# Effect of inclination angle and pressure for the CHF under the IVR-ERVC condition

Jun Yeong Jung[1)], Dong Hoon Kam[1)], Hae Min Park[2)], Yong Hoon Jeong[1)*]
[1)] *Department of Nuclear Quantum Engr. Korea Advanced Institute of Science and Technology*
[2)] *Korea Atomic Energy Research Institute*
[*]*Corresponding author: jeongyh@kaist.ac.kr*

## 1. Introduction

In-Vessel Retention through External Reactor Vessel Cooling (IVR-ERVC) is one of severe accident mitigation strategies. The ERVC's main objective is keeping molten corium in a reactor vessel. The ERVC removes the decay heat by externally cooling the reactor vessel. Fig. 1 shows the conceptual diagram of the IVR-ERVC. When the Critical Heat Flux (CHF) occurs on somewhere of the vessel, there is no more heat removal at that location, and, finally, keeping the molten corium is not guaranteed.

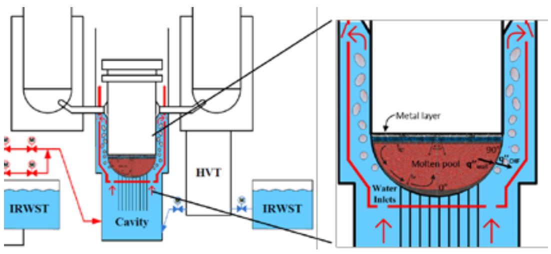


**Fig. 1. Conceptual diagram of the IVR-ERVC**

Therefore, the Critical Heat Flux (CHF) is one of the most important criteria for determining the success of the ERVC strategy. Amount of molten corium is determined by the accident scenario. It means the maximum heat flux angular location is different for the scenario. Therefore, the location-specific CHF database is required to assess the IVR-ERVC success.

Occurrence of the CHF is determined by liquid film dried out [1]. The liquid film thickness is affected by the pressure and heater surface inclination angle. At high pressure, volume of generated vapor is small, and hence the film is thick. It means that the CHF is increased by the high pressure. On the other hand, at the low inclination angle, the film is thin, because vapor buoyancy force is toward the heater surface. It means the CHF is decreased by the low inclination angle.

## 2. Experimental Apparatus

To simulate the IVR-ERVC's thermal hydraulic condition, experimental loop was designed. Fig. 2 shows schematic diagram of the experimental loop. During the ERVC, the coolant is naturally circulated, and its temperature is finally reaching to saturated condition. For making this condition, a pump and flow meter are installed to control working fluid mass flux, and pre-heater is also installed to control the fluid temperature. DI water was used for working fluid.

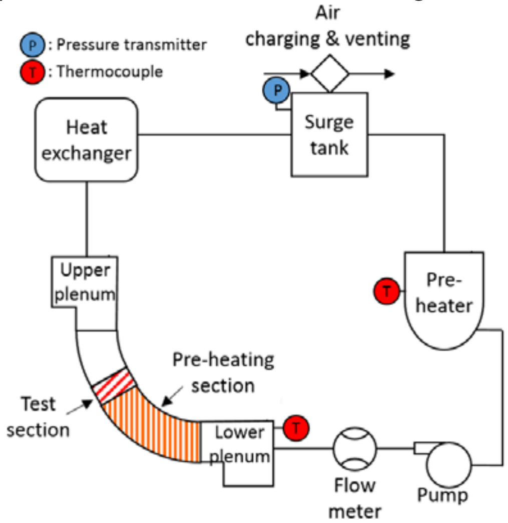


**Fig. 2. Schematic diagram of the experimental loop**

The vessel lower plenum outer wall is down ward facing 3D hemisphere, but this geometry is difficult to manufacture and conduct experiment too. Therefore, 2D slice test section was used for experiment to measure the CHF value. Fig. 3 shows the test section. At Fig. 3, the 2D slice test section is connected with two copper electrodes and directly heated by joule heating until its heat flux reach to the CHF. The effective heating length and width of the test section are equal to 30 mm, and it is made of stainless steel 304 (SUS304).

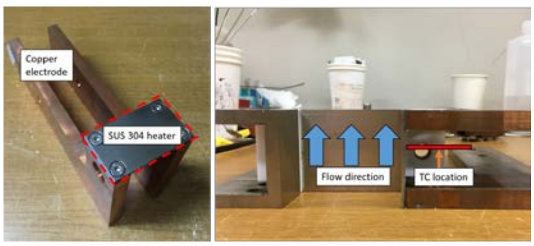


**Fig. 3. The SUS heater and test section side view**

Before the test section, pre-heating part was installed not only to make the water channel but also to apply proper heat flux which was came from molten corium. Fig. 4 shows the pre-heating section, there are three different angle: 30 °, 60 ° and 90 °. For each inclination angle experiment, the length of pre-heating section was different.

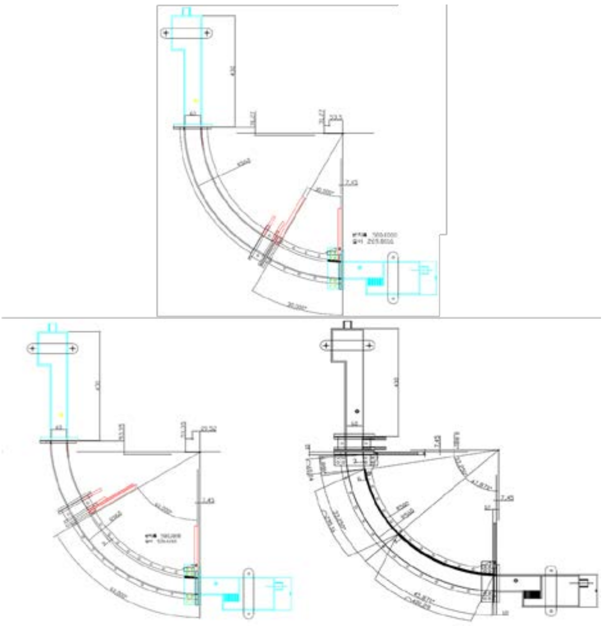

**Fig. 4. Side view of the pre-heating section (top: 30 °, left: 60 °, right: 90 °)**

### 3. Experimental Method

When the heat flux reaches the CHF value, the heater surface globally covered by generated vapor, because heat transfer mode is changed from nucleate boiling to film boiling. In addition, the heater temperature rapidly increased because heat transfer coefficient is dramatically reduced. By using this mechanism, it is determined whether the CHF occurred or not. Two K-type thermocouples were used for measuring the test section temperature like Fig.3. Fig. 5 shows example of temperature data at the CHF occurrence.

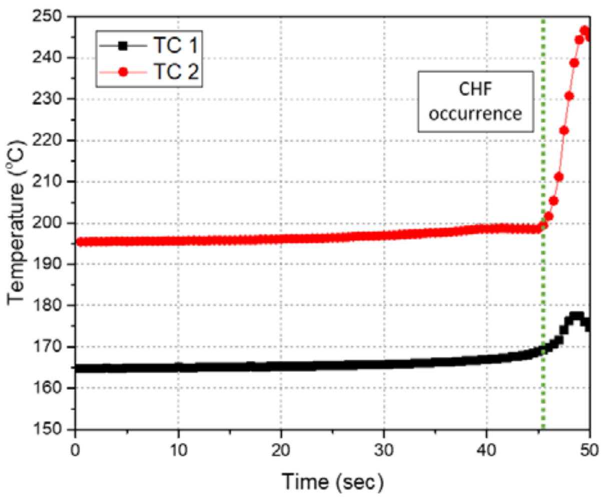


**Fig. 5. Temperature graph at the CHF occurrence**

To measure the CHF, the test section heat flux increased systematically as follows: 1st, the heat flux was smoothly increased by 100 kW/m$^2$ for 1~2 minutes, 2nd, waited at least 1 minute to make a steady state, and last, repeated this process until the CHF occurred.

### 3. Result and discussion

Experiments were conduct for 30, 60 and 90° inclination angle. For each inclination angle, pressure were 1, 2 and 4 bar. Fig. 6 – 8 show the CHF results for 30, 60 and 90° inclination angle respectively. At figure, error bar means not the CHF error but standard deviation of the CHF data. At 30 ° angle condition, the CHF considerably enhanced as the pressure increased from 1 bar to 2 bar, but there was a little enhancement from 2 bar to 4 bar. At 60 ° angle condition, the CHF was enhanced as the pressure increased, and degree of the CHF enhancement was similar between the pressures. At 90 ° angle condition, the CHF also was enhanced as the pressure increased, degree of the CHF enhancement was maximized at 4 bar and 300 kg/m$^2$s mass flux condition.

Overall, the CHF was improved as the pressure increased at all inclination angle conditions, however the CHF enhancing tendencies varied by inclination angle. At the lowest angle condition, between 2 and 4 bar, there was a little enhancement of the CHF, on the other hand, there was the enough CHF enhancement between 2 and 4 bar.

In terms of inclination angle, the lower inclination angle made the declined CHF. At same pressure condition, the CHF reduced as the inclination angle decreased, except for the CHF results 60 and 90 ° of 1 bar condition.

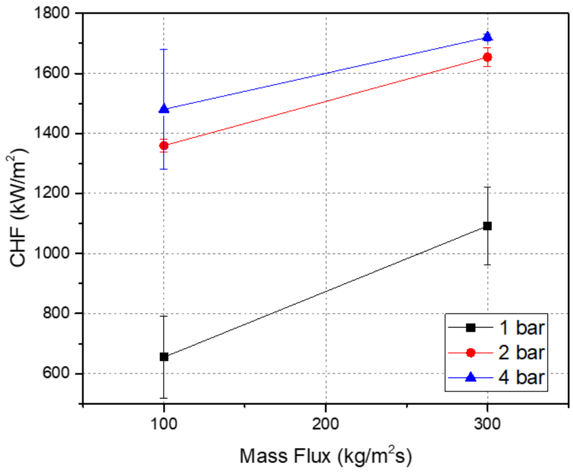


**Fig. 6. The CHF result at 30 ° inclination angle**

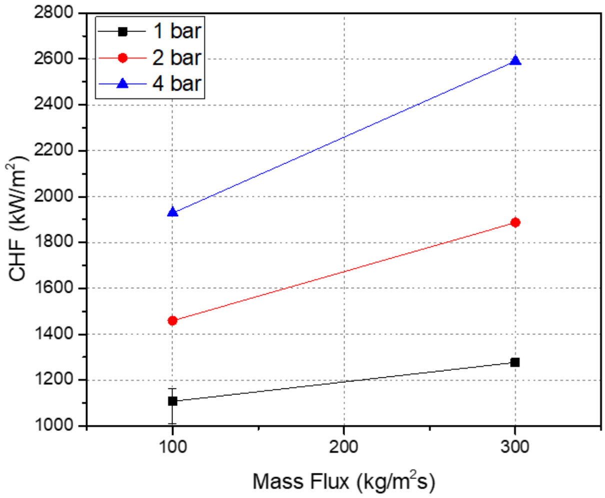


**Fig. 7. The CHF result at 60 ° inclination angle**

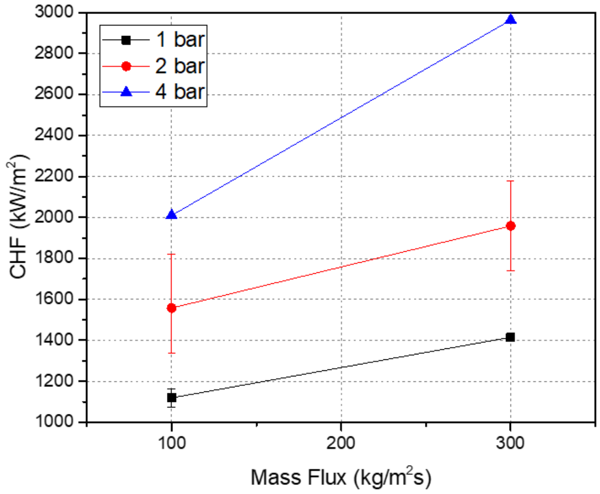


**Fig. 8. The CHF result at 90 ° inclination angle**

## 4. Conclusions

The high pressure made the enhanced CHF, however the low inclination angle made the reduced CHF. Two factors affected the CHF independently. The CHF enhancement tendency had no quantitative relations with the pressure and inclination angle.

## REFERENCES

[1] F. B. Cheung, K. H. Haddad, A Hydrodynamic Critical Heat Flux Model for Saturated Pool Boiling on a Downward Facing Curved Heating Surface, International Journal of Heat and Mass Transfer, Vol. 40, p. 1291-1302, 1997.