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CNT Coating Enhances Pool Boiling Heat Transfer and Critical Heat Flux

Gwang Hyeok Seo [a], Jongwoong Yoon [a], Wonjoon Choi [b], Gyoodong Jeun [a], Sung Joong Kim [a*],
[a]*Department of Nuclear Engineering, Hanyang University*
222 Wangsimni-ro, Seongdong-gu, Seoul, 133-791, Republic of Korea
[b]*School of Mechanical Engineering, Korea University*
145 Anam-ro, Seongbuk-gu, Seoul, 136-713, Republic of Korea
[*]*Corresponding author: sungjkim@hanyang.ac.kr*

1. Introduction

In the nuclear reactor systems, critical heat flux (CHF) and nucleate boiling heat transfer coefficient (NBHTC) are well known as the main parameters determining the safety and efficiency of the system [1]. Generated heat flux during the normal operation of a reactor is strongly limited below CHF. Moreover NBHTC is a key parameter representing efficiency of heat transfer. Consequently, a lot of studies on CHF and NBHTC have been conducted in various fields.

2. Effect of the Surface Characteristics on Boiling Heat Transfer

Pool boiling heat transfer and CHF phenomena have been studied qualitatively and quantitatively over several decades. Many researches have shown that conditions of a working fluid and surface characteristics affect the NBHTC and CHF [2]. Liaw and Dhir noticed that CHF decreased with increasing contact angle in a range of 27^o to 107^o as shown in Fig. 1 [3-4].

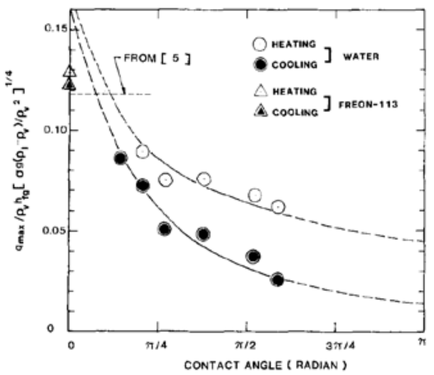


Fig. 1. Dependence of CHF on contact angle [3-4]

However, unlike the effect of fluid conditions, there is still lack of understanding on the effect of surface parameters such as surface effective thermal conductivity, roughness, wettability, and porosity [2]. Recent research on the surface parameters showed that porosity is a key factor which greatly affects the CHF [5]. There has been a need on the improvement of the boiling heat transfer and CHF to enhance the safety of the relevant components such as fuel rod and reactor vessel. Enhanced surface characteristics may contribute on In-vessel and ex-vessel retention problem. A proposed technique is to coat the relevant components using reactor-friendly materials and improve the heat transfer. In this study, carbon nanotube (CNT) is introduced as a coating material on the metal surface for pool boiling heat transfer experiments. CHF and NBHTC of the bare and CNT coated surfaces were evaluated under the atmospheric conditions

3. Description of Pool Boiling Facility and Heater Design

3.1 Experimental Apparatus

Figure 2 shows a 3D drawing of the pool boiling apparatus. For visualization work three quartz windows are installed on different sides. At the top side there are two guide holes to insert copper electrodes which supply electrical power during a test.

Fig. 2. 3D drawing of pool boiling apparatus

3.2 Heater Design

The plate heater assembly consists of a test heater and two copper electrode plates. Detailed dimensions and surface treatment are presented in Table 1.

Table 1: Heater Dimensions and Surface Treatment

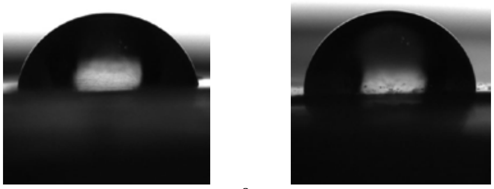
	Bare sample	CNT sample
Length (m)	0.016	0.016
Width (m)	0.004	0.004
Thickness (m)	0.002	0.002
Surface area (m^2)	8.0×10^{-6}	8.0×10^{-6}
Surface treatment	Non-coating	CNT-coating

4. Experimental Results

The experiments of the pool boiling heat transfer on the plate heater were carried out for two different surfaces, which are the non-coating stainless steel 316 and CNT coated surfaces.

4.1 Surface Characterization

The contact angles of each heater were measured as shown in Fig. 3. The results show that there is no significant difference in wettability.



(a) Non-coating – CA: 86.7° (b) CNT coating – CA: 87.0°
Fig. 3. Contact angles of non-coating and CNT coated surfaces

4.2 Experiments of Pool Boiling Heat Transfer

During the experiments the heaters was powered electrically, and a gradual heat flux of 30 kW/m^2 was applied to the heaters. Temperature and heat flux changes with time are shown in Fig. 4.

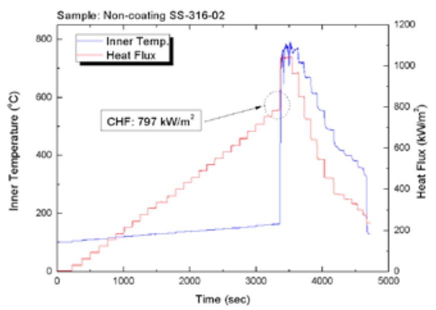


Fig. 4. Variation of heat flux and inner temperatures with time

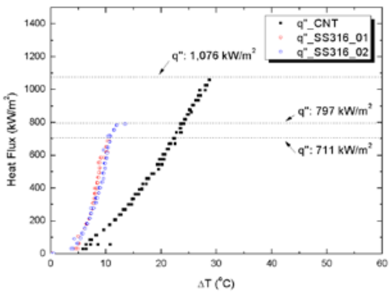


Fig. 5. Boiling curves of non-coating and CNT coating surfaces

Despite the similar contact angles on two different surfaces, the experimental results showed a higher CHF with the CNT coated surface as shown in Fig. 5. It is also observed that slope of the CNT surface is lower than that of the bare surface, which suggests that NBHTC is degraded in case of the CNT surface. The values of CHF for the samples are presented in Table 2. The enhanced CHF could be attributed to the enhanced thermal conductivity of the surface and/or the increased porosity.

Table 2: CHF values

	CHF (kW/m^2)
Bare sample 01	711
Bare sample 02	797
CNT coated sample 01	1,076

5. Conclusions

Pool boiling experiments were carried out with the bare and CNT coated plate surfaces to confirm the effect of the surface characteristics, especially porosity and thermal conductivity. The experimental results showed that CHF of the CNT coated surface was enhanced by 33% as compared to the bare surface. However, degraded NBHTC was observed regardless of the similar contact angles. The enhanced CHF could be due to the increased thermal conductivity and/or the increased porosity. Degraded NBHTC is the direct result of the reduced nucleation site density, which is affected by the size of the nucleation cavity. More study is needed to confirm the emerged result and different size of the CNT will be used for coating process.

Acknowledgements

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