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New Unheated Cold Wall Correction Factor

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1. Introduction

CHF in a rod bundle of nuclear fuel depends on various factors, such as rod diameter, existence of unheated guide tube (GT), grid spacer characteristics including mixing promoter design, etc. The effect of unheated cold wall due to GT on CHF is thought to be adverse due to "wasted" portion of the liquid flow. Actual fuel assembly consisted of both types of channel, with and without unheated guide tube wall, in parallel showed more complicated manner per open channel. In this study, the new cold wall correction model is proposed with the review of analytical bases and existing correction factors.

2. Bases of Unheated Wall Correction

The effects of cold wall on CHF had been studied analytically under the following assumptions [1].

(1) Local quality at the location of CHF is same regardless of the existence of cold wall
(2) Flow within the channel is proportionally allocated with wetted area when both heated wall and cold wall existed

Starting from two-extreme conditions, perfect mixing and no mixing as shown in Fig. 1, the general cold wall relationship derived based on inlet condition hypothesis as ;

$$q''_{CW} = q''_{M} \cdot \left[1 + \varepsilon \left(\frac{D_E}{D_H} - 1 \right) \right] \qquad (1)$$

where

$$\varepsilon = \frac{\Delta H_{cold}}{\Delta H_{hot}} \sim \left(\frac{\beta \, s \, L}{A_{F,cold}} \right)$$

Per above equation (1), two-extreme cases can be easily represented by,

ε = 1 → perfect mixing
ε = 0 → zero mixing.

The magnitude of heat flux at each extreme is the expected maximum and the expected minimum, respectively. In actual situation where both types of channel, with and without unheated guide tube wall, are arrayed in parallel, the CHF at the channel with cold wall is expected between the maximum and the minimum.

By interpretation, the CHF with cold wall is same or higher than that without cold wall at same inlet condition. This seems to be fairly true due to the limitation of power deposited when cold wall existed. But it is controversial with respect to general axiom of cold wall penalty based on local condition hypothesis.

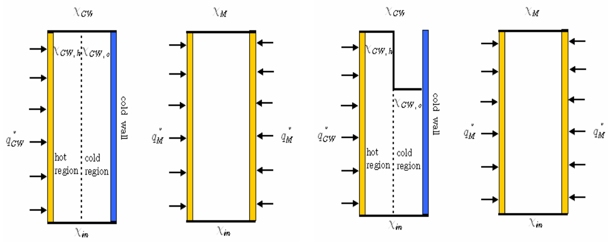

Figure 1. Schematics of perfect/zero mixing

In Fig. 2, the reason of the confusion is clearly explained with cross-sectional enthalpy distribution per each hypothesis. The " C " act as cold wall benefit rather than " A."

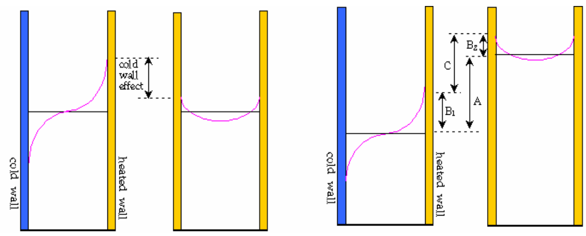

Figure 2. Cold wall effects per hypothesis

The mixing promoter is expected to act as reducing the effects of cold wall by flattening the enthalpy gradient between adjacent channels and/or surfaces.

3. Review the Existing Correction Factors

The explanatory variables of existing cold wall correction factors have been reviewed in conjunction with functional relationship. Most of correction factor consisted of geometric parameters such as equivalent hydraulic diameter (D_E, D_{EM}), equivalent heated diameter (D_H, D_{HM}) or wetted perimeter (P_W, P_{WM}) and variables of fluid condition (Pr, G_{loc}, X_{loc}) included only for limited cases. Table 1 shows the summary of cold wall correction factors reviewed. F_{GT} in Table 1 is a function of local fluid variables.

4. Proposed Cold Wall Correction Factors

By considering physical intuition and the results of survey summarized in Table 1, the simple cold wall correction factor is suggested as a exponential function of equivalent heated diameter ratio ;

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$$F_{DH} = \exp\left[a_{dh2} \cdot \left(1 - D_{HM}/D_H\right)\right] \qquad (2)$$

The coefficient a_{dh2} in equation (2) is estimated and verified with the matched CHF test data (with and without GT) given in Table 2. Data from TS108 and TS109 are used for independent verification.

Table 1. Summary of various cold wall correction factors

CHF Correlation	Explanatory Variable	Applied by	General Behavior	Remark
W-3 [2]	D_E, D_H, Pr, G_{loc}, X_{loc}	x	≤ 1	
CE-1 [2,3]	D_H, D_{HM}	x	≤ 1	
WRB-1 [4]	D_E, D_H	+	< 0	
HTP [5]	P_W, P_{WM}, D_g, D_{EM}, L_H	x	≤ 0	F_{DF}
NV [3]	D_H, D_{HM}	x	≤ 1	F_{GT}
TV [3]	D_H, D_{HM}	x	≤ 1	F_{GT}

Table 2. Information for CHF test sections

TS		DROD/DTHM	HL	Dg
w/ GT	wo GT	(inch)	(inch)	(inch)
97	96	0.374/0.474	168	10
98	99	0.374/0.474	168	20
101	102	0.374/0.980 *	150	15.7
113	112	0.360/0.471	144	10
109	108	0.374/0.482	144	10/7

* 2 x 2 GT

The physical behavior of F_{DH} is tested with arbitrary value of D_{HM}/D_H and acceptable as shown in Figure 3. The application of correction factor given in equation (2) is multiplier to base correlation. Application of the proposed correction factor gives the ratios of average M/P between matched data set ($(M/P)_{avg}$ Ratio) are close to 1 and differences in standard deviation (delta $(M/P)_{std}$)are random with respect to 0 as shown in Figure 4. It means that the effects of cold wall are corrected reasonably regardless of guide tube size and/or guide tube types. And mild but non-adverse trend is identified with respect to spacer grid spacing (D_g) as shown in Figure 5. This is related to persistence of flow turbulence at the downstream of mixing vane. The more margin and the less uncertainty is expected to address mild dependency per short grid spacing.

5. Conclusion

New cold wall correction factor is proposed as a simple exponential function of equivalent hydraulic diameter ratio with single estimated coefficient. The verification based on the matched data set showed the effectiveness and inherent validity of new cold wall correction factor.

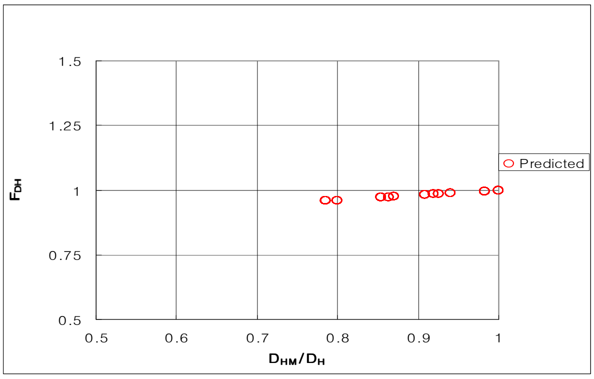

Figure 3. Physical behavior of F_{DH}

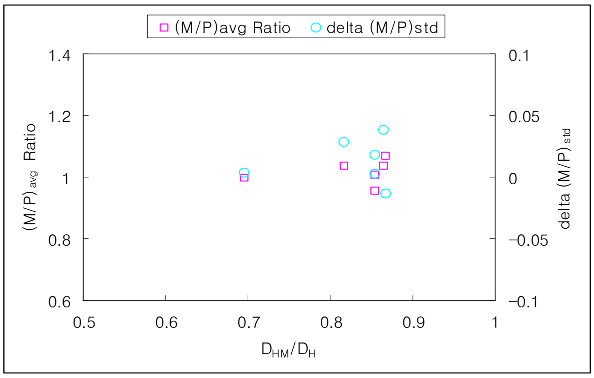

Figure 4. $(M/P)_{avg}$ and $(M/P)_{std}$ per equivalent heated diameter ratio

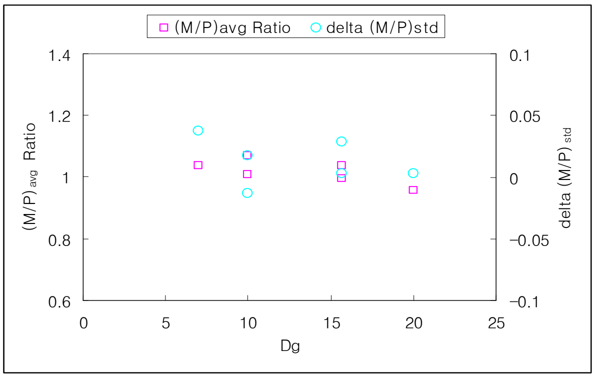

Figure 5. $(M/P)_{avg}$ and $(M/P)_{std}$ per grid spacing

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