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Experimental study of CHF enhancement using Fe_3O_4 nanofluids in the subcooled boiling region

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1. Introduction

Two phase flow heat transfer mechanism is evaluated importantly in thermal hydraulic field due to big latent heat of liquid-vapor phase change. The mechanism of boiling and condensing plays an important role on removing heat for nuclear safety. Especially Critical Heat Flux(CHF) is very important for boiling heat transfer. CHF phenomenon occurs when the boiling heat transfer coefficient decreases rapidly by changing liquid phase to vapor phase on heater surface. Various methods to improve CHF characteristics are introduced, especially nanofluids are used for enhancing the CHF. Nanofluids is a colloidal suspension that nanoparticles are mixed with basic fluid. Normally the use of nanofluids as working fluid improves the flow boiling CHF characteristics.

Lee et al. [1] already researched the CHF characteristics using nanofluids. As exit quality increased from 0.07 to 0.74, CHF enhancement gradually decreased and approached zero. CHF enhancement was observed when exit quality was low and a DNB-like thermal crisis occurred. But CHF enhancement didn't occur for high exit quality, but LFD-type thermal crisis occurred. Because LFD phenomena are nearly unaffected by the surface conditions, CHF enhancement is not expected for annular flow with high exit quality. Kim et al. [2] performed flow boiling CHF enhancement at subcooled region using alumina-water, zinc-oxide-water and diamond-water nanofluids. The CHF was enhanced by increasing wettability from nanoparticle deposition. CHF enhancement occurred in high mass flux (2000-2500 kg/m2s), but CHF enhancement didn't occur in low mass flux (1500 kg/m2s).

The amount of nanoparticle deposition on each tube can be different during experiments by the several conditions such as deposition time, mass flux and heat flux. So, before the nanofluid experiemt conducted, all tube are deposited in same condition of heat flux, concentration and time. The purpose of our experiment is to confirm how the CHF enhance by initial condition and exit quality condition. This study may give overall trends of CHF enhancement in the subcooled boiling region.

2. Experimental Apparatus and Procedure

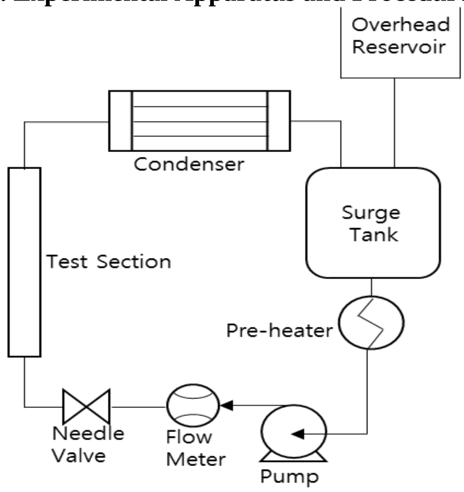

Fig. 1. Schematic of flow boiling CHF test loop

A schematic of experimental loop used in this study is shown in Fig. 1. The experimental loop for flow boiling tests consists of pump, flowmeter, needle valve, test section, condenser, surge tank, and preheater. The test section tube is located vertically, and is uniformly heated up with 100 kW DC rectifier. A description of test section is arranged in Table I.

Table I: Description of test section

Material	SS316
Outer Diameter	12.70 mm
Inner Diameter	10.92 mm
Heated Length	250.00 mm (L/D = 22.90)
Entrance Length	550.00 mm

During experiments, heat flux are gradually increased in accordance with the prepared heat flux plan. Experimental conditions are summarized in Table II.

Table II: Test matrix

Working fluid	DI water, Fe_3O_4 nanofluids
Concentration	10 ppm volume
Mass flux	1000, 2000, 3000, 4000, 5000 kg/m^2s
Pressure	1 bar
Inlet temperature	40, 60, 80 ℃

Before nanofluids experiment, working fluid is heated up to 100 ℃ by preheater to deposit same amount of nanoparticles sufficiently on inner surface of all test section. Then, deposition process was conducted in condition of mass flux of 1000 kg/m^{2}s, inlet temperature of 100 ℃ and heat flux of 2500 kW/m^2 during 30 minute for enough nanoparticle deposition by nucleate boiling. Then, experimental loop was cleaned and DI water was filled to conduct the nanofluids experiment. The reason of this process is to exclude effects of evaporation time, heat flux and mass flux on nanoparticle deposition.

3. Result and Discussion

The nanoparticle deposition improves the flow boiling CHF characteristics drastically. By the nucleate boiling, nanoparticles are deposited on the heater surface and this phenomenon makes the improvement in the wettability and rewetting characteristics of deposited surface.

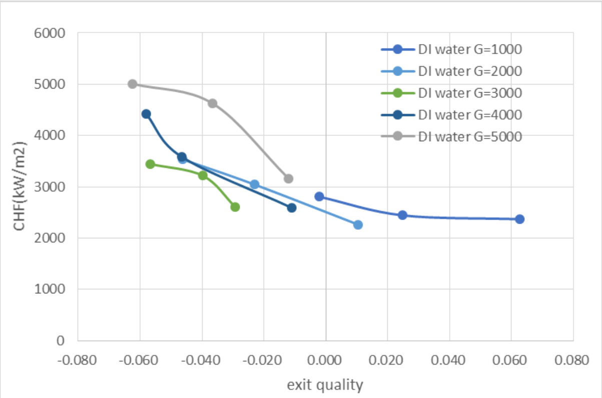

Fig. 2. Measured CHF values in pure water

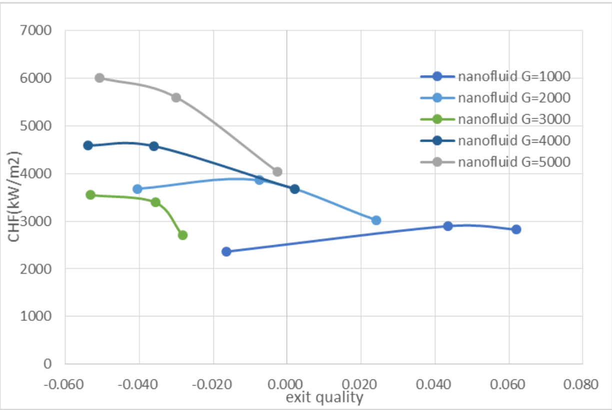

Fig. 3. Measured CHF values for nanoparticles-coated in pure water

Figure 2 show the measured CHF for water in mass flux of 1,000 ~5,000 kg/m^{2}s at atmospheric pressure. In same mass flux line, CHF is decreased as inlet temperature increased from 40℃ to 80℃. Figure 3 show the measured CHF for nanoparticles-coated in pure water. Same deposition process was conducted at all tube and working fluid was changed to DI water.

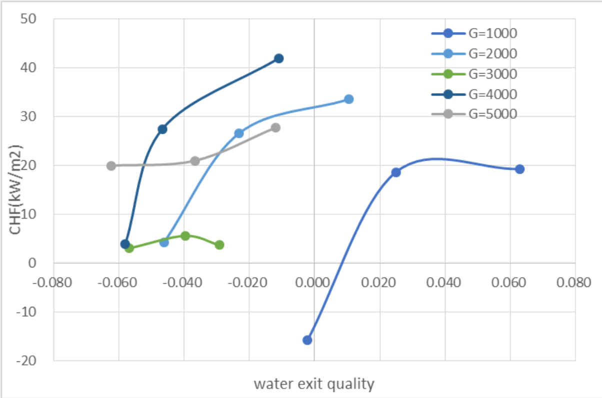

Fig. 4. CHF enhancement ratio as water exit quality

Figure 4 show the CHF enhancement ratio for exit quality of water in subcooled boiling region. The enhancement trend is not constant as exit quality. But in same mass flux, overall trend of CHF enhancement is decreased as exit quality is decreased except mass flux of 3000 kg/m^{2}s. This means that CHF enhancement is decreased as the inlet subcooling get bigger. CHF enhancement in subcooled boiling region is lower than enhancement in saturated boiling region.

Static contact angle was measured to check the surface condition because CHF is affected by surface deposition during nucleate boiling and change of surface properties. Nanoparticle coating can be detached from coated surface because mass flux is much high, so contact angle was compared according to mass flux. CHF enhancement trend should be considered in terms of inlet subcooling, mass flux and contact angle.

4. Conclusion

In our experiment, subcooled flow boiling CHF enhancement phenomena in water and nano-coated surface was investigated in mass flux from 1000 to 5000 kg/m^{2}s. CHF enhancement of nanoparticles coated tube in DI water increased as exit quality get bigger at same massflux. CHF enhancement by nanoparticle occurred by the improvement in the wettability and rewetting characteristics of deposited surface. CHF enhancement should be analyzed with surface property.

REFERENCES

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[2] S.J. Kim, T. Mckrell, Buongiorno, L.-W. Hu, Experimental study of flow critical heat flux in alumina-water, zinc-oxide-water, and diamond-water nanofluids, J. Heat Transfer 131 (2009) 043204