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Reflood Heat Transfer in SiC and Graphene Oxide Coated Tube

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1. Introduction

The quenching experiments were conducted to investigate the effect of deposition of nanoparticles on a boiling heat transfer during a rapid quenching in a long vertical tube. The deposition of SiC and graphene oxide (GO) nanoparticles was achieved during the boiling of 0.01 volume fraction (%) SiC/water and GO/water nanofluid in the vertical tube for 600 and 900 seconds. And the reflood tests have been performed flowing water into bare tube and nanoparticles coated tube at constant flow rate (3 cm/s). The quenching curves have been obtained at atmospheric pressure. Finally, Scanning Electron Microscopy (SEM) images are acquired and contact angles are measured in order to observe the surface structures and wettability effect on cooling performance.

2. Experiment

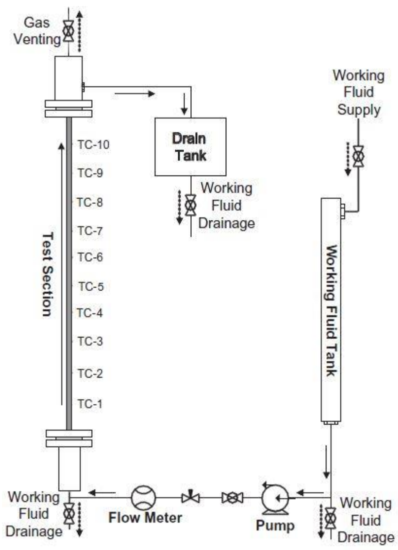


Fig. 1. Schematic diagram of reflood test facility [1]

Fig. 1 shows the reflood test facility. The stainless steel 316 L test section has sheath outer diameter of 1/2 inch and 1300 mm heating length. And ten K-type thermocouples are installed on the test section surface with constant gap from the bottom copper electrode to record the temperature histories according to height. And then, we covered the test section with glass fiber insulator which is one of the most commonly used insulation materials. We coated SiC and GO nanoparticles by circulating nanofluids to 600~650 ^oC preheated test sections for 600 and 900 seconds with 3 cm/s injection flow rate.

The experimental procedure is as follows. The bare test section or nanoparticles coated test section is heated up to 620~720 ^oC, and then cold water of 25 ^oC in the working fluid tank will be injected to the test section by the pump. When the water fills the below chamber fully, the DC power supplied to the tube was switched off. And the injection flow rate (3 cm/s) was controlled by pump and the needle valve in the upstream of the test section. The experiments were performed three times for each test sections.

3. Results and Discussion

The Fig. 2 and 3 show the enhanced cooling performance of nanoparticles coated tube compared to the bare tube. Table 1 demonstrates the cooling performance (quenching time and quenching velocity). The quenching times are decreased about 20 s and 25 s in SiC nanoparticles tubes coated for 600 s and 900 s. In GO nanoparticles tubes coated for 600 s and 900 s, the quenching times are decreased about 10 s comparing to that of bare tube.

Table 1. Average quenching time and quenching velocities for each tube

Experiment	Quenching time (seconds)	Quenching velocity (cm/s)	LP Temp. (^oC)
Bare Tube	109.41	0.90	305
SiC tube (600 s)	89.33	1.05	365
SiC tube (900 s)	83.97	1.12	389
GO tube (600 s)	99.59	1.01	321
GO tube (900 s)	97.05	1.03	323

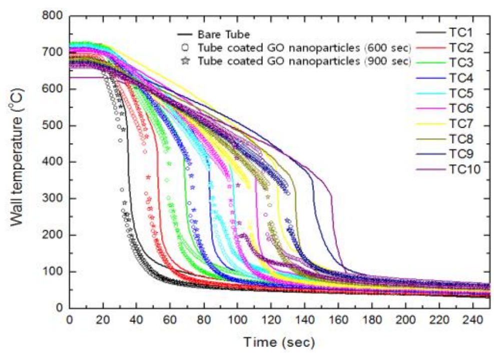


Fig. 2. Temperature histories during quenching of GO nanoparticles coated tube

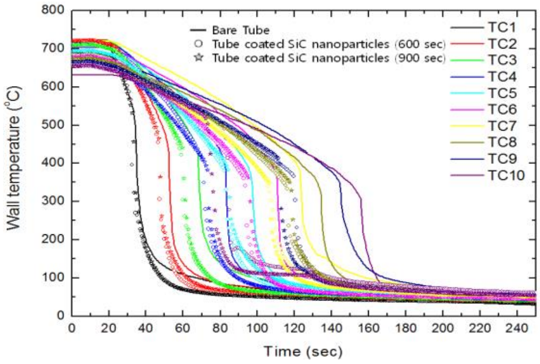
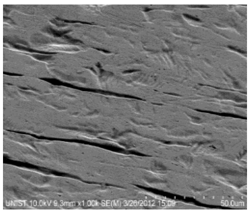


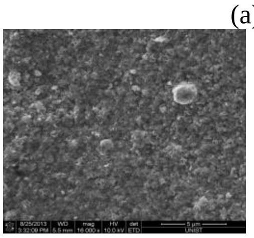
Fig. 3. Temperature histories during quenching of SiC nanoparticles coated tube

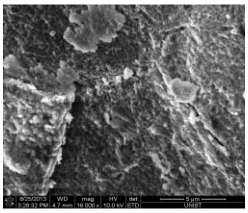
The minimum Leidenfrost point (LP) temperatures [2] for each tube are also measured. As the Leidenfrost point temperature increases, the vapor film is ruptured earlier and the quenching time decreases. Hence, the peak cladding temperature decreases by the amount of heat generated in the decreased quenching time.

The change of roughness and wettability is spotlighted in the enhanced cooling performance for nanoparticles deposition on the test section [2]. Hence, the SEM images were observed with the test section after the quenching experiments. As shown in the Fig. 4 (b) and (c), the inner surfaces of SiC nanoparticles coated tube show the rough surface compared to the bare tube (Fig. 4(a)). And the porous structure is observed in the GO nanoparticles coated tube as shown in the Fig. 4 (d) and (e). The contact angle is measured to observe the effect of wettability on the cooling performance.

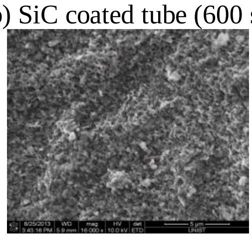


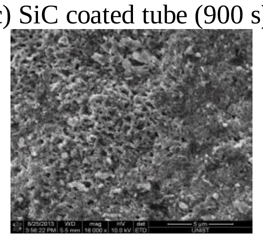
(a)Bare tube





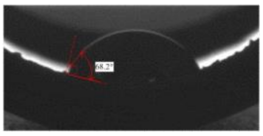
(b) SiC coated tube (600 s) (c) SiC coated tube (900 s)



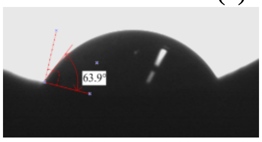


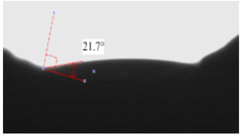
(d) GO coated tube (600 s) (e) GO coated tube (900 s)

Fig. 4. SEM images of the inner surface of the tube after the quenching experiments

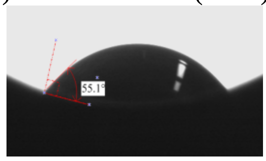


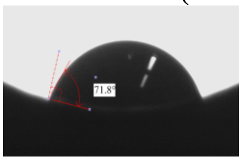
(a)Bare tube





(b) SiC coated tube (600 s) (c) SiC coated tube (900 s)





(d) GO coated tube (600 s) (e) GO coated tube (900 s)

Fig. 5. Static contact angle observation of the inner surface of the tube after the quenching experiments

The contact angle of bare tube is 68.2°. As shown in the Fig. 5, for SiC nanoparticles coated tube, the contact angle decreases as the coating time increases. And, this attributes to the enhanced cooling performance. And there is no consistency for the GO nanoparticles coated tube. Thus, the porous structure of the tube is the more effective component on the enhanced quenching behavior than the wettability.

4. Conclusions

The quenching time decreases and quenching velocity increases as the coating time of nanoparticles on the tube increases, because the nanoparticles deposited on the tube destabilize and rupture the vapor film early in the effect of increased Leidenfrost point temperature. The SiC nanoparticles coated tubes have better quenching performance than GO nanoparticles coated tubes. The SEM images and contact angle observations proved the enhanced wettability and rough surface due to deposition of SiC nanoparticles. And the wettability of GO nanoparticles coated tubes shows the increase at 600 s coating. But, the wettability decreases on GO nanoparticles tube coated for 900 s despite the enhanced quenching performance. Thus, the porous structure affects to the better cooling performance in case of GO nanoparticles coated tubes.

REFERENCES

[1] S. W. Lee, S. M. Kim, S. D. Park, and I. C. Bang, Study on the cooling performance of sea salt solution during reflood heat transfer in a long vertical tube, International Journal of Heat and Mass Transfer, Vol. 60, 2013.

[2] H. Kim, J. Buongiorno, L. W. Hu, and T. McKrell, Nanoparticle deposition effects on the minimum heat flux point and quench front speed during quenching in water-based alumina nanofluids, International Journal of Heat and Mass Transfer, Vol. 53, 2010.