Assessment of critical heat flux model for low mass flux in SPACE

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1. Introduction

The temperature of critical heat flux (CHF) or CHF is an important criterion to determine wall heat transfer regime in thermal hydraulic (T-H) analysis code. In pre-CHF regime, heat transfer is dominant to nucleate boiling, which can efficiently remove the heat from the wall. However the heat transfer is deteriorated due to vapor film.

The critical heat flux (CHF) at low pressure and low mass flux conditions is important during loss of coolant accidents of nuclear power plants. Bjornard & Griffith [1] suggested a correlation for low flow in the following form:

$$q_{CHF} = 0.131(1-\alpha) h_{fg} \left\{\sigma g \left(\rho_f - \rho_g\right)\right\}^{0.25} \rho_g^{\ 0.5} \quad (1)$$

The correlation is widely used for low flow in most T-H analysis codes such as RELAP[2], COBRA[3], MARS[4] and SPACE[5] based on Zuber's pool boiling correlation[6], and therefore called the modified Zuber correlation.

However, there is a problem to apply the Bjornard & Griffith's correlation into the dry-out condition because the liquid fraction is almost 1. Then it is inevitable to underestimate CHF for dry-out conditions. In this paper, we aims to predict the CHF in dry-out condition with more accuracy. In order to predict the CHF properly, the CHF multiplier for low flow will be modified and validated with experimental data.

2. CHF model for low flow in SPACE

For low mass flux, the modified Zuber CHF correlation was used instead of the Groeneveld Lookup Table[7] in the most T-H safery analysis code. In previous study[8], existing CHF models were modified using the interfacial instabilities of viscous potential flow (VPF) and applied into the SPACE code. The modified model shows a considerable improvement of the prediction accuracy in a wide range of pressures. The CHF values were estimated with the additional correlation proposed by Bjornard & Griffith as given below:

$$CHF = \max\left[0.04,(1-\alpha)\right] \times CHF_{VPF} \quad (2)$$

We are confronted with two major problem. One is that CHF values can be underestimated because void fraction is almost 1 for dry-out conditions. Under DNB (Departure from Nucleate Boiling) conditions, it is reasonable to calculate the CHF using the void fraction. However, the CHF occurred with the type of liquid film dryout for most of analysis cases of nuclear power plants in low flow conditions. The other is validity for the multiplier of CHF, which is 0.04 in Eq. (2). There is no background to be 0.04. In order to check the validity of the multiplier, KAIST[9] and Mishima experiment data[10-12] were utilized. Stainless steel tubes was used in KAIST experiments. Mishima's works performed a series of experiments for annulus, rectangular channels, and a tube. KAIST and Mishima's experiments have been conducted for low flow conditions at atmospheric pressure.

Figure 1 shows the CHF ratio corresponding to the mass flux. The CHF ratio can be defined:

$$CHF\ ratio = \frac{CHF_{EXP}}{CHF_{Zuber}} \quad (3)$$

Where, CHF_{EXP} is the mean values of CHF experiments and CHF_{Zuber} is calculated by Eq.(1).

Based on the results, the multiplier of CHF for low flow, which is used in the SPACE, is not reasonable. The values is too small. Therefore, it is required to modify the multiplier of CHF in order to predict the CHF for low flow with more accuracy.

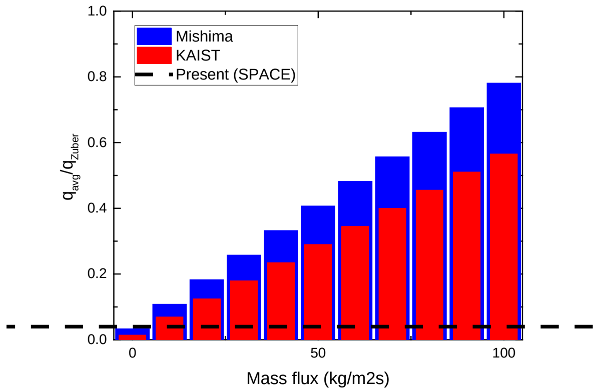

Fig. 1. CHF ratio for KAIST & Mishima's experimental data according to the mass flux

From COBRA-TF manual[3], the multiplier of CHF for low flow is calculated for the annular film dryout as below:

$$CHF = \min\left[1.0, 100(1-\alpha)\right] \times CHF_{Zuber} \quad (4)$$

In this study, the above multiplier is applied into the SPACE code with CHF_{Zuber} replaced by CHF_{VPF}.

3. Validation

In order to validate the multiplier of CHF for low flow, the SPACE analysis performed for 3x3 post-CHF experiments[13]. Table 1 presents the boundary conditions for experiments. The four cases (Case 1, 4, 5 and 6) were selected for the low mass flux conditions. Fig 2. shows the nodalization used in the SPACE calculations.

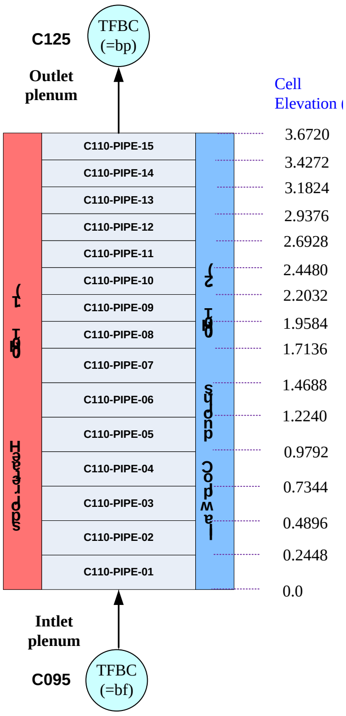

Fig. 2. Node diagram for 3x3 post-CHF experiments

The calculated results for the wall temperature distribution compared with experimental data as shown in Fig. 3. 'Original' represents the results from the original multiplier of CHF for low flow and 'modified' are the results calculated by Eq.(4). The results are well matched when the multiplier, proposed by COBRA-TF, is applied. The tendency of axial temperature distributions are more reasonable using modified ones. Based on the results, the multiplier of CHF for low flow is reasonable to apply into the SPACE code.

4. Conclusions

CHF is an important criterion to determine wall heat transfer regime in T-H analysis code. In SPACE, the modified Zuber CHF model for low flow is used. However there exist problems to predict the CHF for liquid film dryout conditions. CHF model was modified in previous work using the interfacial instabilities of vicous potential flow. In addition, the correlation for the multiplier of CHF model, proposed by CTF, was applied into the SPACE code and validated with experimental data.

The 3x3 post-CHF experiments performed by KAERI was validated using modified CHF model with the new multiplier. The calculated results for wall temperature distribution are well matched with experimental data. Based on the validation, we can conclude that the predictability for CHF in low flow are more improved comparing with the original calculation case.

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Table 1. 3x3 Post-CHF heat transfer experiments (KAERI)

Case	Pressure (MPa)	Mass flux (kg/m^2s)	Tin (℃)	DH_{in} (kJ/kg)	Applied heat (kW)
Case 1	9.006	50.253	289.264	73.484	103.928
Case 4	3.001	50.880	158.424	338.381	132.690
Case 5	5.959	50.588	258.757	78.554	115.978
Case 6	5.98	50.301	233.266	202.169	122.325

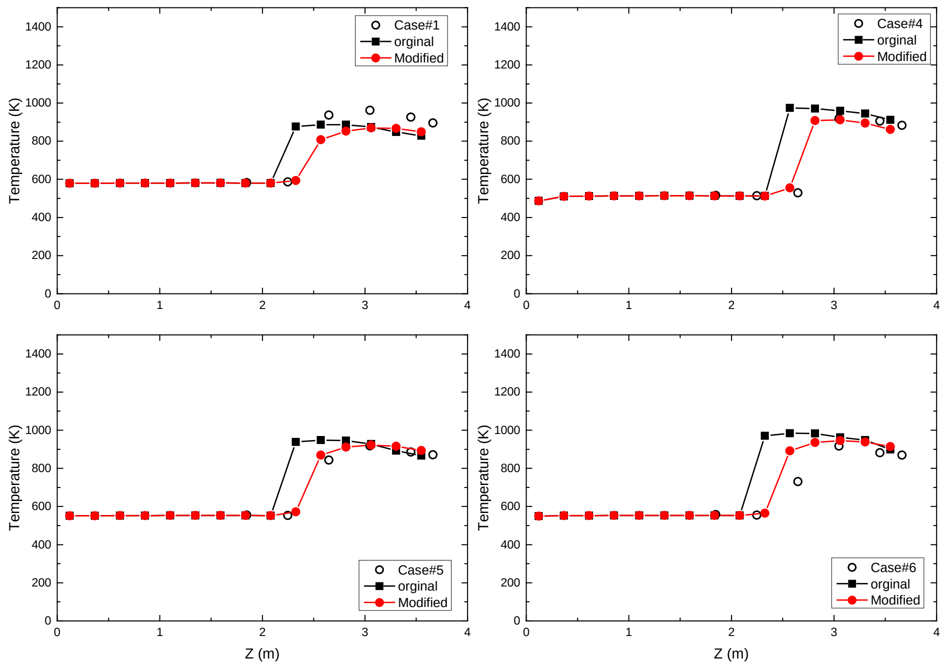

Fig. 3 Comparison of wall temperature distributions between original and modified multiplier of CHF for low flow

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