Pool boiling CHF enhancement in nanofluids using a flat plate heater

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1. Introduction

You [1] showed that nanofluids, containing only 0.005 g/l of alumina nanoparticle, make the dramatic increase (~200%) in CHF in pool boiling at the pressure of 2.89 psia (Tsat=60℃). They concluded that the abnormal CHF enhancement of nanofluids cannot be explained with any existing models of CHF. Vassallo [2] performed the experimental studies on pool boiling heat transfer in water-SiO2 nanofluid under atmospheric pressure. They showed a remarkable increase in CHF for nanofluid and also found that the stable film boiling at temperatures close to the melting point of the boiling surface are achievable with the nanofluid. H.D. Kim [4] said a CHF enhancement mechanism in the nanofluids that is based to surface effect using a wire heater supplying a power as electric DC power. But nanoparticle deposited phenomena may be asked whether by boiling procedure, or by electric filed effect on the surface. So the flat plate experimental apparatus supporting only thermal heating is developed to perform the CHF enhancement experiment with nanofluid in pool boiling. The copper surface was used as heater surfaces and nanofluid was created with Al_2O_3, TiO_2 nanoparticles and deionized water by 2-step methods. And CHF in deionized water enhances on nanoparticles deposited surface. So, CHF enhancement in nanofluid is also achieved by the surface effect. For this result, surface investigation (SEM, contact angle and roughness) about the nanoparticle coated surface was performed.

2. Experiment

2.1 Preparation of nanofluids

In this study, nanofluids are made by dry nanoparticles dispersion in pure water (DI water) as following two-step method. It is dispersed in the ultra-sonic vibrating vessel during 3 hours. Nanoparticles are TiO_2, Al_2O_3.

2.2 Pool boiling experiment

Fig. 1 is the schematic diagram of the pool boiling experimental apparatus that has a flat plate heater. It is made of pool part and boiling heater part. The experimental sample is detachable on the pool and the 99.999% copper. The advantage of this experimental apparatus is what heating type is not electrical joule-heating, but thermal heating. Thermal heating is used by the conduction. The basic assumption is the 1-D conduction. For 1-D conduction analysis and measurement heat flux, the numerical simulation is performed by FLUENT 6.0. H.S. Ahn [3] support the data of the result of numerical simulation. And wall temperature is measured by the K Type thermo-couple at the experimental sample. Eq (1), (2) are the formula of getting the heat flux and the wall temperature.

$$q" = k_{99.999\%\_copper} \times \frac{\Delta T}{\Delta d} \quad (1)$$

$$\Delta T_{wall} = q" \times \Delta d_{sample\_to\_wall} / k_{sample} - T_{sat} \quad (2)$$

The experimental sample is the T-dimension, because of avoiding the flooding and the bubbling at the side wall. So, there is the heat loss by T-dimension sample. The heat loss evaluation is preformed by FLUENT 6.0 in the Fig. 2. the heat loss is 10.4% in the 2000kW/m^2.

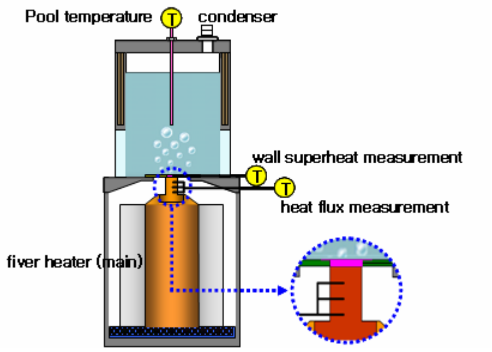

Fig. 1 Schematic diagram of experimental apparatus

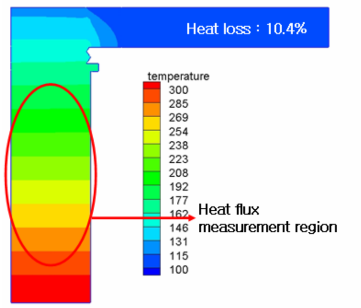

Fig. 2 Heat loss and uniform temperature profile

Table 1 CHF in 0.01% vol. nanofluids (kW/m^2)

surface	nanofluids	CHF_{NF}/CHF_{DI}	CHF
copper	-	0%	1720
copper	Al_2O_3	40%	2300
copper	TiO_2	43%	2450

3. Result and discussion

Fig. 3 is the boiling curve in the pure water. The end point is the CHF point. The CHF experiments in the pure water are performed three-times. CHF values have the reproducibility. CHF enhancement in nanofluids is

40% versus CHF in pure water. Table 1 is the CHF enhancement in the Al_2O_3-water, TiO_2-water 0.01% Vol. Fig. 4 is the boiling curve of pure water, CHF value in the nanofluids and CHF value in the pure water on the nanoparticle deposited surface as Al_2O_3 and TiO_2. The nanoparticle deposited surface is made as input 90% heat flux of CHF in the nanofluids. Fig. 4 is the surface effect of CHF enhancement in the nanofluids. And the surface investigation is performed by the SEM observation, measurement of static contact angle, measurement of roughness (3D-profiler) and dynamic wetting. Fig. 5 is the SEM image of bare surface and nanoparticle deposited surface. The micro-structure is generated by nanoparticles. This micro-structure shape is dependent of a kind of nanoparticle. It has a possibility of porous medium having a capillary force [4]. Fig. 6 is the static contact angle measurement result. Since nanoparticles are oxide particles, nanoparticle deposited surfaces are more wettable than bare surface. Fig. 7 is the roughness change before and after CHF experiment in nanofluids. Ramilison et al said the more wetting and more roughness properties change are the CHF enhancement parameters [5].

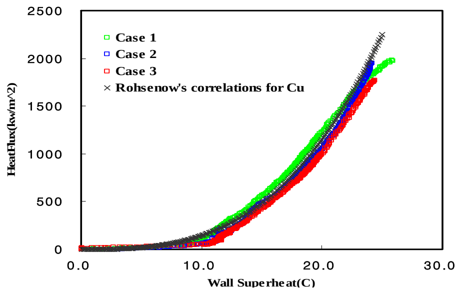

Fig. 3 Pool boiling curve/CHF of pure water

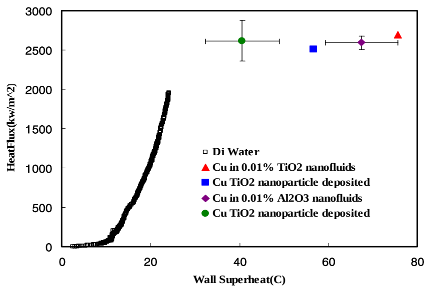

Fig. 4 CHF enhancement by surface effect

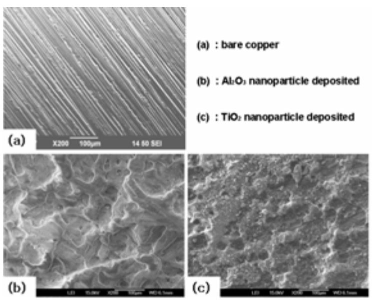

Fig. 5 SEM image of surface

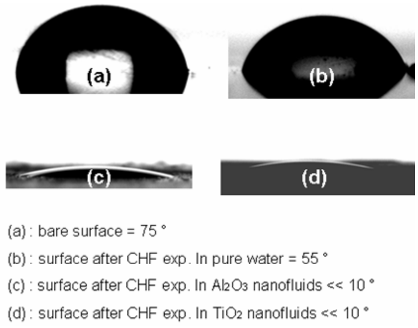

Fig. 6 static contact angle of surface

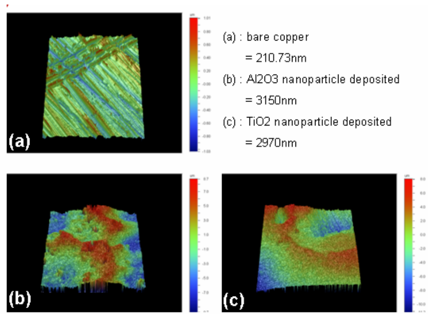

Fig. 7 roughness change

4. Conclusion

CHF enhancement in the nanofluids is due to the surface effect by nanoparticle deposited during boiling phenomena. Nanoparticle deposited surface is made by using not electric heating method, but thermal heating method. So it is clear that nanoparticles are deposited on the heating surface by not electric filed effect but boiling phenomena. And nanoparticle deposited surface have the more wettable and rougher properties than bare copper. These results are as same as wire heater experiment results that used a electric heating method [4]. Finally this surface has the micro-structure. This oxide micro-structure has a possibility of the porous structure having capillary force that delayed to CHF as supplying liquid on the heating surface [4,6].

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