Critical Heat Flux Enhancement using Graphene Oxide Nanofluid in Flow Boiling

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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. It is generally 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.

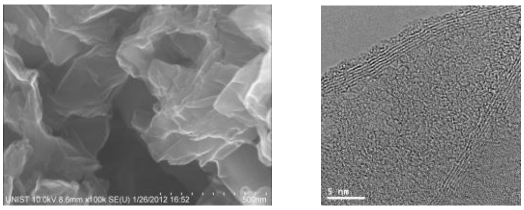
Many methods to enhance the CHF have been investigated and a new technique in recent years among these methods is nanofluids technology. Nanofluids are nanotechnology-based fluids engineered for enhancing thermal conductivity by dispersing and stably suspending nanoparticles in traditional heat transfer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

2. Experiment

2.1 Preparation of GO/water Nanofluid

GO/water nanofluids are prepared by dispersing GO nanosheets into water as a base fluid. GO nanosheets in this study were manufactured by the method of chemical vapor deposition (CVD). Chemical vapor deposition method is a chemical process used to manufacture high purity and performance materials and to produce thin films. It is well-known that the properties of nanofluids depend on the shape and size of the nanoparticles. To identify the morphology of the nanofluids, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were performed. As can be seen in the images in Fig. 1, we identified that GO nanosheets have the shape of the plate and the thickness of one layer is less than 1 nm.

In the present work, 0.01 volume % GO/water nanofluid was prepared. In terms of the colloidal stability or stable nanoparticles-dispersion, zeta potential is a key parameter. The pH and the zeta potential of the GO/water nanofluid was 3.58 and –31.5 mV. It may be said that these values show moderate stability, because the absolute values of zeta potential are larger than 30 mV.



(a) (b)

Fig. 1. SEM and TEM images of GO nanosheets : (a) SEM image and (b) TEM image.

2.2 CHF Experiment

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

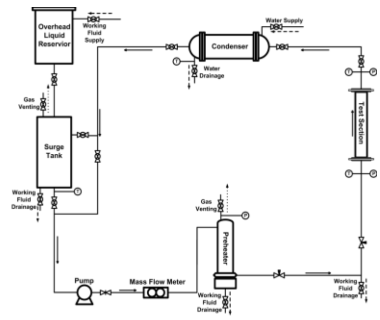


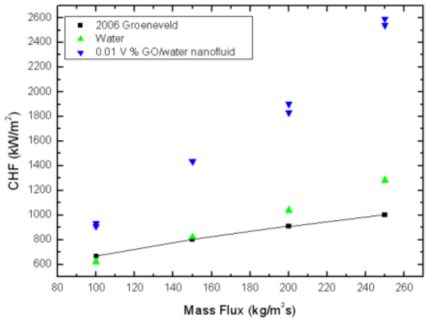
Fig. 2. Schematic diagram of experimental loop

Experiments were performed using 1/2 inch stainless steel 316L (the length of the test section : 0.5 m) with mass flux values of 100, 150, 200 and 250 kg/m^2s and inlet temperatures of 25 and 50 ℃.

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 (water and GO/water nanofluids with smooth tubes).

3. Results and Discussion

The CHF results for water were found to be similar to those in the 2006 Groeneveld look up table, as shown in Fig. 3. In this figure, the black line is the 2006 Groeneveld data. And, the CHF results for GO/water nanofluid were enhanced by the increase of the mass flux at inlet temperatures of 25 ℃ and 50 ℃. The CHF enhancement ratios of GO/water nanofluid were not increased with the increase of the mass flux at inlet temperatures of 25 ℃ and 50 ℃ because the deposition structure of nanoparticles according to the mass flux is different. The maximum CHF enhancement ratio was 100 % at an inlet temperature of 25 ℃ and mass flux of 250 kg/m^2s and the maximum CHF enhancement ratio was 72 % at an inlet temperature of 50 ℃ and mass flux of 250 kg/m^2s.



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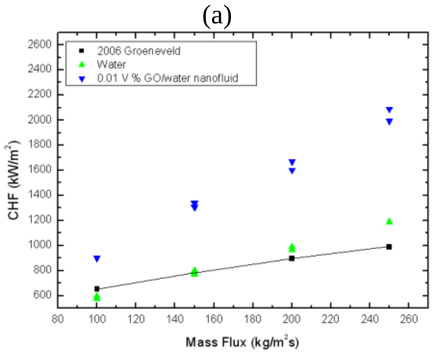
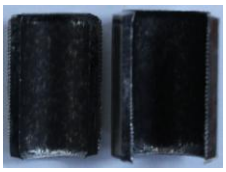


(b)

Fig. 3. CHF data with different mass flux according to inlet temperature: (a) T_{in} : 25 ℃ and (b) T_{in} : 50 ℃

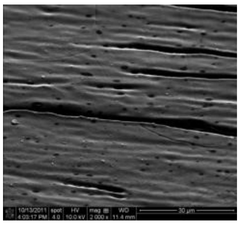
(a)



(b)

Fig. 4. Macroscopic observations of the inner surface of the test section after CHF experiments: (a) Water and (b) GO/water nanofluid

The CHF results for GO/water nanofluid were higher than those for water because of the enhanced wettability of the liquid film on the heater surface due to the deposition of nanoparticles. The deposition of nanoparticles occurs as the local dryout happens. This cause has been mentioned in a lot of papers. The macroscopic observations show the deposition of nanoparticles on the inner surface of the test section, as shown in Fig. 4. And, as can be seen in Fig. 5, SEM observations showed in more detail the deposition of nanoparticles. Also, the contact angle in the inner surface of the test section after CHF experiment with GO/water nanofluid (42.9°) was smaller than one of that after CHF experiment with water (60.5°) after injecting 10 μl of water as can be seen in Fig. 6. These results were shown that the deposition of nanoparticles increased the surface wettability.



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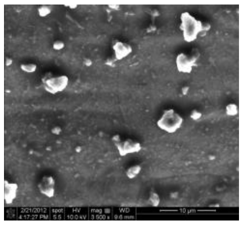
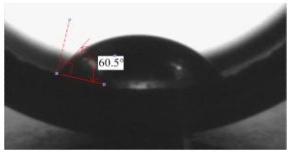
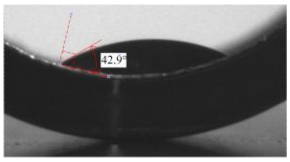


(b)

Fig. 5. SEM observations of the inner surface of the test section after CHF experiments: (a) Water and (b) GO/water nanofluid



(a)



(b)

Fig. 6. Contact angles of the inner surface of the test section after CHF experiments: (a) Water (60.5°) and (b) GO/water nanofluid (42.9°)

4. Conclusions

The following results are obtained.

(1) The maximum CHF enhancement of the GO/water nanofluid was 100 % at an inlet temperature of 25 ℃ and mass flux of 250 kg/m^2s and 72 % at an inlet temperature of 50 ℃ and mass flux of 250 kg/m^2s.

(2) The CHF enhancements of nanofluids were found to have caused enhanced wettability of the liquid film on the heater surface due to the deposition of nanoparticles. This is confirmed through SEM observations and contact angles.

REFERENCES

[1] S. H. Chang, Y. H. Jeong, and B. S. Shin, Critical Heat Flux Enhancement, Nucl. Eng. Technol., Vol. 38, pp. 753-762, 2006.

[2] S. U. S. Choi, Nanofluids:From Vision to Reality Through Research, Journal of Heat Transfer, Vol. 131, 2006.

[3] T. I. Kim, Y. H. Jeong, and S. H. Chang, 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] V. Saeid and W. Dongsheng, 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, J. Q. Shan, A. Z. Vasic, L. K. H. Leung, A. Durmayaz, J. Yang, S. C. Cheng, and A. Tanase, The 2006 CHF Look-up Table, Nucl. Eng. Design, Vol. 237, pp. 1909-1922, 2007.