Experimental Investigation of Bubble Dynamics in Nucleate Pool Boiling for TiO_2 nano particle coated surface.

Yongwook Shin [a] , Won Seok Han, Jae-young Lee [a*],
[a]*School of Mechanical and Control Engineering, Handong Global Univ., Pohang,Gyeongbuk, 791-708, Korea*
[*]*Corresponding author: jylee@hgu.edu*

1. Introduction

Enhancement of CHF of heater in the nano-fluid or nano-particle coated surface in the fresh water has been intensively studied. It was known that the wettability change and formation of the micro-porous structure on the nano-particle coated heater surface cause CHF enhancement [1]. These changes on the heater surface will affect bubble departure dynamics but studies on the bubble dynamics on the nano-particle coated surface are rare. Therefore, the present study is performed to measure the bubble departure characteristics experimentally and to find one of reasons of CHF enhancement.

Zuber[2] correlated the multiplication of the bubble diameter and departure frequency as the drift velocity which appear again in his CHF correlation: $fD = 0.092 m/s$ for the boiling water on the copper heater at atmospheric pressure. However, Ivey[3] categorized three distinguished region based on the dominant physics: $fD^{3/4} = 0.44$ for the small bubbles from 0.2 to 0.5cm, $fD^{1/2} = 0.90 g^{1/2}$ for the mushroom like large bubble (D > 0.5cm) but for the thermal region $fD^2 = consant$. All of these correlations are applicable to the bare heater on the fresh water not for the bare heater in the nano fluid or nano-particle coated heater in the fresh water. Therefore, in the present study, we measured bubble departure diameter and frequency for both bare surface heater and TiO_2 nano-particle coated heater to explain partly why CHF of nano-particle coated surface is enhanced in term of macrolayer under the mushroom bubble.

2. Experimental Methods

2.1 Experimental Facility

A schematic of the experimental apparatus is shown in Fig. 1. A stainless steel vessel of 4L volume is used for water pool which is heated and maintained at water saturated temperature in atmospheric pressure of 100℃ by 1kW cartridge heater. Water vapor generated at the heater surface is condensed back to the pool by a condenser. Three 300W cartridge heaters are inserted in copper block where its top surface exposed to water with the diameter of 5mm and 10mm. Teflon is used for thermal insulation that prevents heat loss and evaporation except the heater surface. Three K-type thermocouples are mounted at the 5mm, 10mm, 15mm from the top of the copper block to measure the heat flux and the surface temperature of the heater.

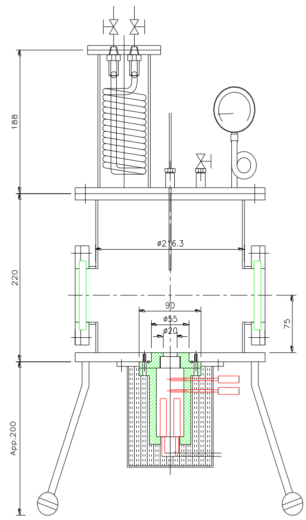

Fig.1. Schematic of the experimental apparatus

2.2 TiO_2 nano-particle coating

In this study, 0.35 vol% of 5-30nm TiO_2 nano-fluid is used to form nano-particle coated layer on the heater surface. The heat surface was coated by the TiO_2 nano-fluids and the surface temperature maintained 110 ± 5℃ for an hour.

2.3 Test procedure

Bubble observations are performed using the experimental setup shown in Fig. 1 and recorded with high-speed camera, Photron Fastcam Ultima 512. Heat flux is increased to CHF that on the conditions of both the uncoated and TiO_2 nanoparticle coated heater surface. For the diameter of 5 mm and 10 mm heater, bubble departure diameter and departure frequency was measured by image processing. Heat flux was calculated by the temperatures of mounted thermocouples. Hydra data logger 2625A, was used for measuring temperatures of the thermocouples. Uncertainty of heat flux was 10.41% for the experiments.

In high heat flux mushroom bubble region, the mushroom bubble growing period is defined by the instantaneous time of the mushroom cap generated on the surface to detaching time of the cap from the surface. The mushroom bubble departure frequency is a reciprocal of the mushroom bubble growing period.

3. Results

The measured departure diameter and frequency of bubbles on the bare surface heater and nano-particle coated heater are depicted in Fig.2. Also, the present experimental data are compared with various exiting correlations of Zuber[2] and Ivey[3].

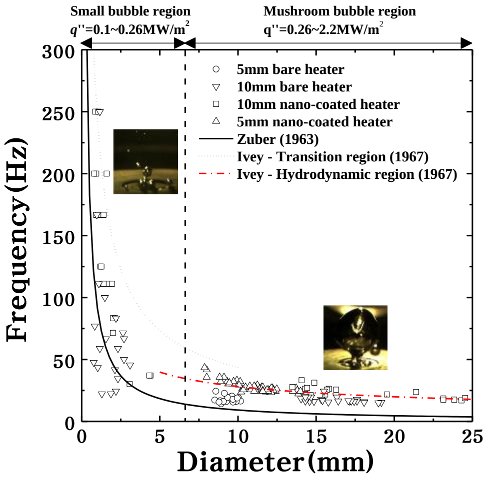

Fig. 2. Diameters and frequencies of low heat flux small bubble region (left side) and high heat flux mushroom bubble region(right side)

The present experimental data showed a good agreement with Zuber[2] for the small diameter bubbles (D<5mm). However, for the large bubbles, the best fit is made by Ivey[3] for the hydrodynamic region. Different departure characteristics between the small bubbles and large bubbles are made by the transient nucleate boiling: in the figure the dashed line. The experimental data of the bubbles from the nano-particle coated surface are higher frequency than the bubbles form the bare heater. However, for the large bubbles more large deviation is observed as shown in Fig. 3.

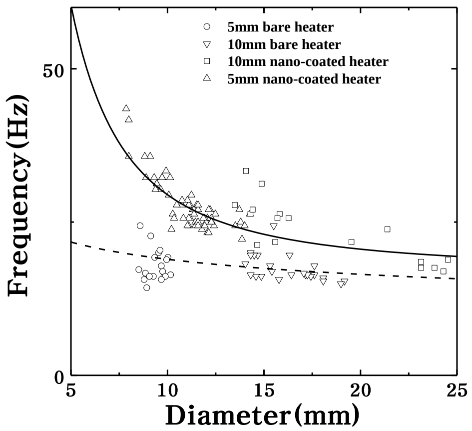

Fig. 3. Comparison of Diameter with Frequency in high flux mushroom bubble region

Katto and Yokaya[5] explained CHF related to the macrolayer thickness δ_c and the bubble departure frequency *f*.

$$q''_{CHF} = \delta_c \rho_l H_{fg} f$$

We can estimate macro layer at the CHF for the nano-particle coated heater. As shown in Fig. 5, the present data shows the thicker macro-layer of CHF which is the one of cause of CHF enhancement in the nano- fluid or on the nano-particle coated heater.

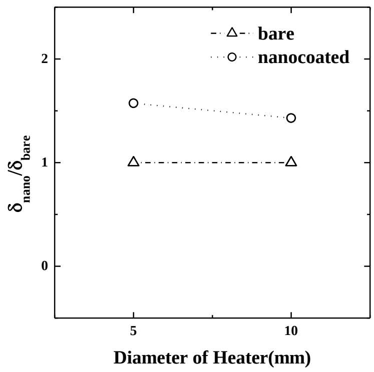

Fig. 5 The increase of the macro-layer of CHF for the nano- particle coated heater

The departure diameter of mushroom bubble is increased with the heater diameter. For the same bubble diameter, the departure frequencies of the nano-coated heater surface in mushroom bubble region, have obviously higher values than the bare surface.

4. Conclusion and Discussion

In the present study we measured bubble departure diameter frequency and diameter by changing the heater size, power and surface condition. It was found that the departure frequency of the nano-particle coated heater is in general larger than that of bare heater, which is partially associated with the contact angle and porous structure. This high frequency of the bubble departure also associated with the thicker macro-layer for the mushroom type bubble near the CHF condition. Therefore, the present study represents the role of macro-layer on the CHF partly.

ACKOWLEDGEMENT

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REFERENCES

[1] Kim, S.J., Bang, I.C., Buongiorno, J., Hu, L.W., Surface wettability change during pool boiling of nanofluids and its effect on critical heat flux, Int. J. Heat Mass Transfer 50 (2007) 4105–4116.
[2] Zuber, N., Hydrodynamic aspects of boiling heat transfer, US AEC Rep. AECU 4439, Tech. Inf. Serv. Oak Ridge, Tenn. 1959.
[3] Ivey, H.J., Relationships between bubble frequency, departure diameter and rise velocity in nucleate boiling, Int. J. Heat Mass Transfer 10 (1967) 1023–1040.
[4] Kim H., Kim M.H., Experimental study of the characteristics and mechanism of pool boiling CHF enhancement using nanofluids, J. Heat mass Transfer 45 (7) (2007) 991-998
[5] Katto Y.and Yokaya S., Principal mechanism of boiling crisis in pool boiling, Int. J. Heat Mass Transfer 11, 993-1002(1968)