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Improvement of gap Stanton number model based on the convective secondary flow

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1. Introduction

Subchannel codes strongly depend on the models and correlations. For single phase flow condition, turbulent mixing and cross-flow model are dominant model that controls the prediction capability of the subchannel code. The cross-flow model is not important in case of the normal flow condition of the typical PWR core without blockages in the flow path. The principal parameter under a normal operating condition is the turbulent diffusion coefficient (TDC), β, in the turbulent mixing model.

Turbulent mixing consisted of the natural turbulent diffusion and macroscopic flow mixing named flow pulsation, generally. Turbulent diffusion was commonly modeled by the Prandtl's mixing length model. Analogically, flow pulsation also modeled by the macroscopic length and velocity scale. These scales were generally determined on the scale analysis and experiment.

In order to theoretically calculate and determine these scales, hypothetical elliptic flow was assumed and then scales based on the flow was calculated. However, recent LES results showed that the mixing strongly related the convective dynamic structure. Present study tried to derive the new length scale based on the LES results. In addition, it is estimated that the conjecture of the dynamic structure, a convective secondary flow, is valid.

2. Methods and Results

2.1 Flow pulsation

Flow pulsation is analogically derived from the turbulent free shear flow[1]. Flow pulsation like the large eddy motion for the free shear flow was characterized regarding the macroscopic length and velocity scale. To determine the length and velocity scale, Kim and Park implemented a hypothetical elliptic flow having the gap and centroid distance as the length scale[2]. Velocity scale of the flow was derived on the elliptic orbital based on the length scale. Principal frequency of the flow pulsation was correlated with the gap to diameter and the correlation was developed by the Wu and Trupp[3]. Using these parameters, anisotropic parameter or gap Stanton number was derived as eq. (1)[4].

$$St_g = 0.00075\frac{D_h}{g}\left(\left(\frac{1333.3}{\Pr \mathrm{Re}^{0.9}}+\frac{1}{\Pr_t}\right)\frac{g}{b\delta}+a_x\frac{z_{FP}}{D}Str\right)\mathrm{Re}^{-0.1} \quad (1)$$

, where D_h is hydraulic diameter, g is gap distance, δ is centroid to centroid distance. a_x and z_{FP} is velocity and length scale derived from the elliptic flow assumption. Strouhal number is determined by the correlation of Wu and Trupp[3].

2.2 Modification of Kim and Park Model

Recently, Large Eddy Simulation (LES) is actively applied to the nuclear core thermo-hydraulics as a tool of the investigation of the detail flow field. The result of LES shows that the flow pulsation is not different from the secondary flow. Ikeno proposed that a convective secondary flow caused to the flow pulsation based on the LES[5]. According to the model, length scale of the x direction of Kim and Park is slightly modified with the distance of rod diameter for the axial flow direction as shown Fig. 1.

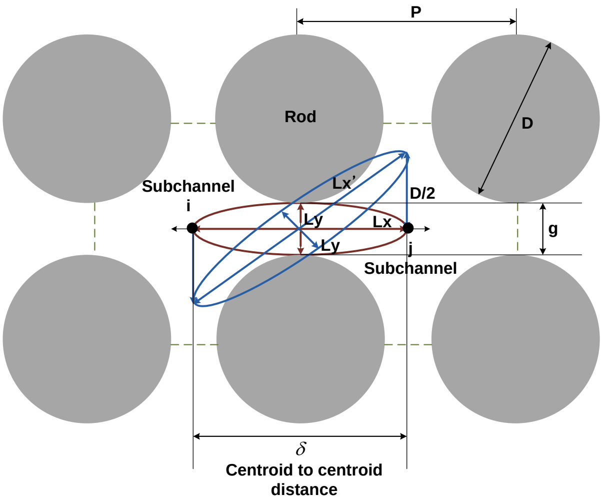

Fig. 1. Hypothetical elliptic flow model in square subchannel, red line : Kim and Park model, blue line : modified model.

The modified characteristic mixing length scale is derived as eq. (2). Convection of the axial flow direction moves the distance of the order of the rod diameter, D. Velocity and length scale is slightly modified using the length scale to consider the convection component. By the effect of the convection, intensity of the mixing by the flow pulsation is larger than the original model by Kim and Park[2].

$$L_x^{'} = \sqrt{L_x^{\ 2} + (0.5D)^2} = \sqrt{\delta^2 + (0.5D)^2} \qquad (2)$$

2.3 Comparisons with other models and experiment

Estimated Stanton numbers was compared with the experiments[6] and correlation of Rogers and Rosehart[7] as shown in Fig. 2. Present study is remarked as the modified Kim and Chung with the hollow diamond shape. Correlation of Rogers and Rosehart was widely used in subchannel codes as expressed in eq. (3).

$$St_g = 0.004\left(\frac{D_h}{g}\right)\mathrm{Re}^{-0.1} \qquad (3)$$

The new length scale relation obtained in this study shows comparatively good agreements especially in tight lattice gap where gap to diameter ratio is under 0.2. The modified relation is closer to the experimental data rather than that of both Kim and Park[2] and Kim and Chung[4].

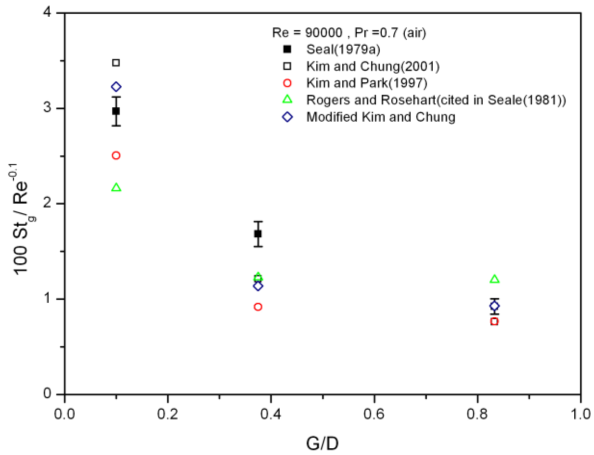

Fig. 2. Experimental and estimated gap Stanton numbers

2.4 Discussions

Modified scale relation implies the convective secondary flow as the main causes of the flow pulsation. This conjecture is indirectly assured from the relation between length scale and Stanton number. The extended mixing length scale makes the mixing rate to be more energetic as shown in Table I.

The length scale and Stanton numbers of three relations are compared and Kim and Chung model has the largest length scale among them. The length scale of the model is determined on basically same model of the Kim and Park but is only slightly different from the series expansion of the elliptic orbit. According the Table I, two models based on the elliptic orbit under or over estimated the experiments. It may mean that the mixing length based on the model require a modification.

Based on the convective secondary flow, the length scale reduces the difference of the Stanton number with improvement of 50% between experiment and scale relation. The result shows that the conjecture is an alternative explain to be more reasonable than the macroscopic mixing that is fully separated from secondary flow.

Table I: Relation of length scale on the Stanton number (g/D = 0.1, St-exp = 2.96798)

	Length scale	Stanton number
Kim and Park	0.07	2.505
Kim and Chung	0.096	3.476
Present study	0.089	3.213

3. Conclusions

Turbulent mixing mechanism of subchannel analysis is investigated with the view of the scale relation. Mixing length scale of the flow pulsation is newly proposed based on the convective secondary flow. The relation has good agreement with experiments than other relation and correlation. The modified relation with new length scale improved the prediction up to 50 % compared with Kim and Chung relation.

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