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A Comparative Study on the Critical Heat Flux Characteristics of Oxidized Multi-Walled Carbon Nanotube and Graphene Nanofluids

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1. Introduction

Boiling heat transfer is one of the most important processes in the various industries such as power generation, heat exchangers, cooling of high-power electronics components and cooling of nuclear reactors. The critical heat flux (CHF) phenomenon is signified the thermal limit during a boiling heat transfer. The heat transfer coefficient before the CHF is high enough to attain a high heat flux at a relatively low surface heat [1]. However, the heat transfer coefficient remarkably decreases after the CHF occurs therefore the heating surface temperature of heat-transfer apparatus should be greatly increased. This induces risk of physical failure of heat transfer apparatus. Therefore, enhancement of CHF is essential for safety and economic efficiency of heat transfer system. In this study, the CHF characteristics of oxidized carbon nanotube and graphene nanofluids under the pool boiling state were comparative analysis.

2. Experiment apparatus and method

2.1 Materials

In this study, multi-wall carbon nanotubes (Hanwha-Nanotech Co.) and Graphene (XG Sciences Co.) fabricated by Chemical Vapor Deposition (CVD) were used. The physical properties of the MWCNT and Graphene are listed in Table 1, and Fig. 1 shows SEM micrographs of MWCNTs and graphene. As indicated in the table, carbon nanotube and graphene used in this study, both of which are carbon allotropes but with different shapes, have the same thermal conductivity.

2.2 Oxidation treatment

Sulfuric acid (98%) 8 ml and nitric acid (63%) 22 ml were mixed. Subsequently, 2 g of nano particles was added to produce a 30 ml liquid mixture. The mixture was stirred for 24 h at 110 8C. The acidic mixture of nano particles containing carboxyl radicals was then diluted by adding 1000 ml of distilled water. This process of washing and filtration was repeated until a pH of 7 was reached. The filtration equipment consisted of a decompression filtration filter holder (KGS-47) and a PTFE-type hydrophilic membrane filter with a hole size of 0.2 mm. The moisture was removed by placing the nano particles mixture in a vacuum oven for 48 h maintaining at 60 8C, resulting in the production of 1.7 g of oxidized nano particles

Table 1: Properties of MWCNTs and Graphene

Properties	MWCNTs	Graphene
Diameter(㎚)	10-15	15
Length(㎛)	10-20	-
Thickness(㎚)	-	6-8
Purity (wt.%)	95	>99.5
Bulk Density(g/cm^3)	0.1	0.03-0.1
True density(g//cm^3)	1.8	2.2
Thermal conductivity(W/m·K)	3000	3000
Surface Area(m^2/g)	200	120-150

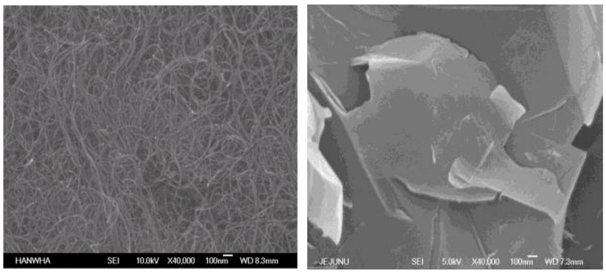

Fig. 1. SEM micrographs of MWCNTs and graphene.

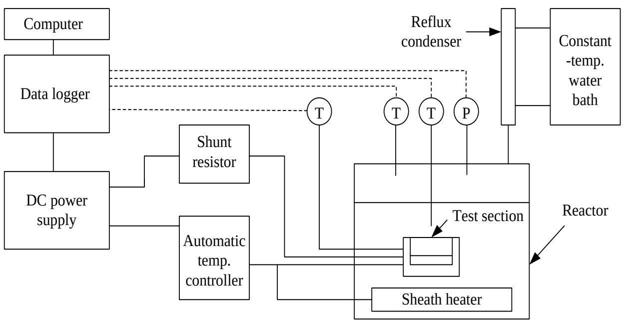

Fig. 2. Schematic diagram of CHF experimental apparatus.

2.3 Experimental apparatus and method

Fig. 2 shows a schematic diagram of the boiling heat transfer experimental apparatus. It is composed of a pool boiling vessel (SUS 316), a constant temperature water bath, a shunt resistance to measure the supplied heat quantity, DC power supply, two automatic temperature controller, a data logger and a computer for collection and saving of data. And the pool boiling vessel consisted of the test section, reflux condenser, sheath heater, two T-type thermocouples and a pressure sensor. The rectangular flat-plate test section is composed of a zirconium specimen(9.53 mm × 9.53 mm × 4mm) and, as the test section heat source, a 25 Ω heat-resistor heater (9.53 mm × 9.53 × 2.00 mm) and three T-type thermocouples.

In this study, CHF and boiling heat transfer coefficient are calculated using equations (1) and (2).

$$q'' = h(T_{wall} - T_{sat}) \quad (1)$$

$$h = \frac{Q/A}{(T_{wall} - T_{sat})},\ Q = IV \quad (2)$$

Where, q'', h, A, T_{wall}, T_{sat}, Q, I, V are the heat flux (kW/m^2), heat transfer coefficient (kW/m^2.K), heat transfer area (m^2), boiling heat transfer test section surface temperature (K), saturated temperature of experiment fluid (K), supplied heat quantity (W), current (A), voltage (V), respectively.

3. Experimental results and discussion

The Fig. 3 shows the comparison of the CHF of oxidized MWCNT CM-100 nanofluid and distilled water. As shown in the figure, for every volume fraction, the CHF of the oxidized MWCNT CM-100 nanofluid is considerably increased when the results are compared with that of the distilled water. The specific CHF as measured in the volume fractions of 0.0001 %, 0.001 %, 0.01 %, and 0.1 % were increased by 78.18 %, 156.36 %, 130.90 %, and 50.54 %, respectively, relative to those of distilled water. The optimal volume fraction for CHF was 0.001 %, as for all of the other MWCNT nanofluids as well. Notably, the boiling curve of the volume fraction of 0.1 % was shifted to the left relative to that of distilled water, which result is different from that for the MWCNT CM-100 nanofluid without oxidation treatment. This indicated that the degree of deposition of the oxidized MWCNT CM-100 was less than that of the MWCNT CM-100 without oxidation treatment. However, the CHF measured in the volume fractions over the volume fraction of 0.01 % decreased further than that measured in the volume fractions of 0.001 %. It was determined, as explained above, that the many nanoparticles prevents the distilled water from being supplied by vapors generated from the specimen.

Fig. 4 is a graph comparing the CHFs of the oxidized graphene M-5 nanofluid and distilled water. As can be seen, the CHFs measured at the volume fractions of 0.0001 %, 0.001 %, 0.01 %, and 0.1 % could get increased values of 64.45%, 123.63%, 187.27%, and 89.09%, respectively, which are compared with those measured values with distilled water. From the result, the optimal volume fraction for enhanced CHF was determined to be the volume fraction of 0.01 %. Also, the CHF curve of the oxidized graphene M-5 nanofluid is similar to the CHF curve of the graphene M-5 nanofluid in the volume fraction of 0.1%.

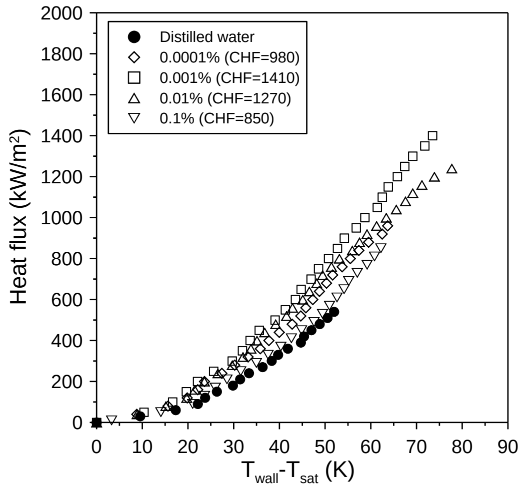

Fig. 3. CHF of oxidized MWCNT CM-100 nanofluids.

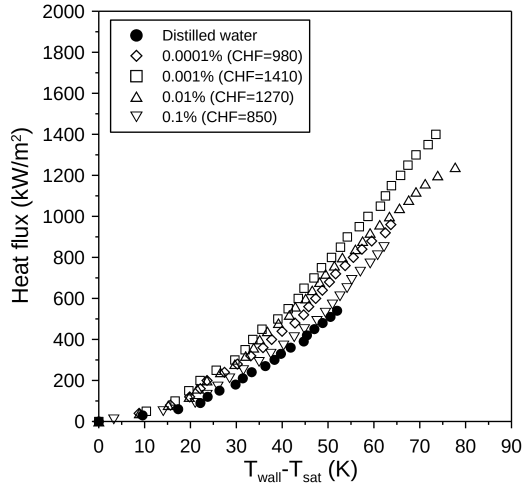

Fig. 4. CHF of oxidized graphene M-5 nanofluids.

4. Conclusions

The pool boiling CHF experiments of oxidized carbon nanotube and graphene nanofluids carried out by the various concentrations. All of the two types of nanofluids showed higher CHF than the pure water. The result shows that the CHF of oxidized graphene nanofluids is higher than the oxidized carbon nanotube nanfluids. The highest CHF increase ratio of oxidized carbon nanotube and graphene nanofluids was at 0.001 vol.%, 0.01 vol.%, respectively.

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