Investigation of Critical Heat Flux Enhancement in Flow Boiling using Nanofluids

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1. Introduction

The critical heat flux (CHF) is characterized by a sudden reduction of the local heat transfer coefficient (HTC) that results from the replacement of liquid by vapor adjacent to the heat transfer surface [1]. Ordinarily, the CHF represents the thermal limitation in which a phase change happens during heating. When the CHF occurs, an inordinate decrease in the heat transfer rate for heat flux and temperature controlled system generates. It is generally more important in applications such as power generation for heat flux controlled system, because of maintenance of the integrity occurring in heated surface. So, it is very important to enhance the CHF to ensure the system safety and improve the efficiency.

Many methods to enhance the CHF have been investigated and a new technique in recent years among these methods is nanofluids technology. Nanofluids are nanotechnology-based fluids engineered for enhancing thermal conductivity by dispersing and stably suspending nanoparticles in traditional heat transfer fluids [2]. One of the most interesting characteristics of nanofluids is their capability to enhance the CHF significantly.

2. Experiment

2.1 Preparation of Al_2O_3/DIW Nanofluid

Al_2O_3/DIW nanofluids are prepared by dispersing Al_2O_3 nanoparticles into deionized water as a base fluid. It is well-known that the properties of the nanofluids depend on the shape and size of nanoparticles. To identify the morphology of nanofluids, transmission electron microscopy (TEM) image is acquired. As shown in the image of Fig. 1, we identified that Al_2O_3 nanoparticles have a cylinder shape. Their size is less than 50 nm.

The process of preparation of Al_2O_3/DIW nanofluids is as follows: (1) weigh the mass of Al_2O_3 nanoparticles by a digital electronic balance; (2) put Al_2O_3 nanoparticles into the weighed deionized water and prepare the Al_2O_3/DIW mixture; (3) sonicate the mixture continuously for 12 hours to obtain uniform dispersion of nanoparticles in deionized water.

In the present work, 0.01 vol% Al_2O_3/DIW nanofluid was prepared. In terms of the colloidal stability or stable nanoparticles-dispersion, zeta potential is a key parameter. Zeta potential of this nanofluid was 36 mV and it may say that this value is moderate stability.

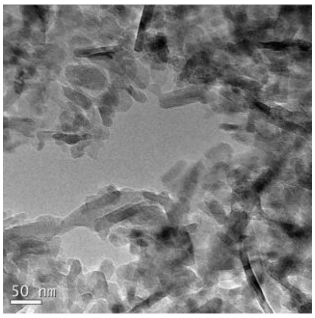

Fig. 1. TEM image of Al_2O_3 nanopaticles.

2.2 CHF Experiment

The influences of Al_2O_3/DIW nanofluid and fluid thermal hydraulic conditions (mass flux) on CHF have been experimented in flow boiling loop which is shown in Fig. 2.

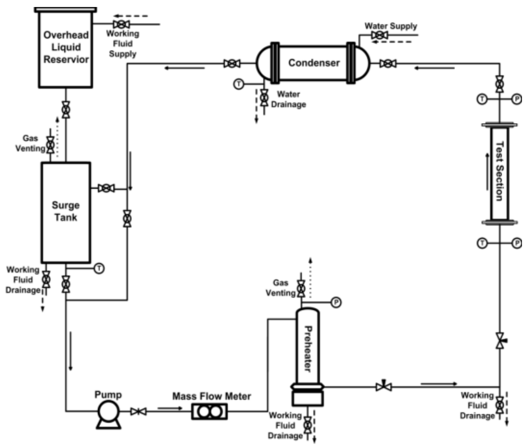

Fig. 2. Schematic diagram of experimental loop

Experiments were performed using 1/2 inch SUS 316L (length of test section : 0.5 m) when the mass flux is 200, 300, 500 kg/m^2s and inlet temperature is 25 ℃. The main components of the experimental system include an overhead liquid reservoir, a surge tank, a magnet turbine pump, a pre-heater to control the inlet temperature of the working fluid, a test section, a DC power supply and a condenser. The test section was installed to adjust the angle, in other words, the test section can be vertical and horizontal flexibly. Two piezoresistive transmitters were installed at inlet and exit of test section to monitor pressure of inlet and exit of test section. Also, eleven thermocouples were installed to monitor temperature of test section part, inlet and exit of test section, tank and condenser exit. The test section was direct electrically heated by a 75 kW DC power supply. Also, an Agilent data acquisition system was used to read the individual instrument outputs and translate them into physical parameters. A computer was used to sample all data periodically and to monitor the experiment.

The experimental procedure is as follows. The working fluid is flowed by a pump and heated by pre-heater to remove non-condensable gas and adjust inlet temperature. The voltage is increased stepwise until the CHF is occurred [3, 4]. Two runs were experimented for each condition (DIW and Al_2O_3/DIW nanofluids with smooth tubes).

3. Results and Discussion

All experiments were carried out in flow boiling under atmospheric pressure at fixed inlet temperature (25 ℃) and mass flow (200, 300, 500 kg/m^{2}s). The CHF results of DIW were compared to CHF look up table prepared by Groeneveld [5] as shown in Fig. 3. The experimental results were higher. In comparison with Groeneveld look up table, the critical steam quality was calculated using heat balance equation at first action.

The heat balance equation is as follows:

$$X_{cr} = \frac{1}{h_{fg}}\left[\frac{4q''z}{DG} - (\Delta h_{sub})_i\right] \qquad (1)$$

where, X_{cr} is the critical steam quality, h_{fg} is the latent heat of vaporization (MJ/kg), q" is the critical heat flux (MW/m^2), z is the tube length (m), D is the tube diameter (m), G is the mass flux (kg/m^{2}s), and Δ $(h_{sub})_i$ is the enthalpy inlet subcooling (MJ/kg).

As shown in Fig. 4, the CHF results of Al_2O_3/DIW nanofluid were enhanced at 300 kg/m^{2}s and 500 kg/m^{2}s. The CHF enhancement ratio was 15.47 % and 36.63 % at 300 kg/m^{2}s and 500 kg/m^{2}s. The cause of CHF enhancement is the deposition of Al_2O_3 nanoparticles on the inner surface of test section. So, the wettability of the liquid film on the heater surface is enhanced.

4. Conclusions

The following results are obtained.

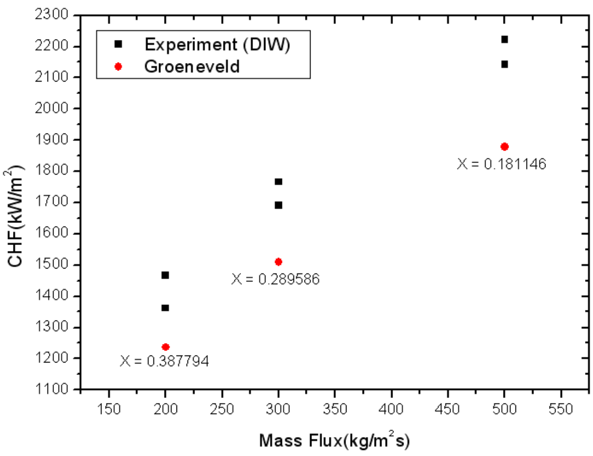

Fig. 3. CHF of DIW compared with Groeneveld look up table. (inlet temperature 25 ℃)

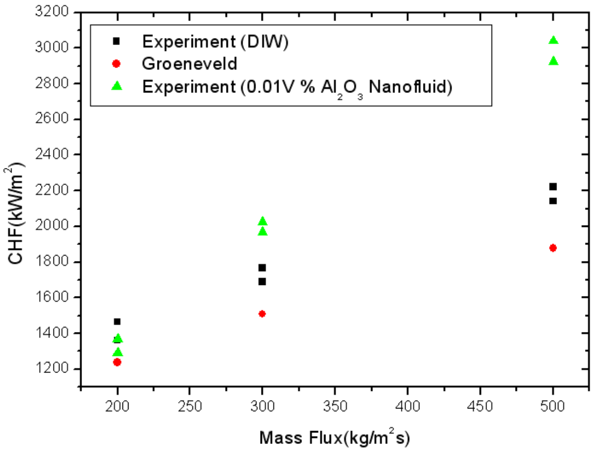

Fig. 4. CHF of Al_2O_3/DIW nanofluid with different mass flux (inlet temperature 25 ℃)

(1) In comparison with Groeneveld look up table, the experimental results of DIW were higher.

(2) The CHF enhancement ratio of Al_2O_3/DIW nanofluid was 15.47 % and 36.63 % at 300 kg/m^{2}s and 500 kg/m^{2}s. This is caused to enhanced wettability of the liquid film on the heater surface.

REFERENCES

[1] Soon Heung Chang, et al., Critical Heat Flux Enhancement, Nuclear Engineering and Technology, Vol. 38, No. 8, 2006.

[2] Stephen U. S. Choi, Nanofluids:From Vision to Reality Through Research, Journal of Heat Transfer, Vol. 131, March 2009.

[3] Tae Il Kim, et al., An experimental study on CHF enhancement in flow boiling using Al_2O_3 nano-fluid, International Journal of Heat and Mass Transfer, Vol. 53, pp. 1015-1022, 2010.

[4] Saeid Vafaei, et al., Critical Heat Flux (CHF) of Subcooled Flow Boiling of Alumina Nanofluids in a Horizontal Microchannel, Journal of Heat Transfer, Vol. 132, 2010.

[5] D. C. Groeneveld, et al., The 1995 look-up table for critical heat flux in tubes, Nucl. Eng, Vol. 163, pp 1-23, 1996.