Visual Observation of Bubble Departure Characteristics in the Nano-particle Coated Heating Surface

Won-Soek Han[a], Shin Yoo[a], and Jae-Young Lee[a,b]
[a]*School of Mechanical and Control Engineering*
[b]*Global Green Research Institute Handong Global University*
Heunghae, Pohang, Kyungbuk, Korea, 791-803
* *Corresponding author: jylee7@handong.edu*

1. Introduction

Although the great enhancement of the thermal conductivity of the nanofluids, the fluid mixed with small amount of the nano meter sized particles, has been known, many experimental data of the boiling heat transfer reported degraded heat transfer rate than the fresh fluid. However, the great enhancement of the critical heat flux in nanofluids has been reported by many investigators. Due to the opaque scattering of the nano particles in nano fluids, direct observation of the bubble dynamics in the boiling process has not been made. However, it has been known that the boiling heat transfer characteristics of the heater coated by the nano particles in the fresh water are almost similar to that in the nano fluid. Recently, consensus has been made in the understanding of the CHF enhancement of nanofluids or nano-particle coated heater as the surface phenomena. Therefore, in the present paper, we do experimental study to observe the bubble departure in the pool boiling process with the nano-particle coated heater.

2. Experimental Facility

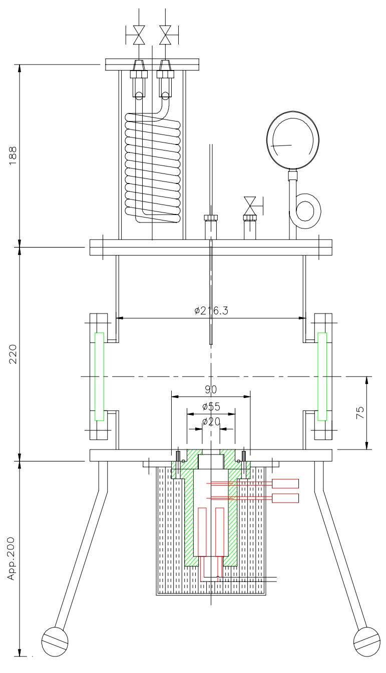

Fig. 1. Subcooled pool boiling Experiment Facility

To investigate the nanofluids subcooled boiling experiment in nucleate region, 0.35vol% of 10nm TiO_2 is used and experiment apparatus is designed as shown in Fig. 1. The experiment facility is divided into three parts. The first part is a main container with 1kW heater is fixed to maintain the fluid temperature we want to adjust. Second part is consists with a condenser to resupply vaporized water during the experiment.

Third part of the facility is consists of three 300Watt heaters fixed in a copper block. Diameter of 20 mm copper surface is exposed on main container where heat transfer occurs through the nanofluids. To investigate the heat transfer occurrence, heat flux is measured with three K-type thermocouples inserted at 25mm, 40mm, and 55mm from the copper block surface. The subcooled boiling is done at temperature of 45°C.

3. Observation

3.1 Boiling heat Transfer

Three cases were tested: bare heater in the pure water and nano fluid, nano-particle coated heater in the pure water. The nano-particle coated heater is prepared by boiling 10 nm TiO_2 nanofluids for three hours. As shown in Fig. 2, the pure water experiments were recorded at all boiling regime even over CHF condition. However, due to the limit of power supply, CHF of nano fluid and the nano particle coated heater were not identified. Therefore, Fig. 2 only shows that the boiling heat transfer of nano fluid and nanoparticle coated surface is poor than that of the pure water.

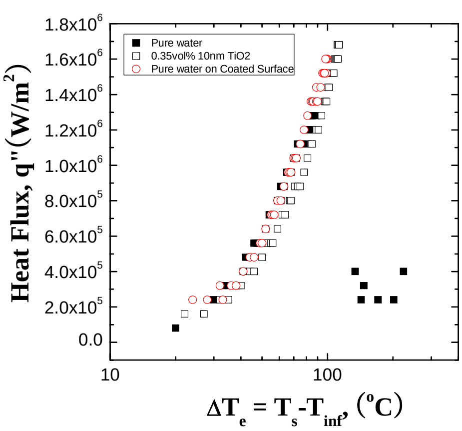

Fig. 2. Boiling Heat transfer curves for the bare heater in the pure water, bare heater in the nano fluid, and nano-particle coated heater in the pure water.

3.2 Visualization of the bubble dynamics

Bubble dynamics in the pool boiling process in both bare heater and the coated heater were observed using the high speed camera. Fig. 3 represents the bubble motion for the same wall temperature. Therefore, for the same wall temperature, the heat flux supplied to the water from the coated heater is little bit less than the bare heater. The left side picture is the bubble motion in the bare heater and the right side picture depicted the bubble motion in the coated heater. It is very clear that the bubble departure diameter of the coated heater is generally larger than the bubbles from the bare heater. It is somewhat abnormal if we recall the bubble departure correlation of Fritz. It was known that the bubble departure diameter depends on the contact angle, so the hydrophilic surface of the coated heater should produce smaller bubbles. Furthermore, the upper part of the heater of the bare heater was totally agitated by the rising small bubbles and eddies as shown in Fig. 3(7, 8, and 9). However, the upper region of the coated heater is still covered by the cold water and is very stable.

Also, the large bubble as the precursor of the CHF occurs in the bare heater, while there is no such a large bubbles appear in the coated heater.

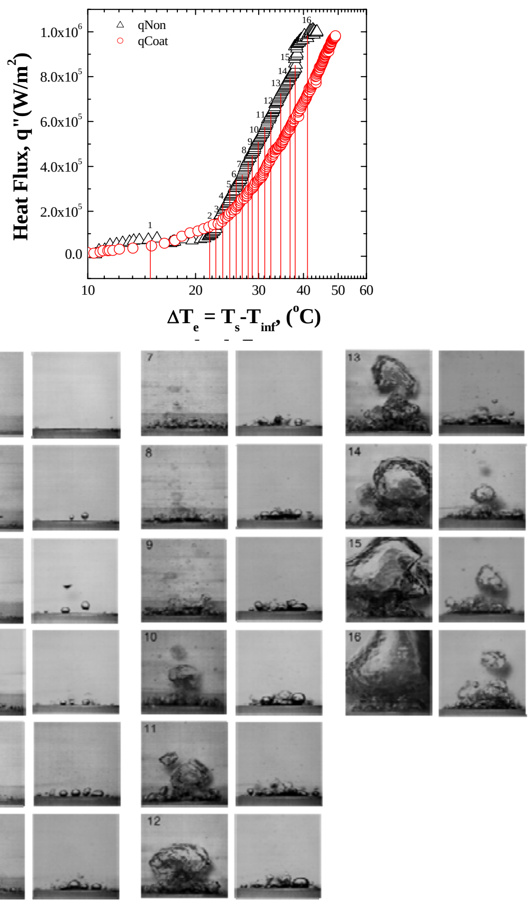

Fig. 3. Comparison of bubble behavior on the bare heater (left) and on the coated heater(right); the picture was taken for the same wall temperature with the different heat flux.

From these visual observations, the bubble departure dynamics of the coated heater of the boiling in the nanofluids shows totally different behavior form the traditional understanding of the bubble departure dynamics. In the present study, the bubble departure diameter and frequency are under measuring to identify the main cause of the higher CHF in the coated heater with the nano particle.

4. Conclusions

In the present study, flat plate pool boiling with the bare heater and the coated heater with the nano particles are experimentally studied. For this purpose, a test facility is constructed and furnished with the copper block with the heater and the thermocouples are mounted to measure the surface temperature. Using high speed camera, the bubble behavior for both heaters was visualized. It was found that the bubble size is large for the coated heater than the bare heater. It violates the traditional model of the bubble departure diameter which has the linear dependency on the contact angle. Furthermore, due to the limit of the tiny bubbles, the upper space of the heater is covered by the stable coolant in the coated heater. However, the jets of tiny bubbles and turbulent eddies in the bare heater provides a large chance of the bubble agglomeration which produce a mushroom type of bubble. Therefore, the CHF in the coated heater could be delayed up to very high heat flux which easily is over 200% of the CHF of the bare heater.

Acknowledgment

The present work is supported by the Korea Science and Engineering Foundation(KOSEF) grant funded by Ministry of Education Science and Technology(MEST).

REFERENCES

[1] N. Zuber, Hydrodynamic aspects of boiling heat transfer, US AEC Rep. AECU 4439, Tech. Inf. Serv. Oak Ridge, Tenn. 1959.

[2] N. Zuber, Recent trends in boiling heat transfer research Part I: nucleate pool boiling, Appl. Mech. Rev. 17 (1964) 663–672.

[3] M. Jakob, Heat Transfer, vol. 1, Wiley, New York, 1949 (Chapter 29).

[4] N. Zuber, Nucleate boiling. The region of isolated bubbles and the similarity with natural convection, Int. J. Heat Mass Transfer 6 (1963) 53–78.

[5] H.J. Ivey, Relationships between bubble frequency, departure diameter and rise velocity in nucleate boiling, Int. J. Heat Mass Transfer 10 (1967) 1023–1040.

[6] C.Y. Han, P. Griffith, The mechanism of heat transfer in nuclear pool boiling – Part I. Bubble initiation,