Influence of the Particle Length of Carbon Nanotube for Pool Boiling Critical Heat Flux Enhancement of Nanofluids

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1. Introduction

Boiling heat transfer is used in a variety of industrial processes and applications, such as refrigeration, power generation, heat exchangers, cooling of high-power electronics components and cooling of nuclear reactors. The critical heat flux (CHF) phenomenon is the thermal limit during a boiling heat transfer phase change; at the CHF point the heat transfer is maximised, followed by a drastic degradation after the CHF point [1]. The consequence is a substantial increase in wall temperature which may result in physical failure phenomenon of heat transfer systems. Therefore, the CHF is important being considered in the cooling device design, such as nuclear reactor and nuclear fuels, steam generators, high-density electronic component, etc. And, CHF enhancement is essential for safety of heat transfer system. Recently, CHF reported increased when applied to the nanofluids, with its high (higher-than-base-fluid) thermal characteristic in the nuclear power plant system [2].

Therefore, in this study, carried out the pool boiling CHF experiments by the particle length using carbon nanotube nanofluids, and the results are compared and analyzed for the CHF enhancement.

2. Experimental

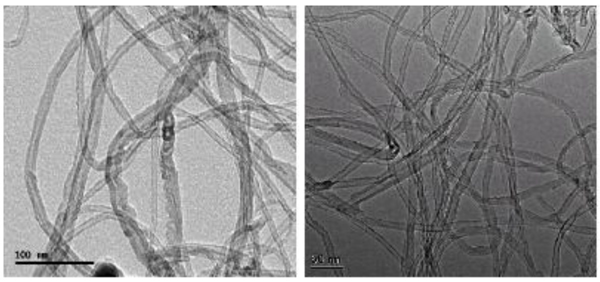
2.1 Materials

In this study, two types of multi-walled carbon nanotube (MWCNT) formulated by Chemical Vapor Deposition (CVD), namely CM-95 and CM-100, were used (Hanwha Nanotech Co.). Table 1 lists their properties. As is shown, the most significant different between them is in their lengths. To prepare the base fluid, tap water was distilled using an automatic water distiller (ADA-04). Fig. 1 shows a 200,000-times-magnified scanning electron microscopy (SEM) image of the two types of MWCNT.

The general problem encountered in the formulation of nanofluid is that simple mixing cannot achieve a stable nanoparticle suspension. Therefore, in the present study, an ultrasonic processor was employed for that purpose. Primary distilled water was utilized as the base fluid, which was mixed with carbon nanotube particles in the ratio of 0.0001 ~ 0.1 vol%, and the resultant carbon nanotube nanofluid was then suspended, by ultrasonication, for 2 hours.

Table 1: Properties of MWCNTs

Properties	CM-95	CM-100
Diameter(㎚)	10-15	15
Length(㎛)	10-20	~200
Purity (wt.%)	95	95
Bulk Density(g/cm^3)	0.1	0.05
True density(g//cm^3)	1.8	1.8
Thermal conductivity(W/m·K)	3000	3000
Surface Area(m^2/g)	200	225



(a) CM-95 (b) CM-100
Fig. 1. SEM micrographs of MWCNTs (×200,000)

2.2 Apparatus and methods

Fig. 2 is a schematic diagram of the experimental apparatus, which comprises a pool boiling vessel (SUS 316) to measure the CHF of carbon nanotube nanofluids, a constant temperature water bath (RW-3025, Jeio-tech), a DC power supply(DAP-125, Dau nanotek), a shunt resistance to measure the supplied heat quantity, two automatic temperature controller (NX9, Hanyoung nux), a data logger (Agilent 34970A) for collection and saving of data, and a computer. And the pool boiling vessel was composed of the reflux condenser, test section and sheath heater, with two T-type thermocouples and a pressure sensor. Also, quartz glasses with a diameter of 45 mm were installed at the front and rear sides of the pool boiling vessel to allow observation of the CHF reaction. Especially, boiling heat transfer test section (37 mm × 40 mm × 30 mm, peek) of internal vessel was composed of a zirconium plate block (9.53 mm × 9.53 mm × 4mm) and a heat resistance heater (9.53 mm × 9.53 mm, CCR-375-1, Component General Inc.) suppling heat to the surface and three T-type thermocouples. And three holes were drilled within the zirconium plate, 2 mm away from the heat transfer surface with equal intervals and fine T-type thermocouples were inserted to these holes for measuring exact temperature of the zirconium surface.

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

$$h = \frac{Q/A}{(T_{wall} - T_{sat})},\ Q = IV \quad (1)$$

$$q" = h(T_{wall} - T_{sat}) \quad (2)$$

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

Fig. 3 shows the pool boiling curves obtained from a zirconium surface for CM-95 nanofluids of 0.0001-0.1 vol%. As shown in the figure, the CHF increased at all nanofluids of mixing ratios as compared to that of pure water. Specifically, it was confirmed that at 0.001 vol%, the highest CHF is obtained and the value is 1090 kW/m2, or about 98.2 % higher than that for the pure water.

Fig. 4 shows the pool boiling curves of CM-100 nanofluids as a function of volume fraction. As shown in the figure, the pool boiling curves of CM-100 nanofluids are similar with the curves of CM-95 nanofluids. The highest CHF of CM-100 nanolfuids was 1150 kW/m2 at 0.001 vol% along with the CM-95 nanofluids. And This value is the 5.5 % higher than that of the CM-95 nanofluids. Additionally, the length of the carbon nanotube particle influences the pool boiling CHF of nanofluids: that is, particles of longer length offer a superior, and excellent, CHF increase effect.

4. Conclusions

The pool boiling CHF of experiments of carbon nanotube nanofluids carried out by the length of particles and the various concentrations. The results of this experiment were that the CHF of the two nanofluids increased along with the volumetric fraction until 0.001 vol%, and the two types of nanofluids are the highest CHF at 0.001 vol%. Also, the results show clearly that the rate of CHF increase of the CM-100 MWCNT nanofluid with longer-length nanoparticles is higher than that of the CM-95 MWNCT nanofluid. These results indicate that the length of carbon nanotube influences the pool boiling CHF of carbon nanotube nanofluid and that long-length MWCNT, as above-noted, offers a superior effect in this regard.

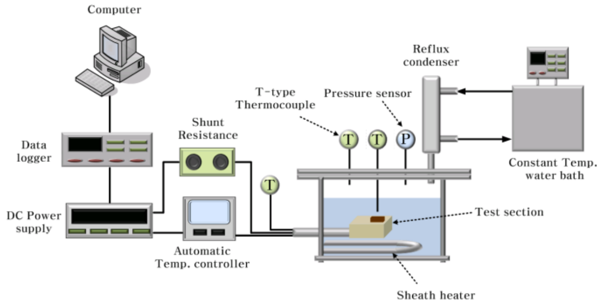


Fig. 2. Schematic diagram of the experimental apparatus.

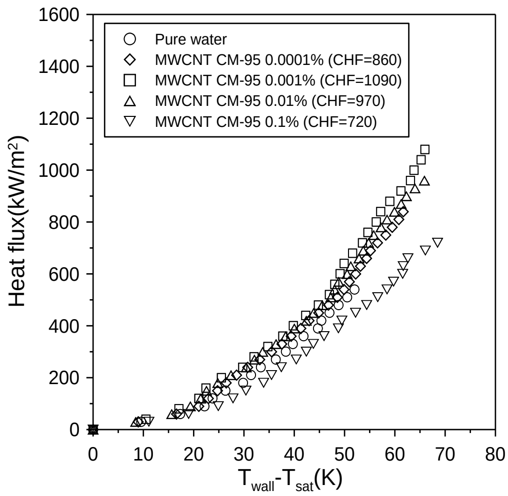


Fig. 3. CHF of MWCNT CM-95 nanofluids.

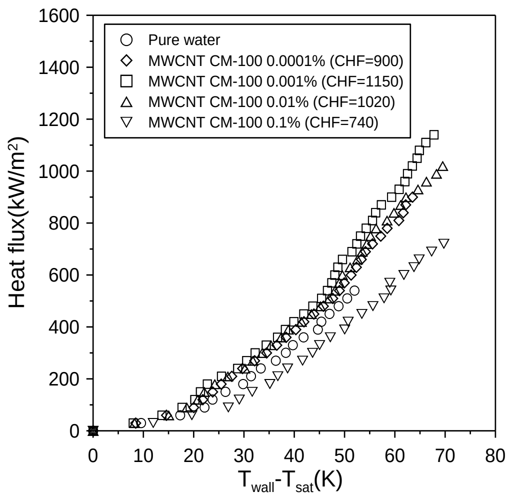


Fig. 4. CHF of MWCNT CM-100 nanofluids.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MEST) (No. 2013M2B2A9A03051391)

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