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Flow Boiling Critical Heat Flux Enhancement with Tri-Sodium Phosphate and Boric Acid Solution in the Tube

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1. Introduction

In a nuclear power plant, the cooling water is used to remove the decay heat and the safety system such as safety injection system (SIS) and cavity flooding system (CFS) has the cooling water including boric acid. During severe accident, tri-sodium phosphate (TSP, $Na_3PO_4{\cdot}12H_2O$) is utilized to maintain pH in water within reactor containment.

In this study, the purpose is to investigate the critical heat flux (CHF) characteristic of boric acid and TSP solution.

In previous studies, Lee et al. [1] and Jeong et al. [2] have reported that boric acid and TSP solution can enhance CHF on a tube. This study examines CHF enhancement on a tube with mixture solution of boric acid and TSP as well as boric acid and TSP solution.

2. Experimental apparatus

To investigate the effect of boric acid and TSP solution on CHF in the tube structure, an experimental water loop and test section were constructed. Fig 1 shows a schematic diagram of experimental loop. The loop has condenser, surge tank, preheater, pump, flow meter and tube test section.

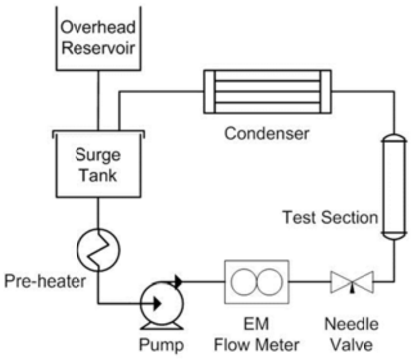

Fig 1. Schematic diagram of the experimental loop

As shown in Fig 2, the test section was a tube of SS316 used in Lee et al. and Jeong et al.'s works. The outer and inner diameters were 12.7 and 10.92 mm, respectively. The flow direction was vertically upward. The heated length of test section was 250 mm and the tube was heated by direct current (DC) heating method using a 100 kW capacity DC rectifier. The experimental conditions of this study are summarized in Table I.

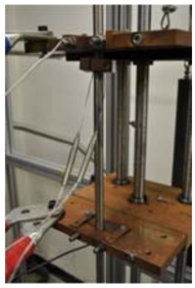

Fig 2. Tube test section

Table I. Experimental conditions of this study

Pressure	Atmospheric pressure
Inlet subcooling	50 K
Mass flux	100~500 kg/m^2s
Working fluid	DI water 0.4 wt% boric acid 0.5 wt% TSP solution 0.4 wt% boric acid+0.5 wt% TSP solution 0.4 wt% boric acid+0.2 wt% TSP solution

3. Results and discussion

In this study, flow boiling CHF experiments were conducted and the CHF data of 15 points were measured on the vertical tube under atmospheric pressure. The obtained CHF data of additive cases are compared with those if DI water case and plotted in Fig 3.

For all additive cases, the CHF enhancement was confirmed. And the TSP solution had better CHF characteristic than boric acid solution. The mixture solution of TSP and boric acid also enhanced CHF, however under mass flux condition of 500 kg/m^2s the CHF enhancement tendency was different from under relatively low mass flux conditions.

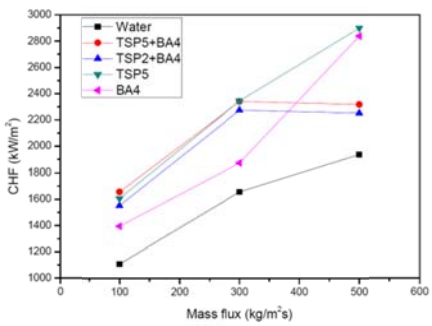

Fig 3. CHF data according to mass flux (BA: boric acid)

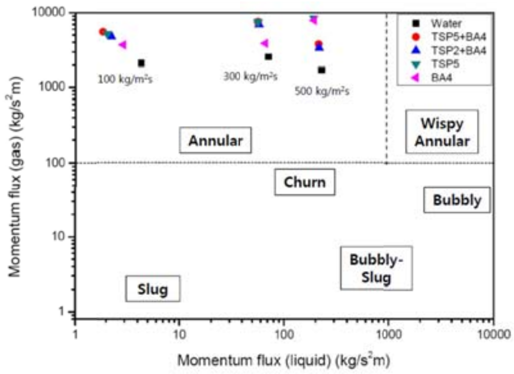

Fig 4. Flow regime map (Hewitt and Roberts map)

To explain CHF enhancement mechanism, the flow regime was studied. According to Hewitt and Roberts map [3], the flow regime was annular flow under all test conditions as shown in Fig 4.

Fig 5 explains mass transfer in annular flow. In this flow regime, the CHF (liquid film dryout) occurs when the sum of droplet deposition and liquid supply rate is lower than the sum of droplet entrainment and evaporation rate. The working fluid can affect liquid supply rate on heated surface and enhance the surface wetting.

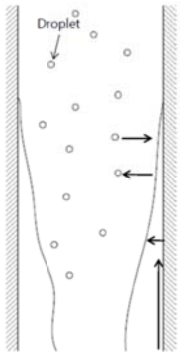

Fig 5. Mass flow in annular flow

To examine the wettability of each working fluid, the contact angle measurements were performed by static sessile drop method on bare stainless steel surface. Fig 6 shows the contact angle of a drop. The contact angle of all additives was lower than that of DI water and similar with each other. In that, all additives have better wettability than DI water and can enhance CHF. However, the difference of CHF among each additive cannot be explained.

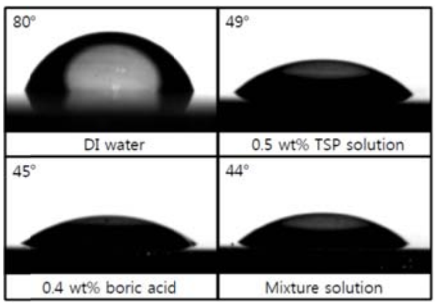

Fig 6. Contact angle measurement

4. Conclusions

Through this study, the CHF characteristic for boric acid, TSP solution and mixture solution of boric acid and TSP was studied. Using the tube test section, flow boiling CHF experiments were conducted.

For all additive cases, the CHF enhancement was confirmed. To determine CHF enhancement mechanism, it was regarded that the flow regime is annular flow using Hewitt and Roberts map and the contact angle measurements were performed to compare the wettability with each working fluid. It was confirmed that the wettability of all additives was better than DI water. Therefore, additives can enhance CHF. However, the further study is necessary for the different CHF characteristic among each additive.

ACKNOWLEDGEMENTS

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