evaluate whether nanofluid is stable enough for experiments. In practice, Lee et al. [1] measured the zeta potential of magnetic nanofluids and observed that the stability could be guaranteed even after certain periods of time. Based on the method suggested in their research, the nanofluids in this study were made by mixing the nanoparticles into deionized water with a sonification process for more than 3 hrs. In this study, 25nm of magnetite nanoparticles and 10nm of silica nanoparticles (Catalog No. 637246) were used, provided by Nanostructured & Amorphous Material Inc. and Sigma Aldrich, respectively.

3. Result

The pool boiling experiment was conducted at an atmospheric pressure condition with concentration and time. Fig. 3 shows CHF trends with concentrations of magnetite fluids over deposition time. Since the deposition occurs from the beginning of boiling phenomena, the deposition time on the graph was measured from the onset of nucleate boiling to the CHF. No improvement on CHF was found for a short period of boiling time. After certain time, it showed relatively constant CHF values. As the concentration increased, the nanoparticles coated on the surface of the specimen could be visually observed, which formed porous layers and enhanced the wettability (Fig. 4), resulting in an improvement of CHF values by efficiently cooling the hot spot where the DNB could happen.

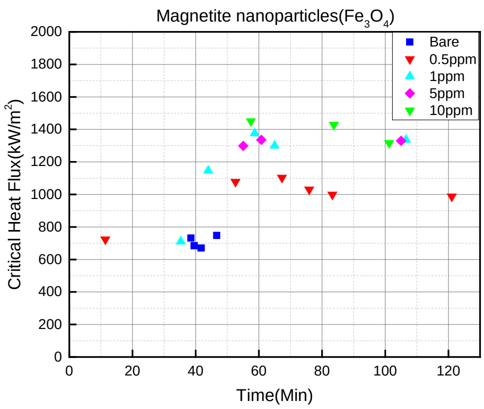

Fig. 3. Variation of CHF for magnetite nanofluids depending on the deposition time

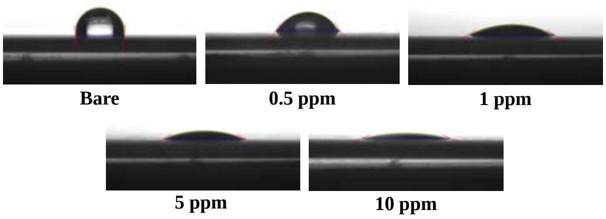

Fig. 4. Wettability variation for magnetite particles with increasing the concentrations

Fig. 5 represents the CHF values of silica fluids depending on the concentrations in terms of time. It showed different results from the previous studies on nanofluids, which indicates, surprisingly, the lower CHF values than that of bare at the relatively low concentrations. Starting from 5ppmv, the values are recovered up to the original values and the CHF for 10ppmv rises up to 150% of the bare. Besides, the effect of time on the variation of CHF was relatively small.

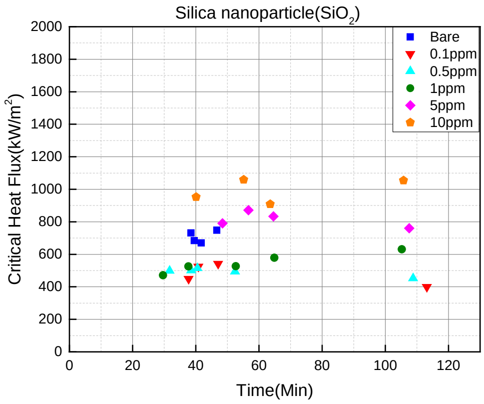

Fig. 5. Variation of CHF for silica nanofluids depending on the concentrations from 0.5 ppm Vol. to 10ppm Vol.

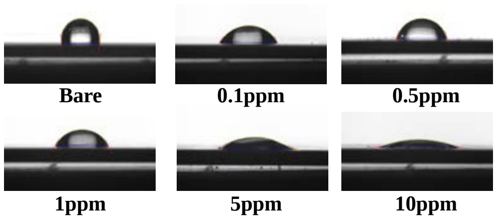

Fig. 6. Wettability variation for silica nanoparticles with increasing concentration

The improvement of the wettability is also shown in Fig. 6. The contact angles higher than 60° were measured up to 1ppmv, but lower than the bare case. The contact angles lower than 20° were also observed from 5ppmv with increasing concentration. However, when we consider the enhanced wettability at the low concentrations while CHF has been decreased, other factors roled in the reduction.

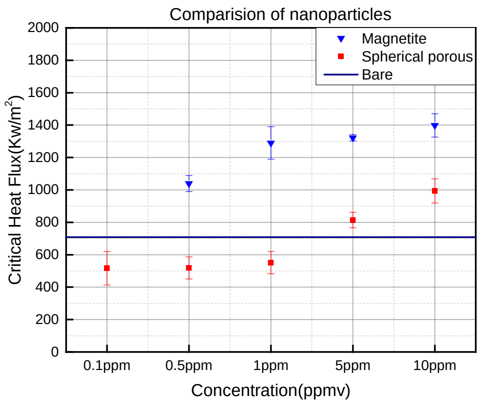

Fig. 7. Comparison of CHF for each nanoparticle depending on the concentrations

4. Conclusion

In this study, pool boiling tests were conducted in order to find how the CHF values would vary according to time and concentrations of nanofluids. The results are shown in Fig. 7 and summarized as follows.

- For magnetite nanoparticles, the CHF rises with increasing concentrations in the whole range.
- For silica nanoparticles, the CHF at the relatively low concentration region is lower than that of bare. The CHF enhancement begins from 5ppmv
- CHF values become saturated beyond certain periods of boiling time.

A number of studies on the enhancement of CHF using nanofluids have been published, and they have reported that wettability increased by the deposition of nanoparticles results in the increment of CHF. In this study, however, the reduction of CHF was observed, while wettability increases with the concentrations of nanofluids. The reason for these trends is not clarified yet. Therefore, further studies are required to explain specific causes for this phenomenon.

REFERENCES

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[2] S.J. Kim, I.C. Bang, J. Buongiorno, and L.W. Hu, Study of pool boiling and critical heat flux enhancement in nanofluids, Boulletin of the polish academy of sciences, Vol.55, No. 2, 2007.