

Experimental Study of Effect of Graphene Oxide Colloid on the Critical Heat Flux

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1. Introduction

Nucleate boiling is one of most efficient mode for heat transfer in real application such as power plants and chip cooling devices. In the heat flux controlled systems, its operating conditions are limited by the critical heat flux (CHF), where vapor film covers entire heating surface so that the surface temperature rapidly increases and melts down, resulting in a severe accident. In order to delay the CHF phenomena, nanofluids as working fluid are well-known as a possible method. Graphene is a new material having extraordinary thermal property and the method to synthesize the graphene as colloid was developed [1, 2, 3]. Park et al. [4] firstly reported the CHF performance of the graphene oxide (GO) and the reduced graphene oxide (RGO) colloid. The GO and RGO colloid showed about 200% and 100% enhancement of CHF, respectively. Ahn et al. [5, 6, 7, 8] reported the boiling performance of RGO colloid and unique structure formation of RGO flakes, so called self-assembled three-dimensional foam-like graphene network (SFG), on the heating surface. The important point of boiling study on the graphene based material is that their CHF enhancement could not be explained by existing theory based on wetting analysis. In this study, we carried out the pool boiling CHF experiments in GO colloids. For analysis of surface characteristics, we conducted scanning electron microscopy (SEM) observation and contact angle (CA) measurement.

2. Experiment

The pool boiling was conducted on wire heater for CHF measurement. The graphene oxide colloid prepared by one-step method was employed as working fluids and its concentration was controlled.

2.1 Preparation of Graphene Oxide Colloid

Graphene oxide colloid was prepared by the Hummer method [1, 2]. The natural graphite powder was chemically oxidized in the sulfuric acid condition. The oxygen group on the graphene oxide flakes helped the individual flakes to repulse each other so that it could be well dispersed in the distilled water. For GO colloid in the experiment, the graphite oxide powder in the distilled water was ultra-sonicated 1 hour and diluted into 0.0001% wt., 0.0005% wt. and 0.0010% wt.

2.2 Pool Boiling Experimental Apparatus

The pool boiling experimental apparatus consisted of main pool, wire heater, and data acquisition system. The main pool containing the working fluid was 250 x 140 x 250 mm³ rectangular glass bath. The bath was placed on the hot plate to heat and maintain the working fluid to be saturated. The upper side of bath also covered with Teflon plate where the reflux condenser using tap water circulation was employed to maintain water level and the atmospheric pressure.

The commercial NiCr wire heater of 0.2 mm diameter and 79.2 mm length was used for heating surface and connected SUS electrodes which were mounted the bath cover. DC power was employed for joule heating. By measuring the voltage of the heater and reference resistance of 1 ohm, the power and the heat flux applied to the heater was calculated.

The working fluid was preheated for 2 hours for degassing process. The heat flux continuously increased until CHF with constant rate of 100kW/m² per min. When the CHF occurred, the wire broke due to tension between the two electrodes and the experiment was over. For represent data, the experiment was repeated ten times for each case.

3. Results and discussion

In the boiling, the bubble dynamics on the heating surface made nano-sized particle deposited on the surface and changed the surface characteristics. In order to change the characteristics, we changed the concentration of GO colloid; 0.0001% wt., 0.0005% wt., and 0.0010% wt. and compared them with a reference CHF data in the distilled water.

The CHF of distilled water case was 978 kW/m² with standard deviation of 70 kW/m². The CHF results of 0.0001% wt., 0.0005% wt., and 0.0010% wt. cases of GO colloids were 1170 kW/m², 1337 kW/m², and 1662 kW/m², respectively. Moreover, the standard deviations of each case were 98 kW/m², 116 kW/m², and 165 kW/m², respectively. As the concentration increased, the CHF was delayed in Fig. 1.

In general, the deposition process of the particles in the colloid was proportional to the concentration, the heat flux, and the boiling time. They could form unique nano/micro structures by bubble dynamics in boiling, with resulting in enhancement of surface characteristics

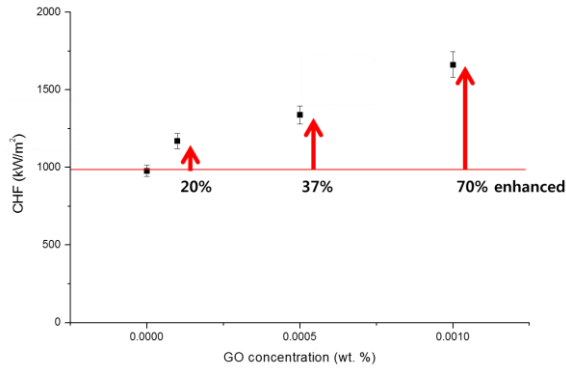


Fig. 1. CHF enhancement with various concentration of GO colloid in which the concentrations were 0.0001% wt., 0.0005% wt., and 0.0010% wt.

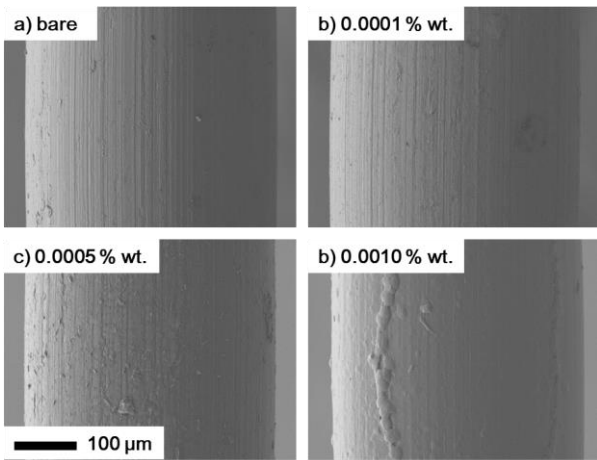


Fig. 2. Surface morphology of GO flake coated layer after CHF experiments

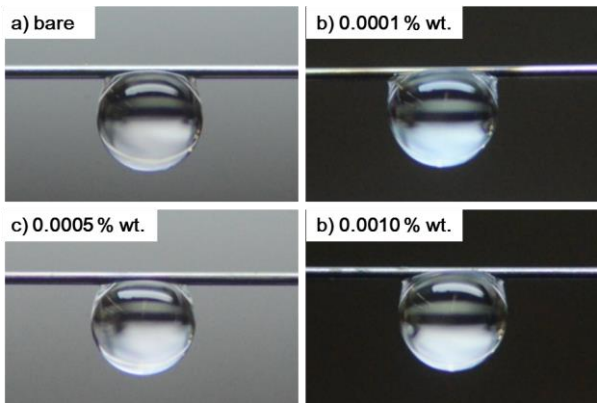


Fig. 3. Contact angle on the GO coated layer.

related with boiling phenomena.

In order to observe the morphology of GO coated layer on the wire heater after the CHF experiments, the scanning electron microscope (SEM) was employed. The GO flake formed a 2D smooth surface by bubble dynamics in Fig. 2., in contradiction to the RGO flakes where the RGO flakes formed 3D structure [5]. This indicated that the CHF enhancement in GO colloid could not be explained by enlargement of surface area induced by deposition layer.

Next, we measured the contact angle on the wire after CHF experiment, but there was almost no change from bare Nichrome wire as in Fig. 3. (bare: 72°, 0.0001% wt.: 68°, 0.0005% wt.: 67°, 0.0010% wt.: 67°). So, wettability also could not explain the CHF enhancement of GO colloid.

3. Conclusions

The CHF enhancement of GO colloids was investigated in this study. To control the surface condition of GO deposition layer, the concentration was changed. As the concentration increased, the CHF performance was enhanced. In order to explain the CHF enhancement, we conducted morphology analysis and contact angle measurement. The deposition layer, however, showed 2D smooth surface and no wettability enhancement.

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