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Comparative Study on the NUAPD Correction Factors

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1. Introduction

Power capability of water-cooled nuclear reactors is limited by CHF (critical heat flux). CHF in a rod bundle of nuclear fuel depends on various factors, such as rod diameter, existence of unheated guide tube, grid spacer characteristics including mixing promoter design, etc. It is generally recommended to perform CHF testing with new prototypical features, if any. Recent trend of CHF testing for advanced fuel development is performing only for a chopped cosine axial power distribution per the invariably ever-changing non-uniform axial power distribution in a nuclear reactor operation. Thus, it is important to review/compare the physical behaviors of current NUAPD (non-uniform axial power distribution) correction factors for general application based on the concept of axial agreement which measures a degree of the consistency between predicted CHF and measured CHF.

2. Current NUAPD Correction Factors

There are couples of correction factor for a non-uniform axial power distribution. The Tong's F-factor (FT) [1] is widely used for actual thermal design analysis with various CHF correlations such as W-3R, WRB-2, and CE-1, etc. The CNU [2] based on Y parameter is used with EPRI-1 CHF correlation and the Fax [3] based on FPBZ parameter is used with HTP CHF correlation. The applicability of FT, CNU and Fax has been verified with the rod bundle data of various axial power distributions [2, 3, 4].

Conceptual approach to NUAPD correction including data verification has been proposed by Kim et al. [5] using the combination of the equivalent enthalpy-rise (DeltaH-EQ) and the power deposition index (zFz).

The physical behaviors of various NUAPD correction factors are given in Figure 1 for a typical cosine axial power distribution (Fz). Where, the FC is the modified shape factor as a function of the FT and the grid spacing. All correction factors in Figure 1 except the FC are independent to grid spacing. As shown in Figure 1, there are 3 distinct way of behavior per NUAPD correction factors. The first group (FT, FC and CNU) shows typical trends of the 'upstream memory effects' for a NUPAD. The correction factors of this group are less than unity (1.0) below the middle region of the heated length. Integrated power below half of the heated length is less than unity as the zFz indicated. Above the middle region of the heated length, correction factors are monotonously increased and well above the unity at the exit region of the heated length for the FT and the CNU. The FC shows saw-blade shape. As described, the value of the zFz is less than unity below the middle of the heated length but it is larger than unity above the middle of the heated length. The zFz is unity at the center of the heated length and end of the heated length. The Fax shows different behavior per other correction factors. The value is larger than unity at lower part of the heated length but less than unity at upper part of the heated length. Those different behaviors implied that CHF correlation should be accompanied with the correction factor considered during development and/or validation.

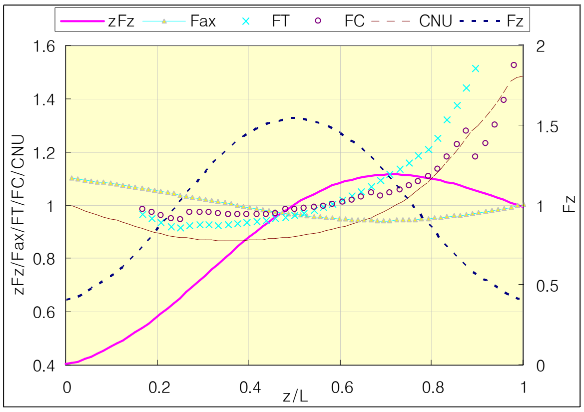

Figure 1. Physical Behavior of NUAPD Correction Factors

3. Effectiveness of Conceptual Approach

For a given power distribution, the local heat flux is directly related to the inlet enthalpy through an energy balance as ;

$$H_{loc} - H_{in} = \frac{4}{GD_E}\int_0^{z_{CHF}} q''\,dz \qquad (1)$$

where

H_{loc} = enthalpy at z_{CHF}
H_{in} = enthalpy at inlet
G = mass velocity

D_E = equivalent hydraulic diameter
z_{CHF} = location of CHF

The effectiveness of the proposed concept with the DeltaH-EQ and the zFz is well identified in Figure 2 with the data given in Table 1 via showing that the corresponding data fall into same lines.

Table 1. Information for CHF Test Section

TS*	Config.	Fz	HL	GS
124	4x4 TYP	1.5 Cosine	8 ft	20 in
125	4x4 TYP	1.7 Top Skewed	8 ft	20 in
132	4x4 TYP	1.4 Top Skewed	14 ft	20 in

*per reference 2

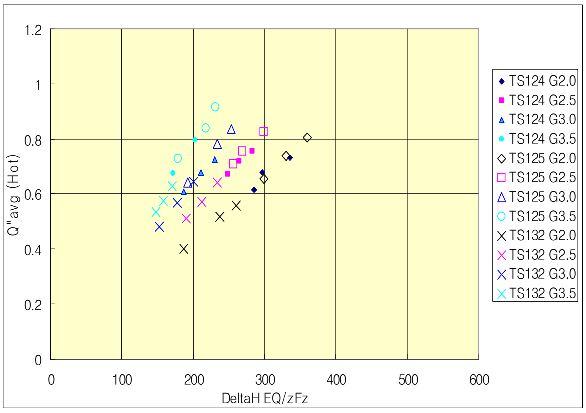

Figure 2. Effectiveness of Conceptual Approach with DeltaH-EQ and zFz

The physical behavior of the zFz for various axial power distributions including reference design shapes (W95) are given in Figure 3. The three-digit number after the zFz and the Fz is the test section number given in Table 1. By investigating the preferred CHF elevation of CHF test sections and the zFz behaviors of each axial power shape, it is found that there is a unique relationship between CHF elevation and the zFz. Even though there is a variation due to axial configuration of spacer grid, CHF occurred at the condition of ;

$$\frac{\partial(zFz)}{\partial z}=0 \qquad (2)$$

The elevation with above criterion is around 75% of the heated length for TS124 (1.5 Cosine), around 85% for TS125/TS132 (Top Skewed). Those elevations are the preferred CHF location. The criterion on eq. (2) is valid to any of CHF test section with a uniform spacer grid configuration (with NUAPD). For the W95 design power shape, actual predicted MDNBR location is matched to the elevation per eq. (2). Thus, the enthalpy-rise up to CHF location is the effective explanatory parameter to qualify/quantify the effects of NUAPD with combination of the relative enthalpy-rise characteristics with respect to a uniform axial power distribution. Therefore, the application of the correction factor is acceptable if/only if it was verified properly and accompanied by CHF correlation considered throughout the process with an extended axial agreement criterion.

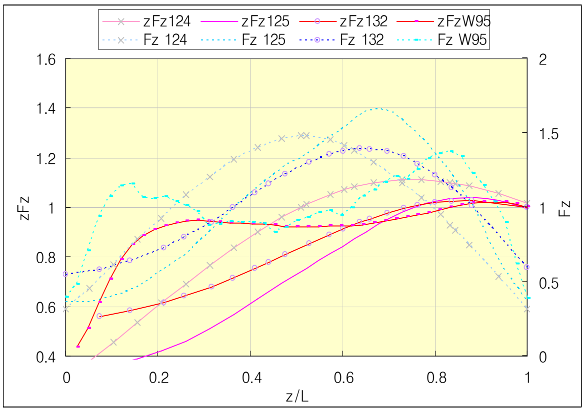

Figure 3. Fz and zFz for Various Axial Power Distributions

4. Conclusion

(1) The enthalpy-rise up to CHF location is the effective explanatory parameter to explain the effects of NUAPD in both qualitatively and quantitatively with combination of the power deposition index.

(2) The general application of any NUAPD correction factor is acceptable with the concept of the axial agreement if/only if NUAPD has already been verified properly.

(3) CHF correlation should be accompanied with the correction factor considered during development/ verification process.

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