Nucleate Boiling Heat Transfer of Nanofluids with Carbon Nanotubes on Plain and Low Fin Surfaces

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1. Introduction

Nuclear power generation is being discussed in many countries as an alternative method to solving the world's energy crisis. For the safe operation of nuclear power plants, ways for increasing the critical heat flux (CHF) related to a loss of coolant accident are being investigated. In the event that the local heat flux exceeds the CHF, there is an abrupt shift in the boiling curve such that the nucleate boiling ceases and transition boiling and ultimately film boiling occur, finally resulting in a physical break down of the surface. Therefore, it is essential to maximize the CHF for the protection of nuclear power plants with maximum system performance.

For the past decade, as a lot of research has been carried out for an improvement of the boiling heat transfer coefficients (HTCs) and CHF, new methods employing nano particles have been proposed [1-3]. The objectives of this study are to measure the pool boiling HTCs of the water without and with carbon nanotubes (CNTs) on plain and low fin surfaces up to the CHF, and to analyze the effect of CNTs on both nucleate boiling HTCs and CHF.

2. Methods and Results

2.1 Experimental apparatus

In this study, nucleate pool boiling HTCs of water without and with CNTs on plain and low fin surfaces up to the CHF were measured on a small square flat plate heat transfer test section using the same experimental apparatus with the same tube specimen described in Park et al.'s study [4]. Fig. 1 shows a schematic of the experimental apparatus for nucleate pool boiling heat transfer tests with nanofluids. The apparatus was composed mainly of the boiling vessel and external condenser. The hermetically sealed boiling vessel was manufactured with a 170 mm long stainless steel pipe with a 120 mm outer diameter and flanges at both ends. The vapor generated by the test heater in the vessel was condensed in the external condenser, and the condensate was circulated to the bottom of the boiling vessel through gravitation. For low vapor pressure fluids, it was sometimes difficult to lower the pool temperature to the desired value. Hence, a small copper tube coil was placed in the vessel through which cold water from the chiller was passed for adjusting the pool temperature.

Fig. 2 shows the details of the test section. For the heat from the heater to be transmitted upwardly to the copper plate block, a plastic insulation block (40.0 mm x 40.0 mm x 20.0 mm) was made with very low thermal conductivity nylon. At the upper portion of the insulation block, a 5.0 mm deep rectangular section of 18.0 mm by 15.0 mm was machined to house the heater and copper plate block assembly. Interested readers are referred to Park et al.'s study (2009) for further details.

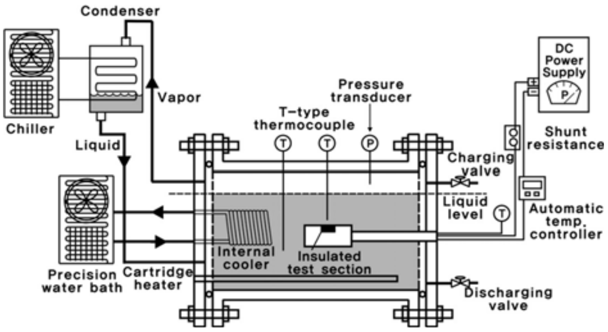

Fig. 1. Schematic of pool boiling test facility using a small flat heater.

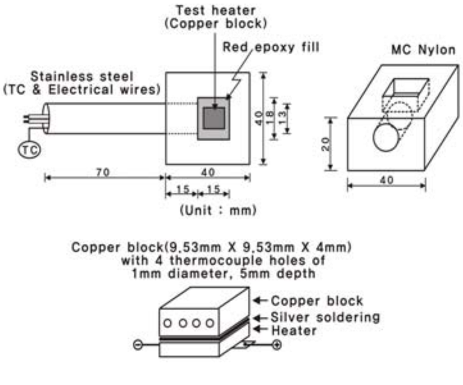

Fig. 2. Test heater specifications.

2.2 Results and discussion

In this study, nucleate boiling HTCs were used to measure the pool boiling HTCs of water without and with multi-walled CNTs whose volume concentrations are 0.001%. For the dispersion of CNTs, CNTs were treated chemically using acid without employing polymers [5]. All data were taken at a pool temperature of 60°C on both plain and low fin surfaces at heat fluxes from 10 kW m2 to the CHF.

Fig. 3 shows the HTCs of the water without and with CNTs as a function of heat flux for plain and low fin surfaces. Pool boiling HTCs on plain surfaces of the nanofluid with CNTs increased as the heat flux increased, which is a typical trend in the pool boiling of pure fluids. At heat fluxes higher than the CHF of pure water (560 kW/m2), no comparison can be made against pure water data. As the heat flux increased, nucleate boiling HTCs of the nanofluid with CNTs were higher than that of pure water at heat fluxes lower than the CHF of pure water. When the CNTs treated chemically are dispersed in water, since the dispersibility with the water is stronger than the affinity among CNT particles, the deposition layer of the CNTs becomes very thin and the CNT particles with high thermal conductivity are floated in the water. During the formation, growth, and departure of the bubbles in the thermal boundary layer, these CNT particles of nano size are strongly disturbed with the water and touch the surface (or thermal boundary layer) and penetrate into the bubble zone near the surface. For these reasons, it may be concluded that CNT particles in the water help enhance the nucleate boiling heat transfer greatly as compared to that of pure water.

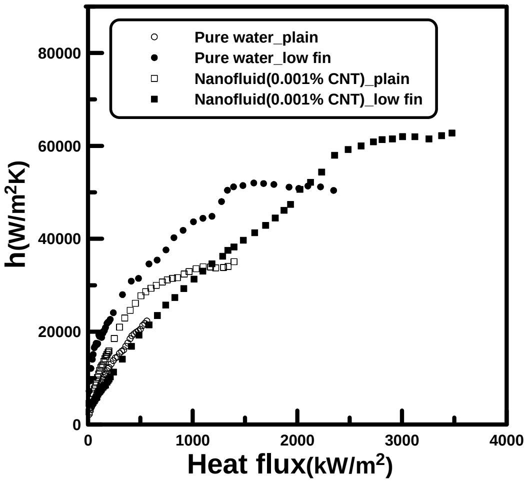

Fig. 3. HTCs of nanofluids with the CNTs up to a critical heat flux on the low fin surface

As shown in Fig. 3, pool boiling HTCs on low fin surfaces of water without and with CNTs increased as the heat flux increased, which is a typical trend in the pool boiling of pure fluids, and similar to the trend of the results the plain surface. However, as the heat flux increased, nucleate boiling HTCs of the nanofluid with CNTs on the low fin surface appeared lower than that of pure water. During the departure of bubbles between low fins, these bubbles make a strong interaction and prevent the heat transfer. For these reasons, it may be concluded that the surface geometry of the low fin surface seem to have a less promotive role in enhancing the boiling heat transfer.

Table 1 lists the CHFs measured on two surfaces. First, it can be seen that the CHF increased on two surfaces as compared to that of pure water. The nanofluid with the CNTs showed a 150% improvement in CHF as compared to that of pure water. The pure water on low fin surfaces showed a 320% improvement compared to that of pure water on a plain surface. From this result, it can be predicted that the CHF on the low fin surface was increased dramatically owing to the increasing heat transfer area and surface geometry.

Nanofluid with CNTs on low fin surfaces showed a 525% improvement compared to that of pure water. From these results, it can be concluded that the maximum CHF occurs on low fin surfaces for nanofluid with multi-walled CNTs. When tested in nanofluid with the CNTs, the CHFs on the low fin surface increased greatly as compared to those obtained in pure water. Since there was a very thin layer on the surface, this layer maintains the nucleate boiling even at very high heat fluxes and reduces the formation of a large vapor canopy at near CHF, resulting in a significant increase in CHF. In conclusion, for a low fin surface, the surface geometry and nano particles produced a double effect of increasing the CHFs.

Table I: Summary of critical heat flux for enhanced surfaces

Surfaces	CHF of pure water (kW/m^2)	CHF of nanofluid (kW/m^2)
Plain	560	1400
Low fin	2350	3500

3. Conclusions

Pool boiling HTCs on all surfaces tested in water without and with CNTs increased as the heat flux increased, which is a typical trend in the pool boiling of pure fluids. For nanofluid with CNTs on low fin surfaces, the surface geometry and nano particles produced a double effect of increasing the CHFs.

REFERENCES

[1] S. Lee, S. U. S. Choi, S. Li and J. A. Eastman, Measuring thermal conductivity of fluids containing oxide nanoparticles, ASME Journal of Heat Transfer, Vol. 121, pp. 280-289, 1999.

[2] P. Keblinski, J. A. Eastman and D. G. Cahill, Nanofluids for thermal transport, Materials Today, Vol. 8 pp. 36-44, 2005.

[3] X. Wang and A. S. Mujumdar, Heat transfer characteristics of nanofluids: a review, International Journal of Thermal Sciences, Vol. 46, pp. 1-19, 2007.

[4] K.J. Park, D. Jung and S.E. Shim, Nucleate boiling heat transfer in aqueous solutions with carbon nanotubes up to critical heat fluxes. International Journal of Multiphase flow, Vol. 35, pp. 525-532, 2009.

[5] J. U. Ha, M. Kim, J. Lee, S. Choe, I. W. Cheong and S. E. Shim, A novel synthesis of polymer brush on multiwall carbon nanotubes bearing terminal monomeric unit. Journal of Polymer Science: Part A: Polymer Chemistry, Vol. 44, pp. 6394-6401, 2006.