CHF of a Downward Curved SA508 Surface with Boric Acid and TSP

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1. Introduction

For severe accident mitigation, a number of nuclear power plants use the in-vessel retention through external reactor vessel cooling (IVR-ERVC) strategy which removes the decay heat of the molten corium. The critical heat flux (CHF) is one of the most important criteria by which to judge the success of the IVR-ERVC strategy. The CHF is affected by the properties of cooling water and the conditions of heated surface.

In APR1400, the cooling water of the IRWST, which contains boric acid (H_3BO_3), is injected into the reactor cavity by an external reactor vessel cooling system (ERVC, an active feature) and a cavity flooding system (CFS, a passive feature) to manage severe accidents (Fig. 1). As the CFS begins to operate, IRWST water flows through the hold-up volume tank (HVT), which contains tri-sodium phosphate (TSP, $Na_3PO_4 \cdot 12H_2O$), and the TSP is dissolved into the cooling water. The reactor vessel is made of SA508 (low alloy carbon steel).

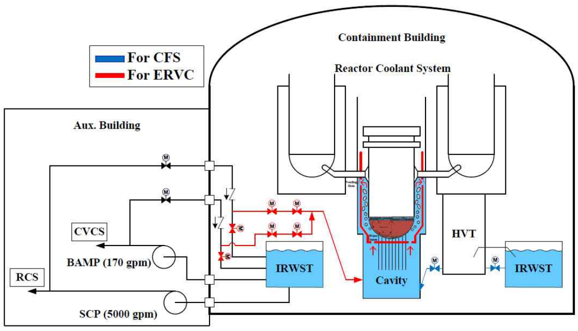

Fig. 1. System configuration for the IVR-ERVC strategy in APR1400

In this study, CHF experiments were conducted in the two-dimensional slice test sections to clarify the combined effects of the heater material of SA508 and additives of boric acid and TSP. In particular, the top of the lower head is the main focus due to the importance of the focusing effect of decay heat through metal layer after corium relocation during severe accident.

2. Experimental Apparatus

To investigate the effect of heater material and additives on CHF in small-scale two dimensional slices, an experimental water loop constructed in Park et al. (2013)[1] and SA508 test sections were used. Fig. 2 shows a schematic diagram of experimental water loop.

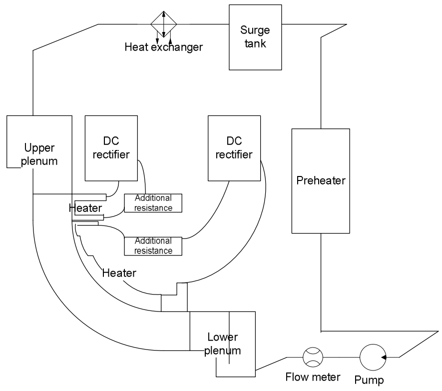

Fig. 2. Schematic diagram of the experimental loop

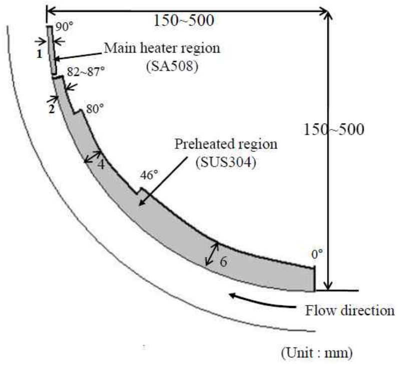

Fig. 3. Test heater section geometry

The shape of test sections was quarter-circle as shown in Fig. 3. The test section consisted of the preheated region and the main heater region. The preheated region made of SUS304 was to simulate the actual heat flux on the external lower head wall after corium relocation. The main heater region was made of SA508 to simulate the CHF phenomenon on the heated surface of external vessel wall. The thickness of the main heater region was 1 mm and the maximum heat flux level was 3 MW/m^2 enough to occur the CHF. The experimental conditions of this study are summarized in Table I.

Table I: The experimental conditions of this study

Dimension of test section	**Radius**	0.15 m	0.5 m
	Gap size	0.03 m	0.06 m
	Width	0.03 m	0.03 m
Pressure		Atmospheric pressure	
Mass flux		100~300 kg/m^2s	
Inlet subcooling		2 K	
CHF point		90°	
Working fluid		DI water, Boric acid, TSP, Mixture solution of boric acid and TSP	

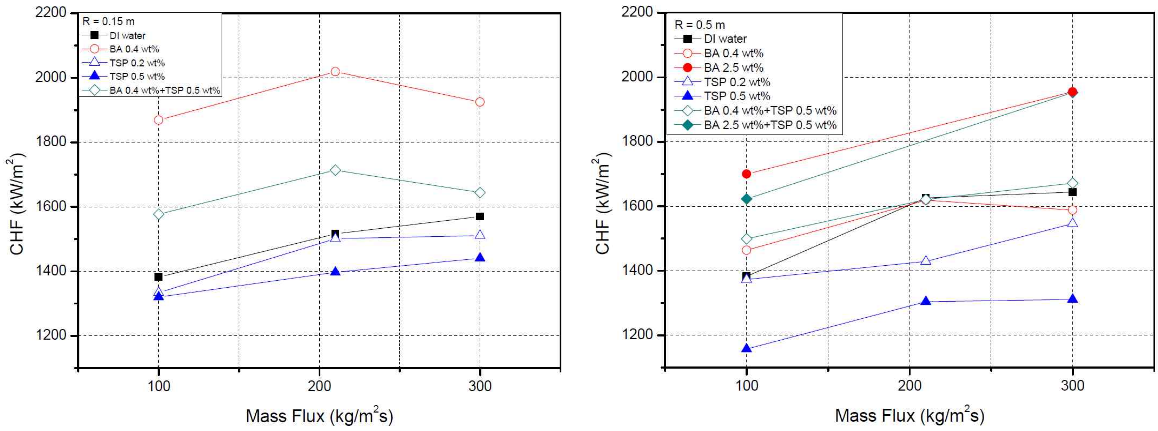

Fig. 4. CHF data for the effect of SA508 and additives

3. Results and Discussion

The 36 points of CHF data were acquired on the heated surface of SA508 for seven working fluids. The obtained CHF data are plotted in Fig. 4.

In the R=0.15 m test sections, the CHF with TSP solution was lower than that with DI water. However, in the boric acid cases the CHF was enhanced up to 2 MW/m^2. In the R=0.5 m test section, the effect of TSP solution on CHF reduction was the same with that in R=0.15 m test section. However, the CHF enhancement in boric acid and mixture solution of boric acid and TSP cases was much smaller than that in R=0.15 m test section. For a relatively high concentration of boric acid (2.5 wt%), the enhanced CHF data were obtained in both cases of boric acid and mixture.

3.1 Effect of Working Fluid on Steel Oxidation

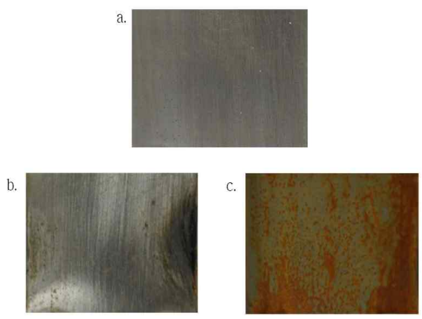

Fig. 5. SA508 surface change after experiments
(a: before exp., b: after TSP exp., c: after boric acid exp.)

To discuss the combined effect of SA508 and additives, the surface changes after the experiments with boric acid were observed as shown in Fig. 5 and it was confirmed that the phenomena are the formation of steel oxide layer through scanning electron microscope (SEM) and energy disperse X-ray spectrometer (EDS). After the experiments with TSP solution, there was no big difference from surface before the experiments. Therefore, the CHF enhancement and reduction mechanism for the combined effect of heater material and additives was explained in aspect of the carbon steel oxidation according to pH of the working fluids [2-4]. However, under the boric acid conditions the effect of steel oxidation and the CHF enhancement can be minimized in terms of local condition because the relatively thick vapor layer in the R=0.5 m test section can interrupt approach of the ion relative to oxidation to the heated surface.

4. Conclusions

Through this study, flow boiling CHF experiments were conducted using two types of test sections to investigate the combined effect of heater material and additives.

For the case of different coolant additives, the CHF using boric acid was higher than that when using DI water, while the CHF was reduced by a TSP solution. The CHF tendencies were attributed to differences in steel oxidation according to the characteristics of the working fluid. The CHF enhancement and reduction mechanisms for the combined effects of heater material and additives were explained as aspects of carbon steel oxidation according to the pH of the working fluids. Under the boric acid conditions, the effect of steel oxidation and the consequent CHF enhancement were shown to be minimized in terms of local condition.

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