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# Doubling of critical heat flux using a grapheme oxide nanofluid and its repeatabiltiy

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## 1. Introduction

CHF(Critical Heat Flux : heat flux which makes dramatic increase of temperature on heater surface) is one of the most important phenomena in the thermal hydraulic system. High CHF makes more thermal margin of heat transfer. This makes high efficiency and safety of power plant especially in nuclear power plant. Much smaller danger can be concerned to public society like radioactive material leakage in the accidents.

Graphene Oxide which can be deposited on the heater surface makes nano-scale structures with enhancing thermal limit of heater. Three major models of enhancing limit of heater have been concerned in many heat transfer studies. In this study, wettability[1] that is about ability to wet on surface and thermal activity[2] which is about thermal property of coated layer are concerned to analyze the mechanism of CHF enhancing.

Also, chemical reduction of Graphene Oxide(GO) to Reduced Graphene Oxide(RGO)[3] on the surface will be concerned with one reason of changing wettability of nano-scale structure on the heater surface. We used GO nanofluid 0.001 volume percent.

## 2. Experimental procedure

Nichrome wire with diameter of 0.5mm is used for joule-heating in 90.5mm * 40.5mm * 120mm water tank. Electrode is Teflon coated copper bar to prevent oxidation of copper electrode. Condenser is used to preventing concentration change of nanofluid.

Graphene oxide nanofluid with 0.001 volume % is used. 30min sonification is used. Voltage divided into 40 steps to CHF point and, to make stationary state, each steps maintained for about 45 seconds.

Whole current in the circuit is calculated with $V_2$ ($R_2$=0.001ohm). The resistance of specimen is calculated with $V_1$. The whole calculation formula is below.

$$I = \frac{V2}{R2} \;,\; q'' = \frac{I^2 R}{\pi DL} \qquad (1)$$

$$T_s = T_* + \left(\frac{R}{R_*} - 1\right)\frac{1}{\alpha} \qquad (2)$$

To calculate specimen temperature for each step, the steady state of each voltage step is used.

For measuring contact angle on the coated nichrome wire, different time steps are conducted to coat wire with GO nanoparticle. Heat flux of about 500kW/m$^2$ is used

## 3. Results and discussion

### *2.1 Boiling Curve*

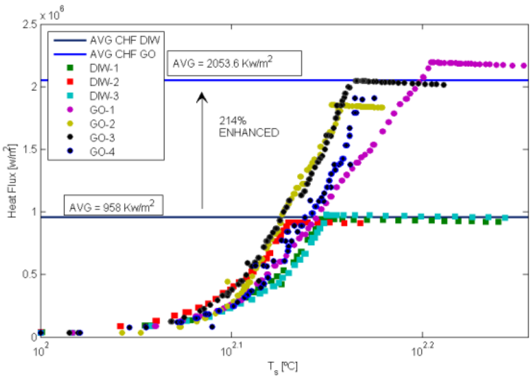


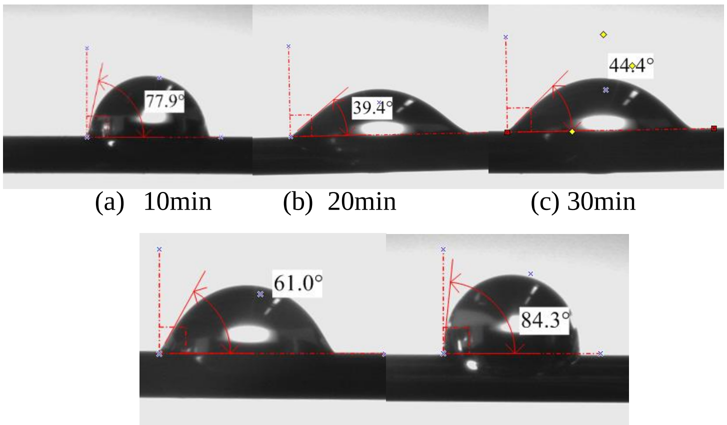

Fig. 1. Boiling curve of DIW and GO nanofluid

For DIW(deionized water), CHF is measured 958kW/m$^2$ in average. Using GO nanofluid, CHF is enhanced up to 2053.6kW/m$^2$ which is 114%. Also, surface superheat temperature is increased. Using DIW, CHF takes place in about 140 $^{o}$C. Using GO nanofluide, CHF takes place in about 150 $^{o}$C. The summarized results are shown in Table 1. This GO nanofluid pool boiling test suggests that this fluid can enhance the CHF with respect to pure water.

Table 1. CHF and surface super heat temperature

| | DIW | GO nanofluid | Increasing ration |
|---|---|---|---|
| CHF[ kW/m$^2$ ] | 958 | 2053.6 | 214% |
| CHF temperature [ ℃] | 140 | 150 | 107% |

2.2 Wettability.




(a) 10min (b) 20min (c) 30min

(d) 40min(CHF) (e) bare wire

Fig. 2. Contact angle with different coating times. Average = (a) 77.05° (b) 40.07° (c) 44.5° (d) 61.07° (e)

Contact angle has relationship with surface wettability. If contact angle is small, the wettability of liquid and surface is big(hydrophilic). And if contact angle is large, the wettability of liquid and surface is small(hydrophobic). It is easy to know that if coolant wet easily on the surface, CHF is higher than specimen which has low wettability.

Tendency in figure 2 shows surface wettability of nichrome wire heater gets smaller to 20min coating and then gets bigger after that. Finally, the contact angle of 40min coating has 61 ° which has just difference of 23.3 ° from bare wire. CHF enhancement is the result of hydrophilic surface.

GO has big electrical polarity compared to just graphene. Grephene has no electrical polarity because the composition of graphene is just graphite. But with oxygen in GO, polarity is made. One reason of these phenomena is that GO and water can be mixed but RGO (after experiment) cannot be mixed with water.

This re-increasing the contact angle tendency from 20min coating can be understood as reducing GO to RGO which has property of less hydrophilic. The balance of deposition of GO, deposition of RGO, and reducing GO to RGO can make this tendency. Temperature and voltage difference between heater surface and nanofluid can make this reduction.

2.3 thermal activity

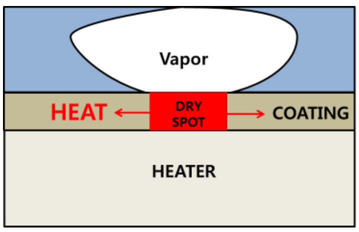



Fig. 3. Dry spot model

For the surface property, the thermal activity is parameter of CHF prediction models. This CHF model explains CHF with heat conduction in the dry spot. There is dry spot in the contact of vapor region and heater surface region. This spot has larger temperature which can make divergence of temperature distribution (Fig. 3.). This distribution means the heat flow each other side. If heater surface cannot afford this heat flow, the heat deposits to dry spot and then gets to the critical heat flux with high temperature and rupture. Thermal activity and CHF equation is,

$$S = \delta\sqrt{\rho_h c_h k_h} \qquad (3)$$

$$\frac{q''}{q''_c} \propto \frac{S}{S+\omega} \qquad (4)$$

$\delta$ is thickness and $\omega$ is asymptotic limit.

Thermal activity is parameter of effect of coated layer's physical property; thickness, density, specific heat and thermal conductivity.

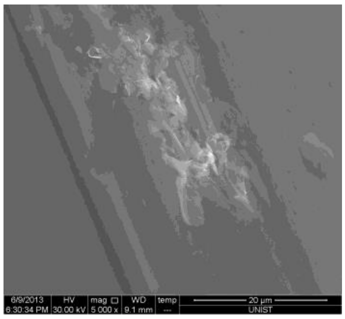


Figure 4. SEM image of 40min coated(5000X)

In Fig 4., the coated layer is not thick to have big effect in thermal activity although Graphite layer has big thermal property.

**3. Conclusion**

Two models are compared to explain how CHF is enhanced. Results show wettability increased with slightly reduced GO and structure. And in thermal activity model, the most powerful term, thickness of layer, is too small to affect thermal activity. It has low ability to explain how GO nanofluid can enhance CHF.

**REFERENCES**

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