Fluid to Fluid Modeling of R134a CHF in SMAT 5x5 Rod Bundles

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1. Introduction

In the preparation of standard SAR for the SMART, a series of experiments on the Freon CHF (Critical Heat Flux) using R134a for SMART 5x5 rod bundles were conducted. The results from the Freon CHF experiment were converted into those of equivalent water CHF by applying to fluid to fluid scaling law. The correction factor for mass flux by Katto[1] was used to obtain an equivalent mass flux for the water. The bundle averaged CHF of the water CHF experiment agreed with the equivalent water CHF of the Freon CHF experiment. However, it is necessary to investigate the relationship of a local CHF for the water and equivalent water CHF conditions. In this study, a method to obtain the local CHF from the bundle averaged CHF conditions of the water and Freon is presented using sub-channel analysis code. Moreover, the mass flux parameter is proposed and the scaling result applying to the proposed parameter by is evaluated.

2. Methods and Results

2.1 Fluid to Fluid Scaling law

The water CHF experiment was very expensive and required high power and high pressure. In order to overcome economical and technical limitations, the model fluids such as the Freon are used instead of the water. The connection between prototype fluid and model fluid is achieved by applying the fluid to fluid scaling law. The researches for the fluid to fluid scaling law have been carried and Katto[1] and Ahmad[2] are representative. They proposed the similarity between the prototype and model fluids as following geometric, hydro-dynamic and thermo-dynamic similarities respectively:

$$\left(\frac{L}{D}\right)_P=\left(\frac{L}{D}\right)_M,\ \left(\frac{\rho_f}{\rho_g}\right)_P=\left(\frac{\rho_f}{\rho_g}\right)_M,\ \left(\frac{\Delta h_{in}}{h_{fg}}\right)_P=\left(\frac{\Delta h_{in}}{h_{fg}}\right)_M$$

where, subscript P and M mean the prototype and model. Katto was presented the mass flux modeling as followings:

$$\left(\frac{G\sqrt{D}}{\sqrt{\sigma\rho_f}}\right)_P=\left(\frac{G\sqrt{D}}{\sqrt{\sigma\rho_f}}\right)_M$$

The equivalent water CHF was obtained as followings:

$$\left(\frac{q_{CHF}}{Gh_{fg}}\right)_P=\left(\frac{q_{CHF}}{Gh_{fg}}\right)_M$$

2.2 Analysis Method

The procedures to compare the local CHF between the water and the equivalent water from the Freon were shown in Fig. 1.

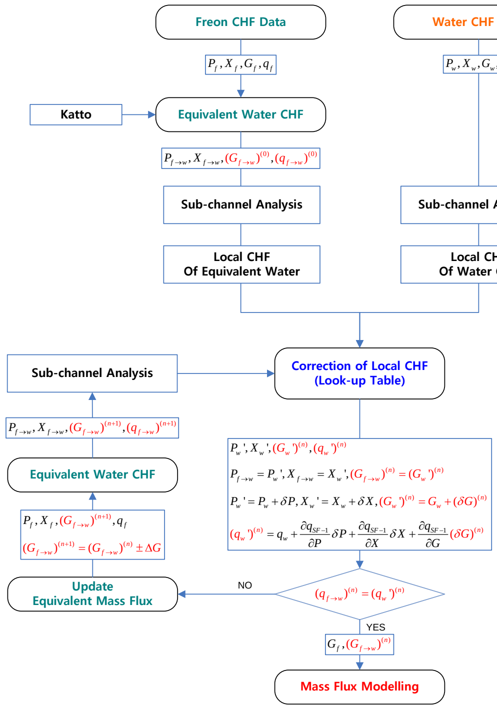

Fig. 1. Procedures to find the equivalent local CHF according to the identical water condition.

The bundle averaged CHF conditions of the Freon are converted into the equivalent water CHF conditions. The local CHF for the equivalent water CHF was obtained using sub-channel analysis code, MATRA-S. The local CHF for the water CHF conditions was also obtained by the MATRA-S code. The correction of the local CHF was achieved using Look-up table because it was possible that each local CHF condition was not identical. If there is a mismatch of the local water CHF and the local equivalent water CHF to be corrected by Look-up table, the mass flux, one of the equivalent water CHF conditions, was adjusted. The updated mass flux and remains of the equivalent CHF conditions except for the mass flux were applied to MATRA-S code to find a new equivalent local CHF. The above procedures are repeated until the local water CHF to be corrected is identical with the local equivalent CHF.

2.3 Sub-channel Analysis Model

MATRA-S code was used as the sub-channel analysis code to acquire the local CHF conditions. The important models of MATRA-S code in this study are summarized as shown in Table I.

Table I: Models for Sub-channel Analysis

Two-phase models	
Subcooled boiling void fraction	Saha-Zuber model
Bulk boiling void fraction	Chexal-Lellouche model
Two-phase friction multiplier	Homogeneous model
Subchannel interaction models	
Turbulent mixing parameter for single-phase	0.038
Two-phase turbulent mixing model	EM model
Hydraulic Resistance Models	
Bundle friction factor	$0.184Re^{-0.2}$
Spacer grid loss factor (MV/ IFM)	1.243/0.729

2.4 Results

Figure 2. shows the relationship between the measured local water CHF and the equivalent local water CHF by the fluid to fluid scaling law. The measured local water CHF means the corrected water CHF from the local water CHF database under an identical local condition(local quality, pressure, and local mass flux) at the sub-channel where the CHF occurs. The equivalent local water CHF means the local water CHF when the equivalent water CHF conditions were applied. At this time, SF-1 correlation was applied to the CHF correlation to find hot-channel. From an iteration result, the mass flux satisfying an identical local CHF was obtained. This means that if the obtained mass flux is considered as the equivalent bundle averaged mass flux by fluid to fluid scaling law, the local CHF between the water and equivalent water CHF condition are identical.

Figure 3. shows the ratio between the equivalent mass flux by Katto and the new equivalent mass flux. It is shown that the equivalent mass flux by Katto is overestimated when the local CHF is considered, not the bundle averaged CHF. The following similarity is proposed as the parameter for the mass flux to satisfy the local CHF conditions between the water and the equivalent water

$$\left[\frac{G\sqrt{D}}{\sqrt{\sigma\rho_f}}\left(\frac{P}{P_C}\right)^{3.0}\right]_P = \left[\frac{G\sqrt{D}}{\sqrt{\sigma\rho_f}}\left(\frac{P}{P_C}\right)^{3.0}\right]_M$$

, where subscript "C" means the critical pressure of each fluid. The mean and standard deviation of P/M for the mass flux were evaluated as 1.267 and 0.0171, respectively when Katto's mass flux parameter was considered. The mean was improved as 1.000 when the critical pressure term was included in the mass flux parameter and the standard deviation was identical.

Figure 4. shows the result of P/M for the local CHF applying to the fluid to fluid scaling using the proposed mass flux parameter. From the result, the mean of P/M for the local CHF was improved from 1.409 with a standard deviation of 0.371 to 1.0712 with the standard deviation of 0.0241 in case of Type-1 experiment (typical channel). In case of Type-2 (thimble channel), the mean and standard deviation of P/M was evaluated as 1.035 and 0.219 when the proposed mass flux parameter was used.

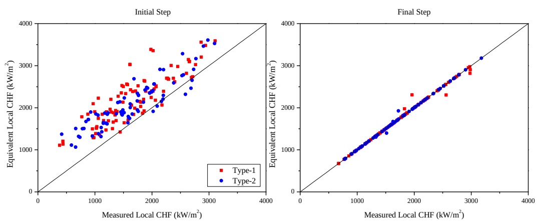

Fig. 2. Iteration result to find the equivalent mass flux satisfying an identical local CHF between Freon and Water

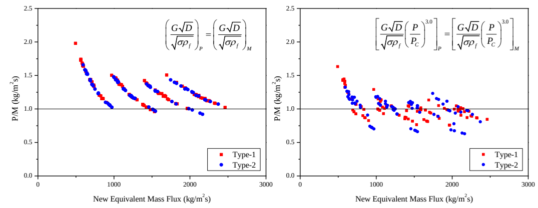

Fig. 3. P/M distribution for mass flux when the critical pressure is considered, or not

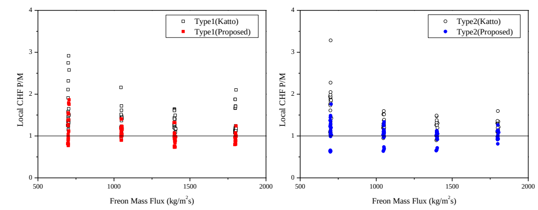

Fig. 4. P/M distribution for the local CHF when the critical pressure is considered, or not

3. Conclusions

The fluid to fluid scaling was evaluated using the Freon and water CHF data for SMART 5x5 rod bundles. The method to analyze the local CHF of Freon and water CHF condition was introduced and the mass flux parameter was proposed. The P/M of the local CHF was improved from 1.389 with the standard deviation of 0.368 to 1.053 with the standard deviation of 0.231.

REFERENCES

[1] Y. Katto, A generalized correlation of CHF for the forced convective boiling in vertical uniformly heated round tubes, International Journal of Heat and Mass Transfer, Vol.21, p.1527, 1978.

[2] S. Y. Ahmad, Fluid to fluid modeling of CHF: A compensated distortion model, International Journal of Mass Transfer, Vol.16, p. 641, 1973.