Development of the Heated Length Correction Factor

Ho-Young Park, KangHoon Kim , Kee-Yil Nahm, Yil-Sup Jung, Eung-Jun Park

Korea Nuclear Fuel Co., LTD., 1047 Daedukdaero, Yuseong-gu, Daejeon, 305-353, hoyoung@knfc.co.kr

1. Introduction

The Critical Heat Flux (CHF) on a nuclear fuel is defined by the function of flow channel geometry and flow condition. According to the selection of the explanatory variable, there are three hypotheses to explain CHF at uniformly heated vertical rod (inlet condition hypothesis, exit condition hypothesis, local condition hypothesis)[1]. For inlet condition hypothesis, CHF is characterized by function of system pressure, rod diameter, rod length, mass flow and inlet subcooling. For exit condition hypothesis, exit quality substitutes for inlet subcooling. Generally the heated length effect on CHF in exit condition hypothesis is smaller than that of other variables. Heated length is usually excluded in local condition hypothesis to describe the CHF with only local fluid conditions. Most of commercial plants currently use the empirical CHF correlation based on local condition hypothesis. Empirical CHF correlation is developed by the method of fitting the selected sensitive local variables to CHF test data using the multiple non-linear regression. Because this kind of method can not explain physical meaning, it is difficult to reflect the proper effect of complex geometry. So the recent CHF correlation development strategy of nuclear fuel vendor is making the basic CHF correlation which consists of basic flow variables (local fluid conditions) at first, and then the geometrical correction factors are compensated additionally. Because the functional forms of correction factors are determined from the independent test data which represent the corresponding geometry separately, it can be applied to other CHF correlation directly only with minor coefficient modification.

As a part of the “Best Estimate CHF Correlation Development Project”, we analyzed the heated length effect on CHF in both inlet condition hypothesis and local condition hypothesis. And then the robust functional form of heated length correction factor was developed and its application validity on CHF correlation was evaluated.

2. CHF Test Data Analysis

In this section, data of three test sections (TS18, TS36, TS38) from EPRI DB[2] were analyzed applying inlet condition hypothesis and local condition hypothesis. The above test sections were selected, because they have similar geometry except the heated length. So the effect of heated length on CHF can come in evidence.

2.1 Inlet Condition Hypothesis

To investigate the effect of heated length on CHF, some of data points which have same inlet conditions (system pressure, inlet mass velocity) were extracted and plotted as Fig. 1.

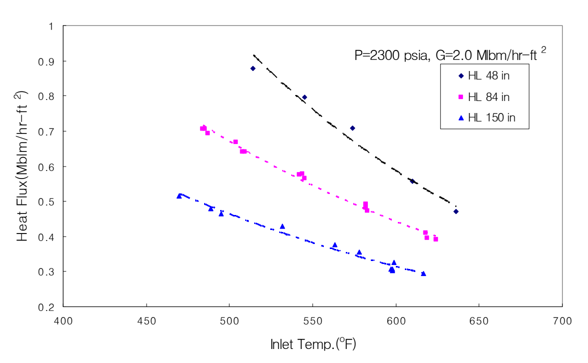

Figure 1. CHF vs. Inlet Temp. (Inlet condition hypothesis)

There is a significant effect on CHF as shown in Fig. 1. The longer heated length shows the lower CHF. This behavior is due to the difference of exit quality at each heated length. So heated length should be considered one of the explanatory variables in inlet condition hypothesis.

2.2 Local Condition Hypothesis

To investigate the heated length effect on CHF in local condition hypothesis, local fluid conditions were calculated by COBRA series subchannel code, TORC [3]. And then local conditions from each test section were extracted and plotted it quality vs. local heat flux as Fig. 2.

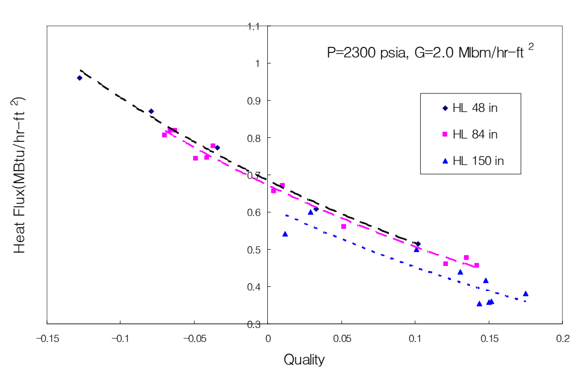

Figure 2. CHF vs. Quality (Local condition hypothesis)

As showed in Fig. 2, the heated length effect on CHF at local condition hypothesis is milder than that of inlet condition hypothesis. But the effect is still existed to be corrected on the contrary to the general acceptance[4]. So the work to develop the correction factor for heated length was proceeded based on the local condition hypothesis.

3. Development of Correction Factor

Through the CHF test data analysis, the need of correction factor for the heated length was recognized and one key point was founded. From the weak dependency on the heated length as shown Figure 2, simple decreasing function is good enough for correction of the length effect. Several of functional forms were initially considered including exponential and power of the heated length and/or relative heated length. The final form of heated length correction factor was determined based on the robustness of physical behavior as given in Fig. 3, as below.

$$F_{HL} = (ZDNB / THL)^{alpha}$$

where, F_{HL} : *Heated length correction factor*

ZDNB : Distance from beginning of heated length to axial location of CHF

THL : Test section heated length

alpha : Coefficient of correction factor

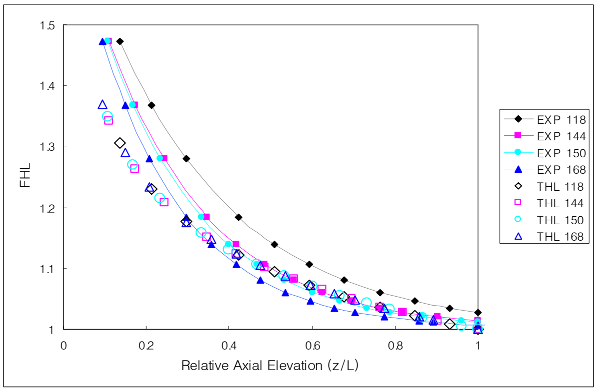

Figure 3. Behavior of Heated Length Correction Factor

The new correction factor keeps up with same value regardless of THL where the relative axial elevation is same and smoothly decays to 1.0 as the ZDNB increasing to THL. While exponential function of ZDNB itself has different value regard to the THL and decays to 1.0 so rapidly as the ZDNB increasing. As a result, the newly developed correction factor is expected to be more consistent for any heated length of test section and/or axial elevation.

4. Application of Heated Length Correction Factor

The effectiveness of the heated length correction factor was verified with implementation to base equation of KNF-A CHF correlation [5]. The database of KNF-A CHF correlation includes test section with various heated lengths and uniform/non-uniform axial power distributions. M/Ps (measure to predict ratio) of modified KNF-A correlation were plotted as a function of axial elevation to investigate any particular trend, as given in Fig. 4.

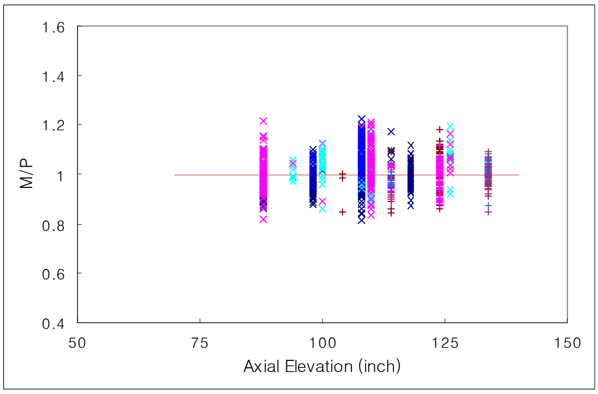

Figure 4. Application of Heated Length Correction Factor

Most of data are uniformly scattered around average of M/P (~ 1.0), and do not show any adverse behavior with respect to heated length or axial elevation. It means that the predicted CHF shows the consistency with measured CHF, and thus correction of heated length is acceptable,

5. Conclusion

Through the CHF data analysis, correction factor for heated length was developed as power of relative axial elevation. The parametric trend of M/P is good and acceptable with implementation of new correction factor on base equation of KNF-A CHF correlation. The application of new heated length correction factor to other correlation is expected to be really straight-forward due to simplicity and robustness of its behavior.

REFERENCES

[1] L. S. Tong, Y. S. Tang, Boiling Heat Transfer and Two-Phase Flow, Taylor & Francis, 2nd Edition, 1997.

[2] C. F. Fighetti, D. G. Reddy, Parametric Study of CHF Data, Volume 3, EPRI, NP-2609, 1982.

[3] Westinghouse Electric Company, USER’S MANUAL for TORC, REV.12, CE-NPSD-628-P, 2001.

[4] Zimmermann, R. et al., Thermophysics 90, 1990.

[5] KNF-A CHF Correlation for ACE7^{TM} Thermal Analysis (to be published).

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