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CHF Enhancement under Pool Boiling using Nano-fluids

Won Joon Chang, Yong Hoon Jeong, Soon Heung Chang
Korea Advanced Institute of Science and Technology
373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea, rawing@kaist.ac.kr

1. Introduction

Recently, various boiling heat transfer enhancement technique have been studied. In particular, nano-fluid which produced by dispersing nano-particles into pure water (nano-fluid is proposed by Choi in 1995 of the Argonne National Laboratory) is known to significantly enhance thermal properties of fluids. Many researchers expected the augmentation of boiling heat transfer performance and the critical heat flux, and experiment results from various group show that thermal conductivity and CHF are enhanced by nano-fluid. However, experiments on boiling heat transfer of nano-fluid show conflicting results.

Relationship between CHF and nano-fluid was studied by many researchers (You et al, 2003; Vassallo et al., 2004; Bang and Chang, 2005; Kim et al., 2006; S.J. Kim et al., 2007). The results show that the nano-fluids significantly enhanced pool boiling CHF compared to pure water. It was supposed that CHF enhancement was due to increased thermal conductivity of fluids, change of bubble shape and behavior, nano-particle coating of the boiling surface.

2. Methods and Results

2.1. Measurement of thermal conductivity

The flash technique is one of the most widely used methods for the determination of the thermal diffusivity and thermal conductivity of solids all over the world. Using this method, the front side of a plane-parallel sample with a well defined thickness is heated by a short light or laser pulse. The resulting temperature rise on the back surface is measured versus time using an infrared detector. Analyzing the measured detector signal with appropriate mathematical models yields information on thermal diffusivity and the specific heat of a material. Together with the density of the material the thermal conductivity can be determined.

Additionally, analysis of multi-layer systems or the measurement of liquids is possible by the flash method. The flash method is a standardized technique (ASTME 1461 or DINEN 821).

Thermal conductivity of nano-fluids (2%) is 0.610W/m^{2}K (25^{o}C) (Water : 0.58W/m^{2}K (25^{o}C). The ratio of thermal conductivity is 1.052 (measurement) vs. 1.18 (Hamilton & Crosser (1962)).

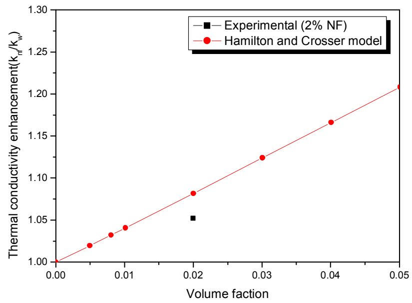

Figure 2. Measurement of thermal conductivity

2.2. CHF enhancement

Use of a thin wire heater is convenient for CHF experiments, but its high curvature makes it inconvenient for surface analysis, such as required to study the porous layer. For this purpose we switched to flat plates, 50 mm * 50 mm * 30 mm, aluminium.

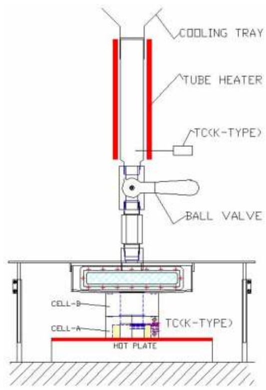

Figure 1. Experiment facility

A new heater was used for each experimental run. Some nano-particles precipitate on the heater surface and form irregular porous structures, which do not appear during boiling of pure water. The surface boiled in pure water is very smooth, while the surface boiled in the nano-fluid presents irregular peak-and-valley structures, which are consistent.

Another important effect caused by the porous layer is the increase in surface wettability. The static contact angle was measured for sessile droplets of pure water and nano-fluids at 22^{o}C in air on the clean and nano-particle fouled surfaces boiled in nano-fluids.

A rather dramatic decrease of the contact angle on the fouled surfaces is evident. Such decrease occurs with pure water as well as nanofluid droplets, thus suggesting that wettability is enhanced by the porous layer on the surface, not the nano-particles in the fluid.

A CHF (56%) enhancement was observed with 1.0% Al2O3 nano-fluid. The addition of nano-particle helped to increase the wettability by reducing the surface tension. This happens with the decrease in bubble diameter, breakup of bubbles and avoidance of bubble coalescence. Thus, nano-fluid enhances the CHF as compared to plain water data. CHF increase or decrease depends upon competition between high wettability and high instability. The main difference in physical properties of plain water and nano-fluids is surface tension. Nano-fluid lowers the surface tension of water increasing wettability.

Thus, reduced surface tension results in better wettability and shorter wave length on the interface between liquid and vapor. Significant decrease in contact angle was observed as compared to pure water. This helped to elaborate the boiling experimental results, because decreased contact angle is a measure of wettability.

An optimum nano-fluid concentration is needed which must have high crystalline content. The concentration of the solutions has a great effect on the surface tension of the solutions. When the concentration reaches at a critical value, the surface tension will tend to a constant value which corresponds to the critical micelle concentration for each surfactant.

And, in case of carbon nano tube, CHF enhancement was shown by experiments. But there was no deposition unlike Al2O3 nano-fluids.

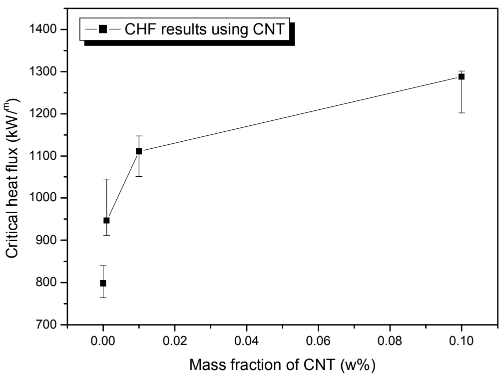

Figure 2. CHF enhancement using CNT nano fluids.

3. Conclusions

The effect of the surface wettability and rewetting of the nano-particle deposition layer is key factor in order to understand the mechanism of the CHF enhancement in pool boiling using nano-fluids. The deposition of nano particles improve the surface wettability and rewetting on surface where the supplied liquid can effectively delay the growth of a dry patch and the CHF in pool boiling.

Enhancement of thermal conductivity and critical heat flux using nano-fluids in pool boiling was manifest. But there was a lot of inconsistency in boiling heat transfer enhancement using nano-fluids. To understand the effect of nano-fluids more exactly, a comprehensive experimental work followed by theoretical modeling would be necessary, and not only properties of nano-fluids but also surface properties such as surface roughness, surface wettability would be considered.

The implications of pioneering the development of nano-fluids are significant and include creating a new area of interdisciplinary research in the filed of nano-scale thermal sciences

REFERENCES

[1] I.C. Bang, S.H. Chang, Boiling heat transfer performance and phenomena of Al2O3-water Nano-fluids from a Plain Surface in a Pool, Int. J. of Heat and Mass Transfer, Vol. 48, pp. 2407-2419, 2005

[2] D.Y. Kwok and A.W. Neumann, Contact Angle Interpretation in Terms of Solid Surface Tension, Colloids and Surfaces, Vol. 161, No. 1, pp. 31-48, 2000.

[3] S.G. Kandlikar, A Therretical Model to Predict Pool Boiling CHF Incorporating Effects of Contact Angle and Orientation, J. of Heat Transfer, Vol. 123, pp. 1071-1079, 2001