Highly-Enhanced CHF of Nanofluids containing Graphene and Graphene-Oxide Nanosheets without improved surface wettability

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1. Introduction

In boiling heat transfer, critical heat flux is the thermal limit of a phenomenon where a phase change occurs during heating. When CHF occurs, heat transfer coefficient decreases. This result causes overheating of heating surface for a controlled heat-flux system. Excessive decrease of heat transfer rate occurs for a controlled surface temperature system. To ensure the system safety and improve economical efficiency, it is required to know and enhance the CHF value.

Since You et al.[1] introduced a new way to enhance the pool boiling CHF value using nanofluids which have nanoparticles suspended in water, many pool boiling experiments have been done using a variety of nanofluids. Materials of nanoparticles include metals (e.g., silver, copper, gold), metal oxides (e.g., titania, alumina, silica, zirconia), carbon allotrope (e.g., carbon nanotube, graphite).

In this work, we prepared graphene and graphene oxide nanofluids by modified Hummers method. Graphene is a monolayer that consist carbon atoms. Suspended single-layer graphene has a good thermal conductivity, 5200W/mK. Graphene oxide is a compound of a carbon, hydrogen and oxygen. Graphene oxide is also the single-layer form of graphite. Surfaces of graphene and graphene oxide are hydrophobic. Many researchers explain CHF enhancement by surface wettability. We attempt to confirm effect of surface wettability. Alumina nanofluid is also prepared with same concentration to compare the wettability.

2. Description of experiment

2.1 Preparation of nanofluids

Alumina nanofluid is prepared by dispersing nanoparticles into the distilled water as a base fluid. Alumina nanoparticles were manufactured by Sigma Aldrich Corporation (size < 100nm, thermal conductivity = 36 W/mK). The concentration of nanofluid is 0.001V%. Eq. (1) is used to calculate the volume concentration of nanoparticle in nanofluids. The prepared nanofluid was performed for 5h with the sonication processing for the more uniform and stable dispersion.

Graphene and graphene oxide nanofluid are prepared from graphite as shown in Fig. 1. In this work, used graphite is manufactured by Sigma Aldrich Corporation (graphite powder, size < 45μm). Modified Hummers method is used in preparing the graphene and graphene oxide nanofluids. The concentration of graphene and graphene oxide nanofluids are 0.001V%.

$$\Phi_v = \frac{1}{(\frac{1-\Phi_m}{\Phi_m})\frac{\rho_p}{\rho_f}+1} \tag{1}$$

where Φ_m is the mass concentration of nanoparticles, ρ_p is the nanoparticle density, ρ_f is the liquid density.

(a) (b)

Fig. 1. Nanofluids (a) graphen oxide nanofluid (b) graphene nanofluid

2.2 Experimental procedure

The heating method on test section is joule heating. The experimental facility consists 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. Heating time remains the same during increasing the equal heat flux. The heat flux was calculated by obtained data in data acquisition system. Measured system resistance is 0.0004Ω.

$$R_w = \frac{V}{I} - R_s \tag{2}$$

$$q'' = \frac{I^2 R_w}{\pi DL} - R_s \tag{3}$$

where R_w is wire resistance, V is measured voltage, I is measured current, R_s is system resistance excluding the wire resistance. D is the diameter of wire. L is the length of heated wire.

3. Results and discussion

3.1 Critical Heat Flux

At first, the pool boiling experiments were performed with distillated water to confirm the repeatability and reproducibility. The experimental CHF value is $950 kW/m^2$ which is 5% lower than prediction of CHF of distillated water using the Zuber's correlation.

The CHF values of test fluids lists at Table I. Graphene oxide nanofluid shows the greatest CHF enhancement ratio. The CHF of graphene nanofluid was 84% higher than CHF of distillated water. Alumina nanofluid shows the 152% enhancement of CHF. After pool boiling experiments, coating layer is observed on the heating surface. Fig. 2 shows the SEM images of heating wire which shows the coating layer geometry.

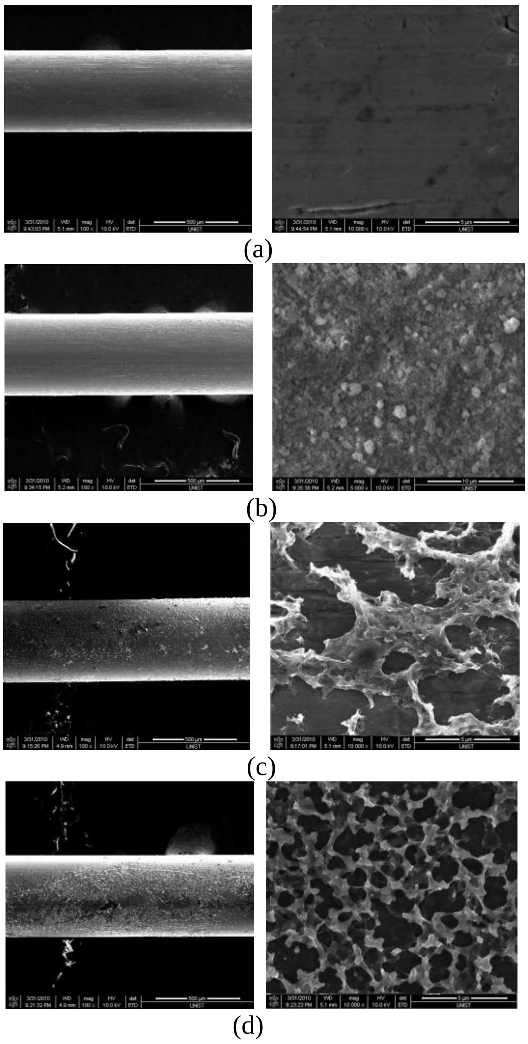

Fig. 2. SEM image of heater surface after pool boiling (a) Distillated water (b) Al_2O_3 fluid (c) Graphene fluid (d) Graphene oxide fluid; (left ×100, right ×10000)

Table I: The results of Critical Heat Flux for test fluids.

Fluids	CHF (kW/m^2)	Enhancement ratio (CHF/CHF_{water})
Distillated water	950	1
Al_2O_3	2400	2.52
Graphene	1750	1.84
Graphene oxide	2650	2.79

3.2 Contact angle

The degree of contact angle indicates the surface wettability. Higher wettability can produce CHF enhancement in previous literatures which mentioned the reason. But the result of observation of contact angle is in discord with the aforementioned fact. The contact angle of graphene oxide and graphene coated test wire is larger than pure wire.

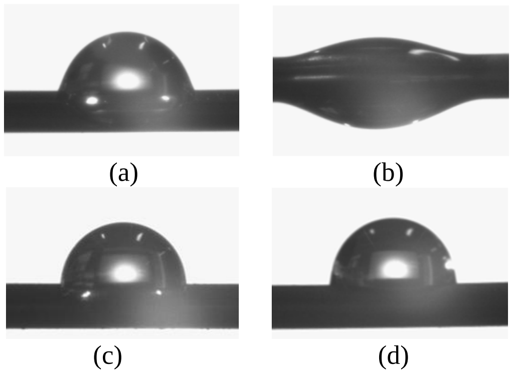

Fig. 3. Contact angle on tested wire surface with 1μl water (a) Pure wire (72°) (b) Al_2O_3 (15°) (c) Graphene (82°) (d) Graphene oxide (85°)

4. Conclusions

The following results are obtained.

(1) CHFs of Graphene, Graphene oxide and Al_2O_3 nanofluid were enhanced at 0.001V%.
(2) After pool boiling experiments, coated layer was observed with the each unique geometry.
(3) The wettability of coated wire by graphene and graphene oxide is worse than pure wire surface.
(4) Although the wettability of graphene oxide coated wire is worst on contact angle, the enhancement ratio is best in CHFs result.

Effect of thermal conductivity on CHF is not critical parameter in comparison with graphene and alumina nanofluids. We confirm heat transfer area between coated layer and fluid is applied as important factor.

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