Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

CHF Experiment for Heater Inclination Angle and Material Effect for Downward Facing Surface

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1. Introduction

For sever accident mitigation, In-Vessel Retention through External Reactor Vessel Cooling (IVR-ERVC) strategy is used to remove the decay heat of the molten corium. The Critical Heat Flux (CHF) is one of the most important criteria in determining the success of the IVR-ERVC strategy.

Amount of molten corium is depend on accident scenario, and hence maximum heat flux location is also changed by it. Therefore, to assess success of the IVR-ERVC, the location-specific CHF database is required.

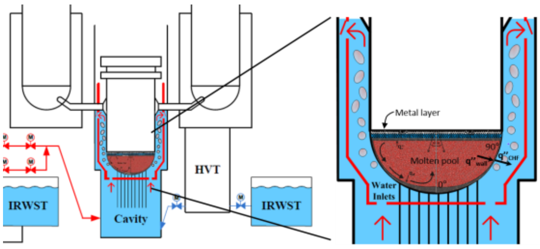

Fig. 1. Conceptual diagram of the IVR-ERVC

In this study, the CHF experiments were conducted to assess heater inclination angle, and at the same time, heater material effect also considered. 2-D slice test section was used as heater simulating outer wall of reactor vessel, and flow condition of the IVR-ERVC situation was performed by experiment water loop.

Our research group has produced the CHF database with various parameters to analyzing the CHF phenomenon under the IVR-ERVC condition. Purpose of this study is analyzing the effect of the heater inclination angle and material on the CHF, and producing and expending the CHF database at the same time.

2. Experimental Apparatus

To evaluate the effect of heater inclination angle and material on the CHF, the CHF experiments were conducted at water loop. Fig. 1 shows conceptual diagram of the IVR-ERVC. Like Fig. 1, during the IVR-ERVC, natural circulation occurred between reactor vessel and thermal insulator, so heat transfer mode was flow boiling heat transfer on the vessel outer wall. To make flow boiling condition, experiment water loop was designed as Fig. 2. The real reactor vessel is downward facing 3-D hemisphere, and its outer diameter is about 5 m. However, the 3-D reactor vessel is hard to manufacture and do experiment, hence the 2-D slice test section was used for experiment. From Fig. 2 the 2-D test section was place at main heater part. Fig. 3 shows side view of test section for 30 °, 60 ° and 90 ° heater inclination angle. Each test section was used for the CHF experiment for 30 °, 60 ° and 90 ° inclination angle.

Experiments were conducted under atmospheric condition, and DI water was used as working fluid. SUS304 (Stainless steel) and SA508 (Alloy steel) were used as heater material to check the material effect of heater surface. The SUS 304 is strong material for anti-corrosive, and hence it is proper material for control group. On the other hand, the SA508 which was material of the vessel is very corrosive material. Experiments were conducted for 30, 60 and 90 ° heater inclination angle to check the effect of heater inclination angle. The test section geometry and experiment condition are summarized at Table 1.

Table 1. Summary of this study

Test section geometry	
Radius	0.5 m
Gap size	0.06 m
Width	0.03 m
Experiment condition	
Pressure	Atmospheric condition
Inlet subcooling	2 K
Working fluid	DI water
Mass flux	100, 300 kg/m^2s
Heater material	SUS304, SA508
Heater inclination angle	30, 60, 90 °

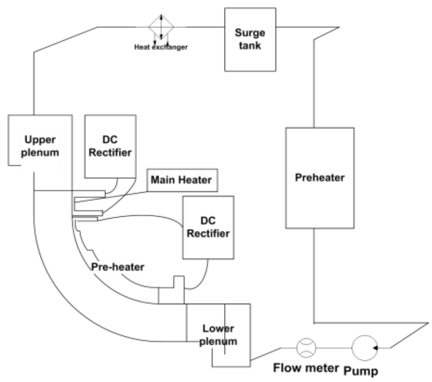

Fig. 2. Diagram of water loop

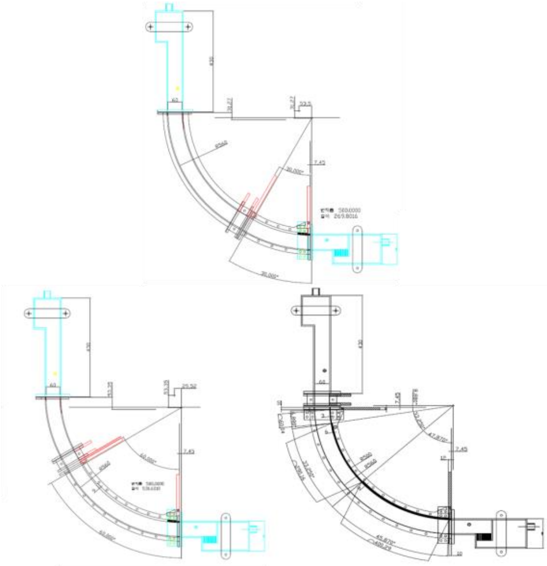

Fig. 3. Side view of test section (top: 30 °, left: 60 °, right: 90 °)

3. Result and discussion

In this section the CHF experiment results are presented, and discuss about the effect of heater inclination angle and material. At result graph, to get every single data point, at least 4 times experiment were conducted. Each data point means averaged value for certain experiment condition. Error bar means not experimental error but the CHF variation which came from repeated experiments. For convenience, same size of scale bar was used for all result graphs.

In case of upward facing boiling, generated vapor will escape from the heater surface by its buoyancy force. However, in case of downward facing boiling, the generated vapor will move toward the heater by its buoyancy, and be rising with sweeping the vessel wall like Fig. 4. This phenomenon strongly occurs, as the heater inclination angle is lower (bottom of the vessel is 0 °). Because of this phenomenon, at the low inclination angle, vapor needs more time to escape the vessel wall than the relatively high inclination angle one.

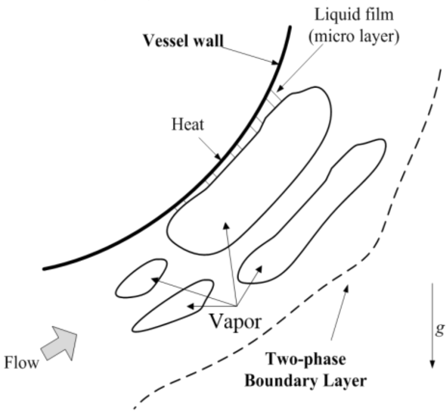

Fig. 4. Downward facing flow boiling diagram

Fig. 4 shows situation of two-phase flow for downward facing flow boiling. There is micro layer liquid film between the vessel wall and vapor. When the liquid film was dried out, it defined the CHF occurrence [1]. For the low inclination angle, the vapor escaping time is longer than the relatively high inclination angle one. Therefore the lower inclination angle one has the higher chance of the film dry out. It means that the lower inclination angle makes the lower CHF values.

Fig. 5 and Fig. 6 show the CHF result of the SUS304 heater and SA508 heater respectively. For both heater material, when the inclination angle reduced, the CHF also reduced. This inclination angle effect was relatively small at low mass flux. The CHF variation was getting large for the low inclination angle and mass flux.

From Fig. 5 and Fig. 6 the CHF value of SA508 is higher than one of the SUS304. Because the SA508 is very corrosive material, it is easily oxidized by the DI water within short time (just few minutes). When the SA508 was oxidized, the surface was getting better surface wettability [2], and it made the high CHF value [3]. The heater material affected the CHF at all inclination angle.

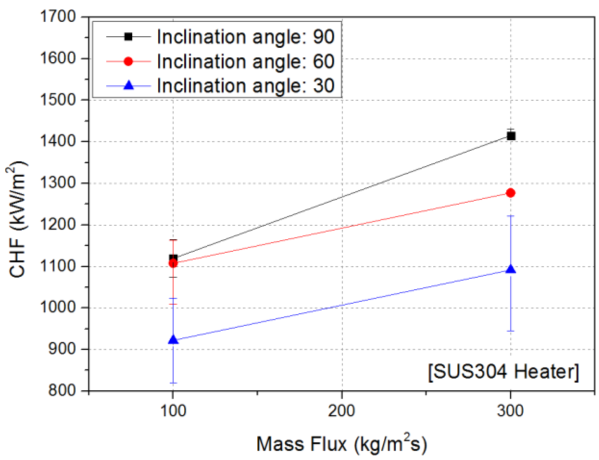

Fig. 5. The CHF result for SUS304 heater

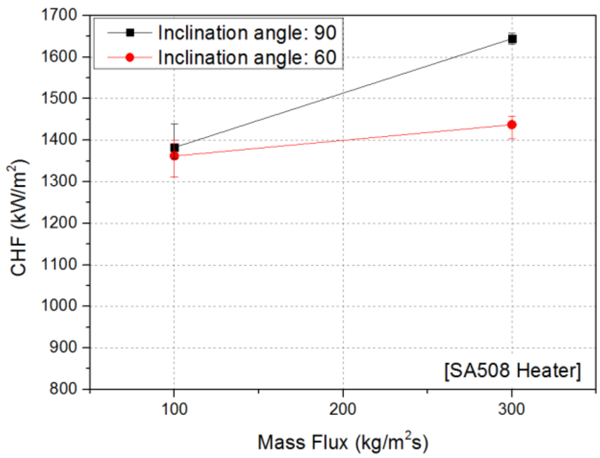

Fig. 6. The CHF result for SA508 heater

3. Conclusions

In this study, the CHF experiments were conducted to evaluate the effect of heater inclination angle and material. For the SUS304 heater, 30 °, 60 ° and 90 ° inclination angle experiments were conducted. For the SA508, 60 ° and 90 ° inclination angle experiments were conducted. Through the experiments, the lower heater inclination angle made the lower CHF value. The reason was the vapor escaping time was getting longer for the lower inclination angle. The CHF of SA508 heater was higher than one of SUS304 for all inclination angle, because the oxidized SA508 surface had better surface wettability and it enhanced the CHF.

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