Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Experimental Study on Heat Transfer Characteristic of Cellulose Nano Fiber Fluid

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1. Introduction

Critical heat flux (CHF) and boiling heat transfer coefficient (BHTC) are the two main properties that can represent the heat transfer characteristic of pool boiling heat transfer medium. CHF is the boundary phenomenon of nucleate boiling and film boiling. Heat transfer rate reaches maximum at CHF point, and drastic degradation follows. Therefore, CHF enhancement would improve the stability and cost efficiency of the boiling system. For a long time, enhancement of CHF is desirable to engineers and researchers in the field. Larger BHTC means larger amount of heat transfer occurs at same temperature difference in system. Hence, the factor is tightly related to heat transfer efficiency of a system.

Nanofluid is one of many methods and comparably well-known way to increase CHF. The characteristic of nanomaterial such as high thermal conductivity had attracted researchers on applications [1]. Owing to its distinctive characteristic, You et al. [2] firstly used nanofluids instead of pure water as working fluid and reported 200% CHF enhancement. Then the interest on nanofluids intrigued many researchers to conduct experimental studies on CHF enhancement using different nanomaterials such as Sulphur oxide, Alumina, Zinc oxide, and Titanium oxide [3].

Unlike the other researchers who used metals (Cu, Au) or metal oxides (Alumina, Titanium Oxide, Zirconium Oxide), Song et al. [4] documented that the CHF was enhanced 108% using 0.1vol% cellulose nano fiber (CNF) fluid from woods as working fluid. Hwang et al. also investigated CHF enhancement using CNF, and a new electrical coating method using CNF was developed [5]. They reported that CHF on the coated wire was enhanced more than 200% compared to that on bare wire. However, BHTC is not investigated in the former research. Hence, the present research focused on finding BHTC of CNF deposition on the wire and comparing with the CHF enhancement.

2. Experimental Apparatus

A schematic diagram of the experiment apparatus is shown in Figure 1. The main test pool consisted of a 250 by 140 by 250 mm rectangular glass vessel from ©Duran. A Teflon cover of 30 mm thickness was used to prevent heat loss and to hold two cylindrical SUS electrodes of 28 mm in diameter. Hot plates were used for maintaining saturated temperature in atmospheric pressure. A K-type thermocouple had tolerance of 0.5 K, and its tip was set on the same height of electrodes' bottom end. To maintain volume concentration of CNF, a reflux condenser was applied, and the top of the condenser was open to atmospheric pressure.

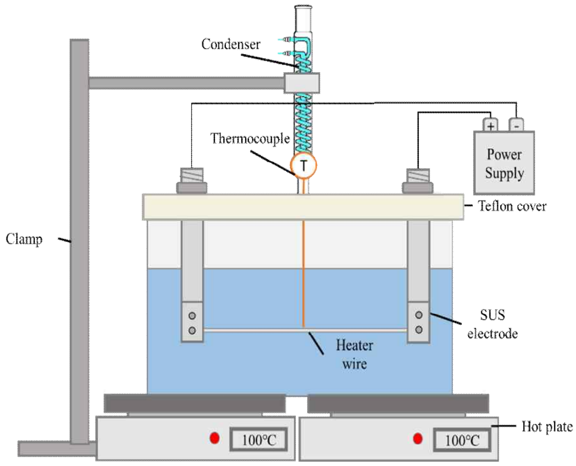

Fig. 1. Pool boiling apparatus

Cylindrical heater Pt wire with 160 mm in length and 0.5 mm in diameter was horizontally installed as boiling section. Both ends of wire were clamped to SUS electrodes. The electrodes pulled the wire tight. Power supply had current tolerance of 0.2% and voltage tolerance of 0.1%. The voltage of heater wire was measured directly from the electrodes. A data acquisition system was used to measure and store data: voltage, current, and temperature.

The temperature uncertainty for the test wire is 5.1, 7.1, and 8.7℃ when temperature of the wire is at 100, 200, and 300℃ respectively.

3. Result and Discussion

Fig. 2. shows the CHFs of pool boiling experiment in CNF fluid and water using platinum wire of 0.5 mm in diameter. The CHF in DI water is 694.5 kW/m^2 which is different from Zuber's prediction, 1080 kW/m^2 [6]. The similar deterioration of CHF in water was reported by Stutz et al. [7]. They used 0.1 mm Pt wire, and CHF was about 800 kW/m^2. Another reason for this degradation is due to dimensional effect suggested by Bakhru and Lienhard [8].

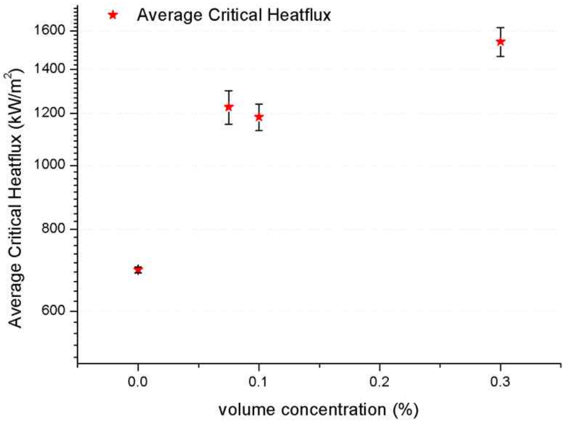

Fig. 2. Experimental result of enhanced CHFs of 0.075, 0.1, and 0.3vol% CNF fluid

Song et al. [4] reported that the maximum CHF enhancement of 0.1vol% CNF fluid was 108% on Nichrome wire. On the other hand, using a 0.5 mm diameter platinum wire, the experimental data in Fig. 2 represented that the CHF increased by 76.4%, 70.6%, and 122% where volumetric concentration is 0.075vol%, 0.1vol%, and 0.3vol%.

To ensure the CNF deposition on the wire, SEM images were taken after the boiling experiments (Fig. 3). As the concentration increases, it is found that the deposition area which is dark widens.

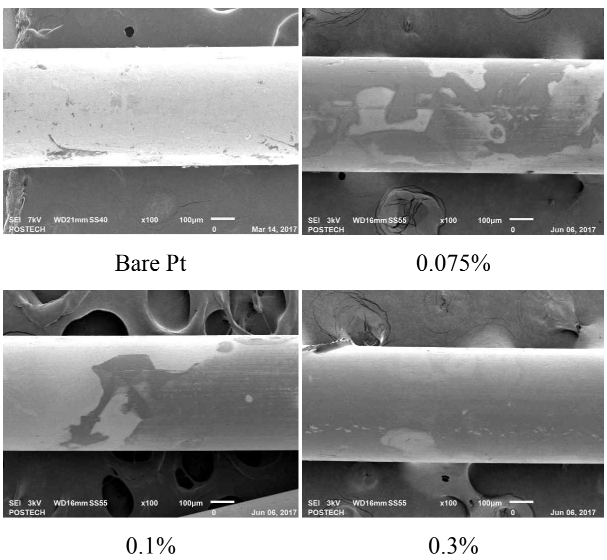

Fig. 3. Magnified SEM images of Pt wires after boiling experiment (×100)

The known causes of CHF enhancement are capillarity and rewetting ability of the coating on the wire. Naturally, CNF is a hydrophilic material and has ability to attract water. At low concentration, the nanoparticle is not deposited enough on the wire to draw water, hence the CHFs are lower in 0.075vol% and 0.1vol% CNF fluid. In case of high concentration like 0.3vol%, the nano-particle deposited near the wire causes water to quickly approach the wire, which eventually delays the CHF.

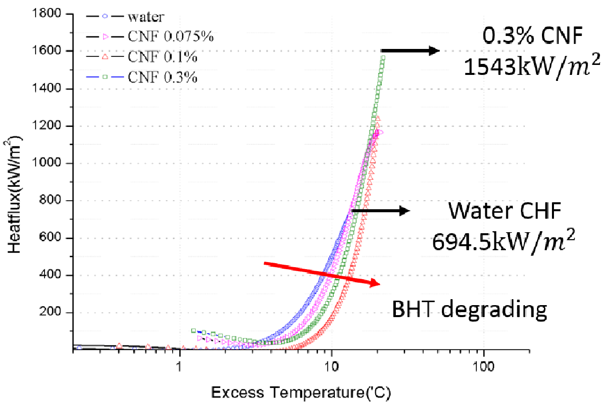

Fig. 4. Boiling curve of CNF fluid with concentrations of 0.075, 0.1, and 0.3vol%

The boiling heat transfer coefficients of CNF fluid with different concentration are investigated in Fig. 4. It should be noted that the boiling curve obtained in water well matches with the Rohsenow's correlation [9].

Average values of BHTC are deteriorated in all cases. At 0.1vol% CNF fluid, BHTC is degraded the most by 35% while BHTC of 0.075vol% and 0.3vol% decreased about 16% and 18% respectively. As the concentration increased, the BHTC decreased as reported by Suriyawong et al [10].

The known factors that affect BHTC are surface roughness and thermal conductivity of heated material. CNF made from wood has relatively low thermal conductivity, so deposition on the wire would decrease the overall thermal conductivity. As degradation of BHTC decreases at lower concentration, there must exist a concentration where BHTC degradation is the lowest and the CHF enhancement is the highest. The further investigations are required to find this optimal point.

3. Conclusions

Critical heat flux and boiling heat transfer coefficient of cellulose nano fiber fluid are investigated. Platinum wire of 0.5 mm in diameter is applied as heating section. Compared to DI water, the CHF of CNF has increased by 122% at 0.3vol%, and at least by 70% around 0.1vol%. BHTCs degraded by 16, 35, and 18% with the concentration increased as 0.075, 0.1, and 0.3vol%. The nanoparticle deposition on the wire is the main factor of enhanced CHF and decreased BHTC. By considering concentration of the fluid and boiling time, the further studies should be conducted to analyze the surface of the wire and to find the optimal concentration where

BHTC of CNF is the closest to the water and CHF enhancement is the maximum.

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