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Preliminary Study on CHF Enhancement of Cellulose Nano Fiber (CNF) Fluid with Wire Pool Boiling Experiment

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1. Introduction

Critical heat flux (CHF) is considered as a thermal limit during heat transfer processes with phase change. Heat transfer is maximized at the CHF point, followed by drastic degradation. CHF enhancement of a boiling system will make more compact and effective cooling systems, for examples, nuclear reactors, and air conditioning units.

For decades, researchers have been trying to develop more efficient working fluid for heat transfer. This is where nano-fluid could play a key role. There have been a lot of researches for CHF enhancements in nucleate boiling by using nano-fluid which are composed of metal such as copper, Al_2O_3 and ceramic [1-3]. And a critical factor of the enhancement is deposition of nano-particles on heating surface, although some results of recent studies are contrary.

Also, previous nano-fluid are expensive and have a problem in mass production, so they are difficult to apply to practical industries. Therefore we chose a new material, cellulose nano fiber (CNF) as a solution. CNF can be applied to real situation because it has some advantages which are cost-effectiveness, easiness to get and to make it in nano scale. Furthermore, there is no heat transfer research with CNF fluid.

2. Experimental Methods

2.1 Preparation of CNF fluid

Fig. 1. shows that CNF whose size is 3-4 nm was manufactured by TEMPO-oxidation method [4] in POSTECH.

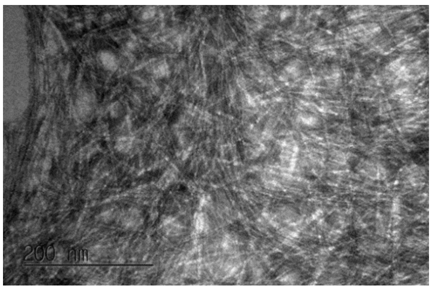


Fig. 1. SEM figure of manufactured CNF

CNF is relatively cheaper than other material and so plentiful on the earth. Also, it has an ability to contain a lot of water and has an advantage of no reaction with water. This fiber was dispersed in the distilled water using household mixer for enough time to have more degree of dispersion so that CNF fluid could be prepared.

2.2 Experimental apparatus and procedure

A schematic diagram of the pool boiling experimental apparatus is shown in Fig. 2. The main vessel was made of Pyrex glass and had an inner diameter of 130 mm and a height of 150 mm. The pool container was filled with distilled water. A hot plate was used to keep water at saturation temperature. Upper side of the vessel was covered with Teflon cover for insulation. Also, the vessel and Teflon cover were fixed with two clamps. One K-type thermocouple which has tolerance of 0.5 K was inserted into the water through the Teflon cover. A condenser which is held with holder is set above the Teflon cover.

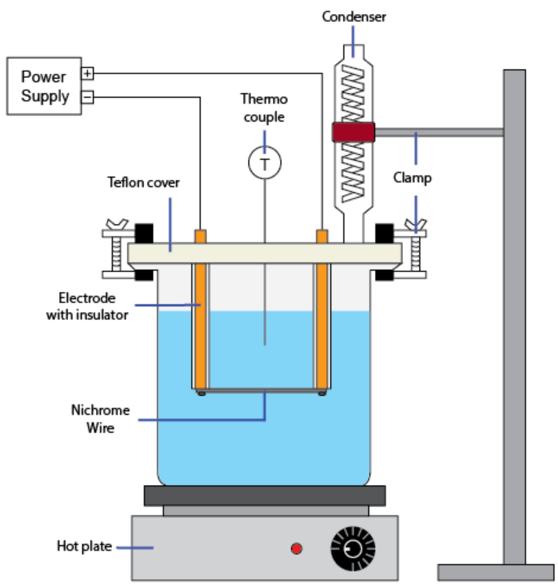


Fig. 2. Schematic diagram of the experimental apparatus

The nichrome wire which had a diameter of 0.1 mm and a length of 50 mm was used as a test wire and attached with two copper electrodes which had a diameter of 2 cm and a length of 12 cm. And two copper electrodes were covered with Teflon spray to prevent electrolysis.

Experiments were carried out using CNF fluid as a working fluid under saturated conditions at atmospheric pressure. Degassing of the fluid in the pool was proceeded by heating for 30 more minutes at 100 degrees Celsius. After that, the hot plate was powered on during the experimental process for maintaining the CNF fluid temperature at saturation temperature. As we constantly increased voltage using the power supply which had current tolerance of 0.2%, voltage tolerance of 0.01%, we waited about a minute for electrical steady-state of the wire. When the current did not change more than 0.2 A, we regarded that the state of the heating wire was on electrical steady-state. As voltage was increased, heat flux from the wire to CNF fluid gradually increased, and boiling started. When heat flux reached CHF, the heating wire was burned and cut soon. We conducted the pool boiling experiments with CNF of 0.001V% and 0.01V% two times, and with 0.1V% CNF three times.

3. Results and discussion

3.1 CHF Enhancement of CNF fluid

The result of pool boiling experiments with the wire is shown in Fig. 3. CHF value of water measured by this experimental apparatus was 25% lower than prediction of CHF of distilled water using Zuber's model [5], Eq. (1).

$$q'' = Ch_{fg}\rho_v \left[\frac{\sigma g(\rho_L - \rho_V)}{\rho_V{}^2}\right]^{1/4} \quad (1)$$

where C is Zuber constant, h_{fg} is latent heat of water, σ is the surface tension, ρ_L and ρ_V are the liquid density and vapor density respectively.

Compared to CHF of distilled water, CHF of CNF continuously increased until volumetric concentration reached 0.01V%. But in region of over 0.01V%, CHF enhancement of CNF fluid was decreased as volumetric concentration increased. The highest CHF value of CNF was $1.8\,MW/m^2$ at 0.01V% which was 104% higher than that of distilled water.

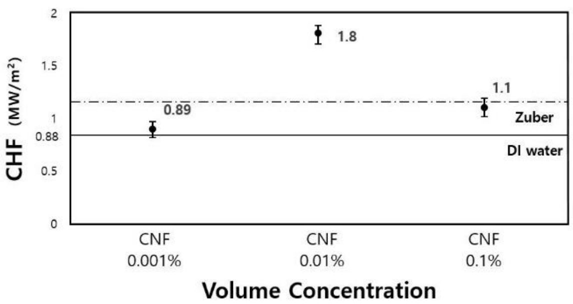


Fig. 3. Result of CHF depending on various CNF volumetric concentration

3.2 Deposition layer of CNF on the heating wire

Like other nano-fluid experiments using metal, ceramic and other nano-particles, deposition layer of CNF was formed on the heating wire. Fig. 4. is shown deposition layer of CNF on the heating wire observed with human eyes after the CNF fluid boiling experiments. And Fig. 5. is enlarged pictures by scanning electron microscopy (SEM). One of the unique characteristics of CNF is that it can contain water inside of its molecule structures. We are assuming that deposited CNF on the wire would contain considerable amount of water in it. We are expecting that CHF enhancement of CNF fluid in this experiment is mainly caused by this characteristic.

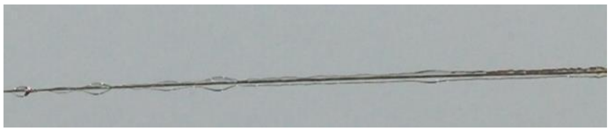
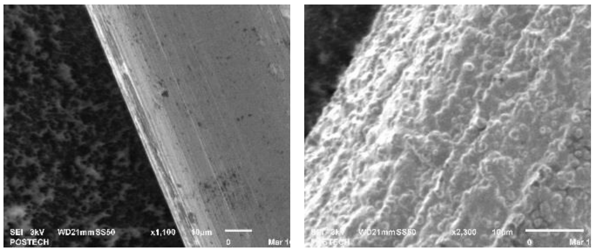


Fig. 4. Deposition layer of CNF on heating wire after the boiling experiments



(a) (b)

Fig. 5. The SEM images of (a) bare nichrome wire before the experiment and (b) deposition layer of CNF after 0.05V% experiment

4. Conclusions

CHF enhancement was experimentally studied with CNF fluid. Pool boiling experiments with 0.1 mm nichrome wire were conducted in case of three different volumetric concentrations. CHF performance of CNF fluid was different from that of distilled water. Compared to CHF of distilled water, CHF of the CNF fluid which had 0.001V%, 0.01V%, and 0.1V% volumetric concentrations were enhanced to 1%, 104%, and 13% respectively.

Likewise other nano-fluid, deposition phenomena was observed in this CNF fluid boiling experiment. We are considering water containing characteristic of CNF as a main factor of CHF enhancement.

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