*Transactions of the Korean Nuclear Society Spring Meeting*
*Jeju, Korea, May 7-8, 2015*

# Experimental study of CHF enhancement using $Fe_3O_4$ nanofluids at 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. [1,2] 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. [3] 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).

Our experimental procedures are modified differently because the amount of nanoparticle deposition of each tube can be different by the several condition such as deposition time, mass flux and heat flux. So, the purpose of our experiment is to confirm how the CHF enhancement by nanofluids changes according to exit quality when same amount of nanoparticle is deposited at all tube.

## 2. Experimental Apparatus and Procedure

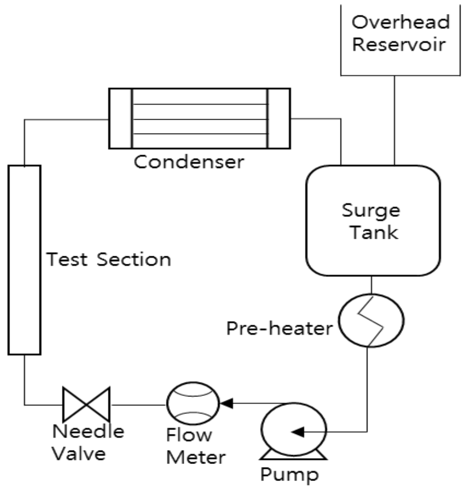


Fig. 1. Schematic of flow boiling CHF test loop

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<br>(L/D = 22.90) |
| Entrance Length | 550.00 mm |

During experiments, heat flux are gradually increased in accordance with the prepared heat flux plan. The occurrence of CHF is detected by sudden rise of temperature at the test section tube wall. 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 | 2000, 5000 kg/m$^2$s |
| Pressure | 1 bar |
| Inlet subcooling | 65 K, 60 K, 45 K |

For experiment using nanofluids, 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 500 kW/m$^2$ during 30 minute for enough nanoparticle deposition by nucleate boiling. The reason of this process is to exclude effects of evaporation time, heat flux and mass flux on nanoparticle deposition. Then, temperature of working fluid is decreased to experimental condition using condenser for experiment.

### 3. Result and Discussion

The use of nanofluids as working fluid 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.

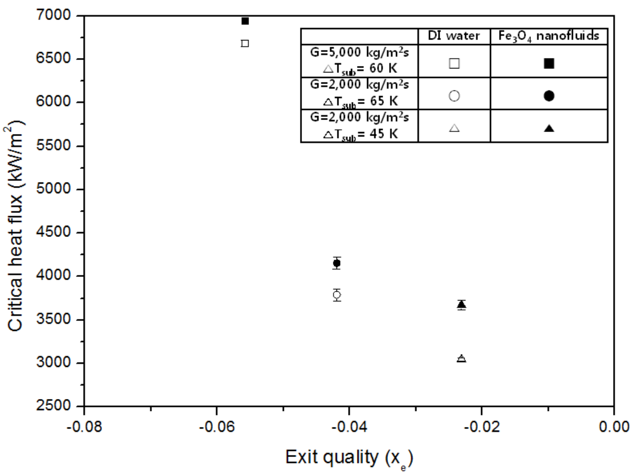


Fig. 2. CHF as a function of exit quality for water and $Fe_3O_4$ nanofluid

In Fig. 2, for the mass flux of 2000 kg/m$^2$s and inlet subcooling of 45 K, the CHF is enhanced about 630 kW/m$^2$ by using $Fe_3O_4$ nanofluids. But for the mass flux of 5000 kg/m$^2$s and inlet subcooling of 60 K, the CHF is enhanced about 260 kW/m$^2$. Although same amount of nanoparticle are deposited before the experiment, the CHF using nanofluids decreased. From the experimental result, the CHF by nanofluids is enhanced as exit quality is increased in highly subcooled region. In other words, the CHF enhancement can't be expected in highly low exit quality region as seen in Fig. 3. CHF enhancement ratio for the mass flux of 5000 kg/m$^2$s is 5 percent, but the enhancement ratio increased up to 20 percent as exit quality increase to -0.02. To analyze the effects of wettability of nanoparticles on CHF enhancement, the surface characteristic like contact angle, roughness should be measured.

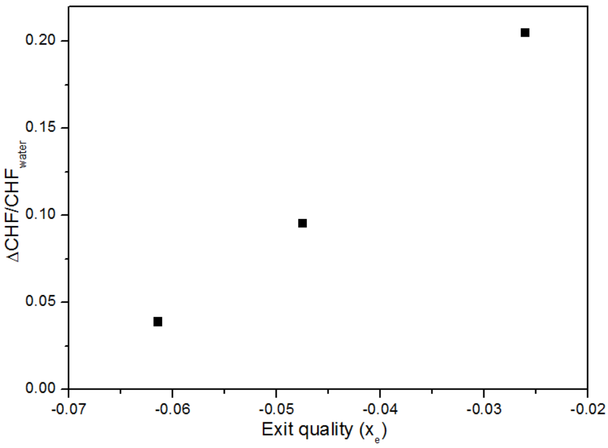


Fig. 3. CHF enhancement ratio as a function of exit quality for water data

### 4. Conclusion

In our experiment, same amount of nanoparticles are deposited sufficiently through nucleation boiling on test section at surface of all test section. CHF enhancement by nanoparticle occurred by the improvement in the wettability and rewetting characteristics of deposited surface. But for low exit quality region, the CHF enhancement was small. The CHF by nanofluids can be enhanced as exit quality is increased in highly subcooled region.

### REFERENCES

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