Boiling Heat Transfer of Water-based Si Nanofluid during Rapid Quenching

Se-Young Chun [a*], Yeon-Jun Choo [a], Jong-kuk Park [a], Chul-Hwa Song [a]
[a] *ThermalHydraulics Safety Research Division,Korea Atomic Energy Research Institute,1045 Daedeokdaero,Yuseong, Daejeon, 305-353 Korea*
[*] *Corresponding author: sychun@kaeri.re.kr*

1. Introduction

"Nanofluids" could be regarded as an alternative for the effective coolant in the various fields of industry. Those could be produced by suspending the nanometric solids in the traditional heat transfer fluids and shows dramatic increment in thermal conductivity compared to conventional fluids. Several researchers have carried out the experiments to confirm the capability of nanofluids in boiling heat transfer. They found that nanofluids did not improve the heat transfer, while their CHF was abnormally increased. Since then, the focus has been moved to the mechanism of reason why CHF point of nanofluids in boiling curve delayed. Milanova[1] found the reason in the ionic properties of nanofluids. Kim[2] et al. attributed the CHF enhancement by high surface wettability of the nanoparticle layer on a heater. Kim[3]et al. concluded that the significant CHF enhancement is a consequence of not only increased surface wettability but also improved capillarity due to the surface deposition of nanoparticles.

The objective of the present work is to investigate the effect of nanofluids on boiling heat transfer during rapid quenching process of platinum wire. In this paper, the experimental results performed using water-based Si nanofluids are reported.

2. Experiments

Thin platinum (Pt) wire is used as a heat source and temperature sensor. Platinum has the high melting temperature (1700 ^{o}C) and well correlated formula for the electrical resistance vs. temperature. The horizontal Pt wire (diameter of 0.25 mm and length of 100 mm), which tightly held to the gold coated copper terminals at both ends of the Pt wire, is electrically heated by 1000 ^{o}C in atmosphere with a constant voltage power supply, and then rapidly plunged into the saturated liquid contained in quartz reservoir (~700 ml). Just before heated wire reaches the liquid surface in reservoir, the power supply to the wire is switched off by photo sensor. At the same time, 20 mA constant current is supplied to wire to measure the variation in the wire temperature. During quenching, the Pt wire temperature is calculated from resistance determined by the voltage and current. In order to acquire the voltage signal, two Pt filaments with 0.025mm diameter as the voltage taps are soldered at two locations 25 mm apart from the center of the wire. It is to minimize the error due to heat loss through the two electrical terminals. The voltage signals are read at the sampling rate of 5128 Hz from two voltage taps and a standard resistor (1 mΩ) employed for measuring the current, respectively.

Table 1 shows the experiment conditions. Water-based Si nanofluids are prepared for two concentrations of 0.01 and 0.001 vol. % using a Pulsed-Laser Ablation in Liquid (PLAL) technique. In order to investigate the effect of the nanoparticle deposition layer on the heated surface on heat transfer performance, the Si nanoparticle -coated wire (used for Case 4) was prepared by the pool boiling in nanofluids. A Bare wire is submerged in Si 0.01 vol. % nanofluid at the saturated temperature and then gradually heated from 130 ^{o}C to 145 ^{o}C for 4 hours. The SEM images (a) of bare Pt wire surface used in Case 1, 2, 3 and Si nanoparticle-coated wire surface (b) used in Case 4 are shown in Fig. 1.

Table 1. The experimental conditions

Case No.	Wire	Fluid
1	Bare	De-ionized water
2	Bare	Si 0.01 Vol. %
3	Bare	Si 0.001 Vol. %
4	Si nanoparticle-coated	De-ionized water

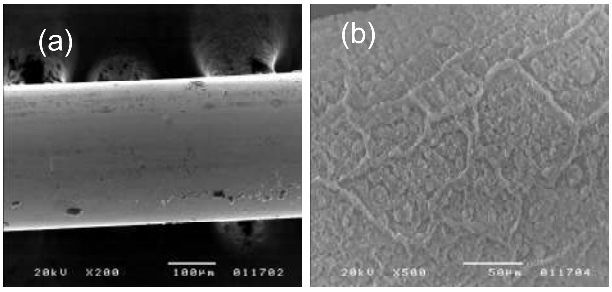

Fig. 1. Platinum wire surface

3. Experimental Results

The transitional temperature variations (i.e., the cooling curves) of the platinum wire during quenching process are shown in Fig. 2. The wire heated up to 1000 ^{o}C is forced to fall in to the liquid reservoir. The wire temperatures *Twire* decrease gradually due to naturally convective cooling by atmospheric air after the power supply to the wire was switched off at the point F near the liquid surface. At the instant the wire contacts with the liquid surface (the points E), the cooling rate in the wire starts to increases promptly. The slope of the cooling curve $\Delta Twire/\Delta t$ increases markedly, when the wire is completely immersed in liquid. The time required to cool down the wire from the points E to the termination of quenching (i.e., 100 °C) is approximately 0.44 seconds for water, 0.47 seconds for Si 0.01 and 0.001 vol. % nanofluids and 0.20 seconds for Si nanoparticle-coated wire. The Si nanoparticle-coated wire shows the cooling rate of more than two times in comparison with the others.

We can estimate the heat flux on the wire surface from the cooling curves of Fig. 2 using the following relationship.

$$q'' = -\frac{mCp(T)}{A}\frac{dTwire}{dt} \cong -\frac{mCp(T)}{A}\frac{\Delta Twire}{\Delta t}, \qquad (1)$$

where q'' is the heat flux, m the mass of the Pt wire, $Cp(T)$ the specific heat of the Pt wire and A the heat transfer area of the Pt wire.

Figure 3 shows the heat flux obtained from Equation (1) as a function of the wall superheat $\Delta Tsat$, i.e., the boiling curve. The typical boiling curve has appeared for water, Si 0.01 and 0.001 vol. % nanofluids. The boiling curve of conventional fluids such as water is usually divided into three regions according to a boiling heat transfer mode from a heated surface to liquid; nucleate, transition and film boiling. In Fig. 3, the regions A-B, B-C and C-D corresponds to nucleate, transition and stable film boiling, respectively. The section E-F is the region where the wire is cooled by atmospheric air, immediately before contacting with liquid surface. A heat transfer mode of the region D-E adjacent to liquid surface immediately after the wire was plunged into liquid is transitional film boiling. In this region, the stable film boiling is not formed, since the influence of the surface tension of liquid acts strongly. As can be seen from Fig. 3, there is no difference in characteristics of boiling heat transfer between water and nanofluids used in the present experiments.

The boiling curve of the Si nanoparticle-coated wire is very different from that of water and Si nanofluids. The heat flux behavior of the Si nanofuluid-coated wire shows nearly the same features as the others in the regions A-B and D-F. However, in the region B-D, the heat flux increases continuously with increasing wall superheat and then have a peak value at a wall superheat of approximately 450 °C. After the peak heat flux, the heat flux decreases monotonously up to the wall superheat of approximately 630 °C. In the region B-D of the Si nanoparticle-coated wire, very high heat transfer coefficient is obtained and the transition boiling does not exist during quenching process.

4. Conclusions

The effect of nanofluids on boiling heat transfer during rapid quenching process of the platinum wire has been experimentally performed using water-based Si nanofluids. The typical boiling curve was obtained from the cooling curves of water and Si nanofluids during quenching. The difference in characteristics of boiling heat transfer between water and Si nanofluids has not been found out. The boiling curve for the Si nanoparticle-coated wire shows very high heat transfer rate and no existence of the transition boiling.

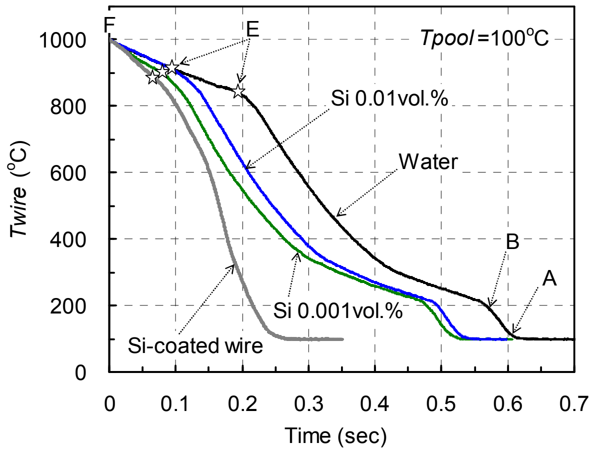

Fig. 2. Cooling curve during quenching

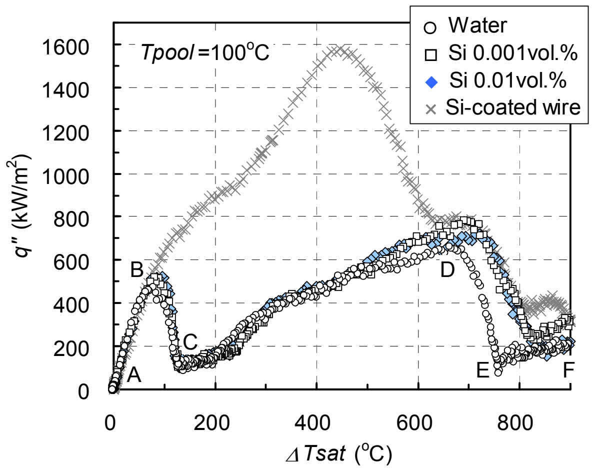

Fig. 3. Boiling curve obtained from the cooling curve

ACKNOWLEDGMENTS

This study has been carried out under the Nuclear R & D Program supported by the Ministry of Science and Technology (MOST) of Korea.

REFERENCES

[1] D. Milanova and R. Kumar, Role of ions in pool boiling heat transfer of pure and silica nanofluids, Appl. Phys. Lett., Vol. 85, 233107, 2005.
[2] S. J. Kim, I. C. Bang, J. Buongiorno, and L. W. Lu, Effects of nanoparticle deposition on surface wettability influencing boiling heat transfer in nanofluids, Appl. Phys. Lett., Vol. 89, 153107, 2006.
[3] H. D. Kim and M. H. Kim, Effect of nanoparticle deposition on capillary wicking that influences the critical hat flux in nanofluids, Appl. Phys. Lett., Vol. 91, 014104, 2007