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Experimental Study of Coating Effect on CHF during Pool Boiling for Nanofluid

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1. Introduction

Since nanofluids, which are colloidal dispersions of nanoparticles in a base fluid such as water, were known as a way to significantly enhance the CHF, the pool boiling CHF test was conducted in a variety conditions depending on the material, the concentration etc. [1,2]. Especially, The CHF value is constant or increasing when the concentration is relatively high [3,4]. However, deteriorated cases were also reported [5]. The concentration is the factor which influences the amount the coating materials on the heater surface. In most papers which is reporting the results of the pool boiling CHF test for nanofluids, the exact heating time is not described according to the heat flux level. The heating time is also an important factor that determines the amount of coated material.

In this work, the CHF experiments were conducted to analyze the coating effect by changing the heating time at constant heat flux level.

2. Experimental Methods

2.1 Preparation of test fluid

Alumina nanofluid is prepared by dispersing nanoparticles into the distilled water as a base fluid. Alumina nanoparticles were manufactured by Sigma Aldrich Corporation (size < 50nm, thermal conductivity = 36 W/mK). The concentration of nanofluid is 0.01V%. The prepared nanofluid was performed for 2h with the sonication processing for the more uniform and stable dispersion and suspension.

2.2 Experimental apparatus and procedure

The heating method on test section is joule heating. The experiment is consisted of rectangle vessel (100mm × 50mm × 120mm), copper electrodes, Teflon cover, reflux condenser, power supply, data acquisition device, hot plate and standard resistor. The concentration of nano-fluid is maintained by the Teflon cover and the reflux condenser. Data obtaining from the data acquisition device which is connected to the upper part of electrodes and standard resistor is saved and analyzed. The material of heating wire is nickel-chrome (80/20).

Before the experiments, the state of fluid was maintained at saturated temperature. Pre-coating process was carried out from 1 to 180 minutes at $600 kW/m^2$.

3. Results and discussion

3.1 CHF Enhancement Results

The first pool boiling experiments were performed with distillated water to confirm the repeatability and reproducibility. The experimental CHF value is 10% lower than prediction of CHF of distillated water using the Zuber's correlation. Heating time affects CHF positively in the region of a relatively short pre-coating time as shown in Fig 1.

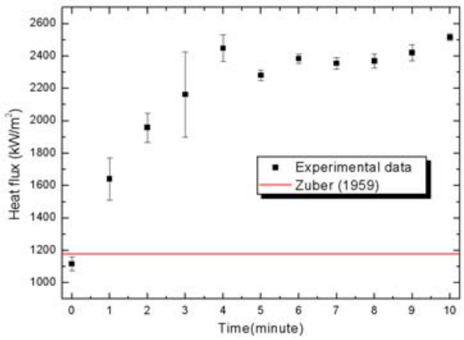

Fig. 1. Result of CHF enhancement depending on pre-coating time (1 to 10 min.)

The trend of CHF change is slowly decreased as pre-coating time is incrased as shown in Fig 2. It is a reasonable phenomenon. When more nanoparticles are coated on the heater surface but not heat transfer area is limited, the heat resistance which is disturbing the heat flow is increasing.

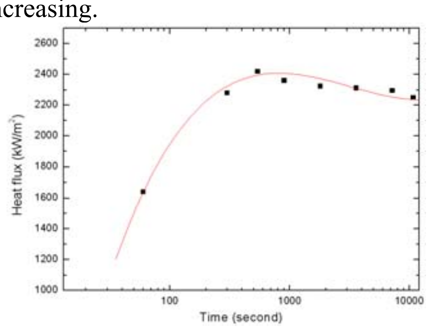

Fig. 2. Result of CHF enhancement depending on pre-coating time (1 to 180 min.)

3.2 Contact Angle

Many researchers explored the CHF enhancement mechanisms for nanofluids. One of the mechanisms is that CHF increase could be caused by the improved wettability of heater. The static contact angle was measured for sessile droplets of pure water (1μl) at

25℃ in air on the clean and nanoparticles coated surfaces boiled in nanofluids. Low values of the contact angle correspond to high surface wettability. Although measured contact angle is not receding contact angle, gradual decrease of the contact angle on the coated surfaces could account for enhanced CHF using Eq. (1). The dramatic decrease of contact angle was observed on the coated heater surface. But the results of contact angle are not uncovering the slight decrease of CHF in high pre-coating region.

$$q''_C = h_{fg}\rho_g^{1/2}\left(\frac{1+\cos\beta}{16}\right)\left[\frac{2}{\pi}+\frac{\pi}{4}(1+\cos\theta)\cos\varphi\right]^{1/2}[\sigma g(\rho_f-\rho_g)]^{1/4} \quad (1)$$

where h_{fg} is latent heat of evaporation, ρ_g and ρ_f are the gas and liquid density relatively. σ is the surface tension. β is the receding contact angle and θ is heater orientation.

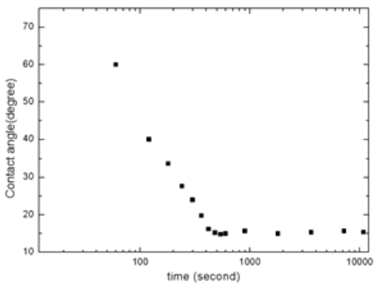

Fig. 3. Static contact angle according to pre-heating time (water, 1μl)

3.3 Wavelength between the Droplets

Hydrodynamic instability theory has been known as model of Zuber who proposed initially. Observed distance between the bubbles is individually different. The nanoparticle-coated surface has a shorter average distance compared with a bare surface. A case of high pre-heating time has a short wavelength in this work. A short wavelength allows to the vapor to prevent the formation of bulk vapor by venting the vapor equally across the heater surface. And a short wavelength is to have the enlarged wetting surface by allowing the liquid to break through which means the enhancement of CHF. But the results of wavelength are not similarly uncovering the slight decrease of CHF in high pre-coating region.

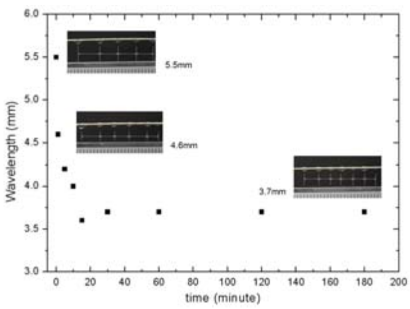

Fig. 4. Wavelength angle according to pre-heating time

3.4 Coating Thickness & Porosity

Coating thickness was measured by analyzing the SEM images. The thickness is continually increased but the gradient is becoming gentle. Reversely, porosity is decreased as the pre-boiling time is longer. It means that the coating layer formed by nanoparticles is becoming dense. It is clear the coating layer functions as a heat transfer resistance.

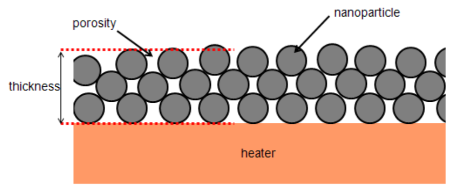

Fig. 5. Schematic diagram of nanoparticles coating layer

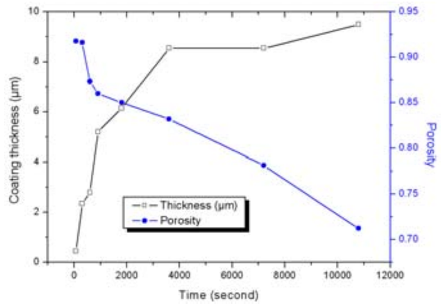

Fig. 6. Coating thickness & porosity according to coating time

4. Conclusions

The following results are obtained.

- CHF of nanofluids was continuouly enhanced until some point.
- In case of the high pre-coating time, CHF is gradually decreased. It is reasonable in a view of heat transfer.
- The CHF enhancement of cases which have short boiling time could be explained by the increased wettability and hydrodynamic instability change.
- The gradual decrease of CHF could be described by decrease of porosity in the coating layer.

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