The Effect of the Geometric Scale on the Critical Heat Flux for the Top of the Reactor Vessel Lower Head

Hae Min Park[a], Yong Hoon Jeong[a,b*]
[a]*Nuclear and Quantum Eng. Korea Advanced Institute of Science and Technology*
291 Daehak-ro, Yuseong-gu, Daejeon, 305-701
[b]*Department of Nuclear Eng., Khalifa University of Science, Technology & Research,*
Abu Dhabi, UAE, P.O.Box 127788
[*]*Corresponding author: jeongyh@kaist.ac.kr*

1. Introduction

In-vessel retention through external reactor vessel cooling (IVR-ERVC) is important strategy to prevent the release of molten corium outside the primary pressure boundary during severe accident.

The purpose of this study is to produce the experimental data to assess the coolability limits on external vessel wall and investigate the effect of the geometric scale.

Especially, the top region of the head for the metal layer is the main concern of this study. We had special interests in APR1400 and the test loop was prepared for the three test sections and flow boiling experiments for IVR-ERVC strategy.

2. Experimental apparatus

To investigate the scale effect of test section on critical heat flux (CHF) in small-scale two dimensional slices, an experimental water loop and test sections were constructed. Fig. 1 shows a schematic diagram of experimental water loop. The experimental water loop consisted of test section, heat exchanger, surge tank, preheater, pump, flow meter, lower plenum, test section and upper plenum.

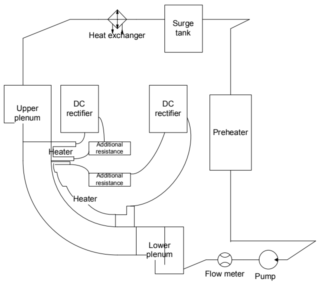

Fig 1. Schematic diagram of the experimental loop

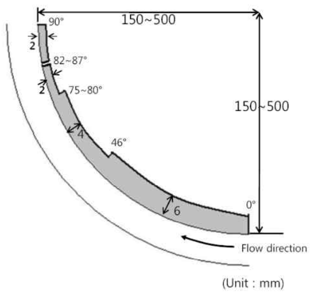

Fig 2. Test heater section geometry

The material of test section was Type 304 stainless steel used in Jeong et al.'s work (2005). In this study, three test sections of 0.15 m, 0.25 m and 0.5 m were used. The shape was quarter-circle as shown in Fig. 2. The test section was divided into two parts. One part was the pre-heated region by direct current (DC) heating and had a connection with a 45 kW capacity DC rectifier. This part was divided into three parts (thickness 2~6 mm). In pre-heated region, the heat fluxes were 280 kW/m^2 on a 6 mm thick region and 420 kW/m^2 on a 4 mm thick region. The maximum heat flux was 839 kW/m^2 on a 2 mm thick region. To control and maintain stably heat flux of the pre-heated region, an additional resistance was added in the circuit for DC heating. Another part of test section was the main heated section. In this heated section, CHF was occurred. Using a 100 kW capacity DC rectifier, this part also applied DC heating. The main heated section was vertical plate. The heater thickness was 2 mm. This heater plate was also connected to additional resistance. The experimental conditions of this study are summarized in Table 1.

Table I. The experimental conditions of this study

Dimension of test section	Radius	0.15 m	0.25 m	0.5 m
	Gap size	0.03 m	0.03 m	0.06 m
	Width	0.03 m	0.03 m	0.03 m
Heating method		DC heating		
Circulation method		Forced circulation		
Pressure		Atmospheric pressure		
Mass flux		50~400 kg/m^{2}s		
Inlet subcooling		2, 10 K		
CHF point		90°		
Working fluid		DI water		

3. Results and discussion

In this study, flow boiling CHF experiments were conducted for three test sections and the CHF data of 14 points were measured on the two-dimensional slice test section at an inclination angle of 90º under atmospheric pressure. The obtained CHF data are compared with Jeong et al.'s work (2005) and plotted in Fig. 3.

The CHF results were discussed for the local conditions. However, an explanation for the local conditions cannot suitably explain the relationship between R=0.25 m and R=0.5 m test cases. To eliminate the inconsistency in the relationships in terms of the local conditions, flow visualization technique was utilized. And a liquid region in which the effect was minor for the heat transfer phenomena with the two-phase boundary layer was observed. Thus, the exit quality only considering the two-phase boundary layer was different from the average exit quality. To determine the feasible relationship between different scales, the equation, which gives the gap size considering the scale, was used as the standard of distinction between the liquid region and the two-phase boundary layer, and the exit quality values were recalculated. The CHF results with the modified exit quality values including all CHF data from Jeong et al.'s work (2005) were shown in Fig. 4.

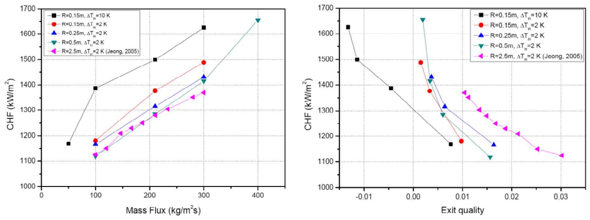

Fig 3. CHF data according to mass flux and exit quilty

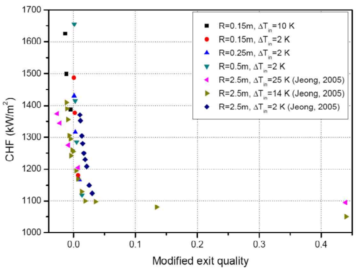

Fig 4. CHF data according to exit quality

Based on the CHF relationship suggested by Cheung et al. (1997), the CHF correlations for the subcooled and saturated conditions were developed as the following equation:

$$q''_{CHF} = \begin{cases} \left(1.062\times10^{9} + 5.476\times10^{6}\dfrac{G}{\alpha^{1/3}}\right)^{1/3} & (x_{exit.\mathrm{mod}} > 0) \\ (1139 - 4258x_{exit.\mathrm{mod}})(1+0.003G)^{1/3} & (x_{exit.\mathrm{mod}} \le 0) \end{cases}$$

$$where \quad \alpha = \left(1 + \frac{1}{1622x_{exit.\mathrm{mod}}}\right)^{-1} \qquad (1)$$

The CHF correlation for the saturated condition predicts the experimental data with a root-mean-square (RMS) error of 3.1% and is applicable when the mass flux is less than 400 kg/m^{2}s and the exit quality is between 0 and 0.5. The CHF correlation for the subcooled condition predicts the experimental data with an RMS error of 5.1% and is applicable when the mass flux is between 100 and 300 kg/m^{2}s and the exit quality is between -0.03 and 0. Both equations can predict the CHF limit for the scale of R=0.15~2.5 m at an inclination angle of 90°.

4. Conclusion

Through this study, the IVR-ERVC strategy was studied in the CHF experiments using three test sections of a small-scale two-dimensional slice. At an inclination angle of 90°, the scaling effect of the CHF using different the local conditions was investigated.

Considering the liquid region observed in the flow under relatively high mass fluxes, an equation that related the scale with the gap size was used as the standard of distinction between the liquid region and the two-phase boundary layer, and the exit quality values for the CHF results were modified. Using this set of data and the results from Jeong et al. (2005), CHF correlations in terms of the mass flux and exit quality were developed for the scale of R=0.15~2.5 m at an inclination angle of 90°.

ACKNOWLEDGEMENTS

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