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Development of generalized correlation equation for the local wall shear stress

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1. Introduction

The pressure drop characteristics for a fuel channel are essential for the design and reliable operation of a nuclear reactor. Over several decades, analytical methods have been developed to predict the friction factor in the fuel bundle flows. In order to enhance the accuracy of prediction for the pressure drop in a rod bundle, the influences of a channel wall and the local shear stress distribution should be considered [1]. Hence, the correlation equation for a local shear stress distribution should be developed in order to secure an analytical solution for the friction factor of a rod bundle. For a side subchannel, which has the influence of the channel wall, the local shear stress distribution is dependent on the ratio of wall to diameter (W/D) as well as the ratio of pitch to diameter (P/D). In the case that W/D has the same value with P/D, the local shear stress distribution can be simply correlated with the function of angular position for each value of P/D. While, in the case that W/D has the different value with P/D, the correlation equation should be developed for each case of P/D and W/D. Hence, in the present study, the generalized correlation equation of a local shear stress distribution is developed for a side subchannel in the case that W/D has the different value with P/D.

2. Methods and Results

2.1. Theoretical development

The theoretical model for an analytical prediction is based on the law of the wall. For the turbulence dominated wall region, the law of the wall has the classical form [2]

$$\frac{u}{u_*} = \frac{1}{\kappa}\ln\frac{yu_*}{\nu} + B \qquad (1)$$

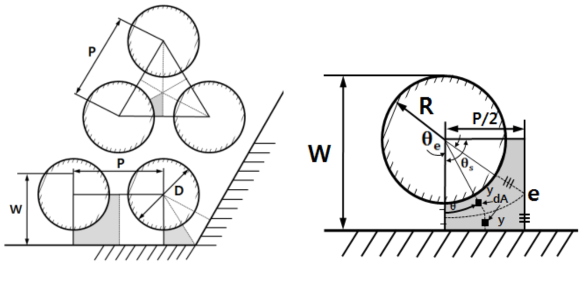
where ν is the kinematic viscosity, u_* is the friction velocity, κ(=0.4) and B(=5.5) are constants. Integration of the law of the wall over cross section results in

$$\left(\frac{8}{f}\right)^{1/2} = A\left[2.5\,ln\left(\frac{1}{2\sqrt{8}}Re\sqrt{f}\right) + 5.5\right] - G^* \qquad (2)$$

where A, G^*donate turbulent geometry parameters. The geometry parameters A, G^* are a function of local shear stress distribution, $Z(\theta)$ as well as the geometry shape [3]. Since the geometry shapes such as P/D or W/D are known, the knowledge of $Z(\theta)$ is necessary to calculate the friction factor of a rod bundle.

2.2. Schematic diagram of subchannel in rod bundle

Figure 1 show the typical geometry of a rod bundle which consists of several types of subchannel. These channels consist of a centre, corner and side subchannel as shown in Fig. 1. In the present study, the rectangular side subchannel, which has the influence of channel wall, is considered.



(a) Rod bundle (b) Side subchannel

Fig. 1. Schematic diagram of subchannel in rod bundle

2.3. Correlation equation of local wall shear stress

In the present study, computational fluid dynamics (CFD) analysis has been chosen as the best practical approach to predict the local shear stress profile. CFD analysis has been performed by using CFX-5.12 code, a commercial CFD code based on a control volume method. The computational domain is divided into hexahedral control volume cells, and about 850,000 nodes are used. The turbulent flow is simulated using the shear stress transport model and a convergence criterion in that RMS residuals of major parameters are less then 10^{-5}. The axial length of the domain was set to the 500 times of a rod diameter. The shear stress distribution is calculated on a rod surface at the far downstream position from inlet. Fig. 3 shows the shear stress distribution for flat wall subchannel respectively. Hence, the local wall shear stress distribution for the square array of rod, $Z(\theta)$, can be correlated as,

$$\boldsymbol{Z(\theta) = (1 - a \cdot cos2\theta - b \cdot cos4\theta + c \cdot sin4\theta)^{\frac{1}{2}}} \quad (3)$$

2.4. Comparison of local wall shear stress for side subchannel

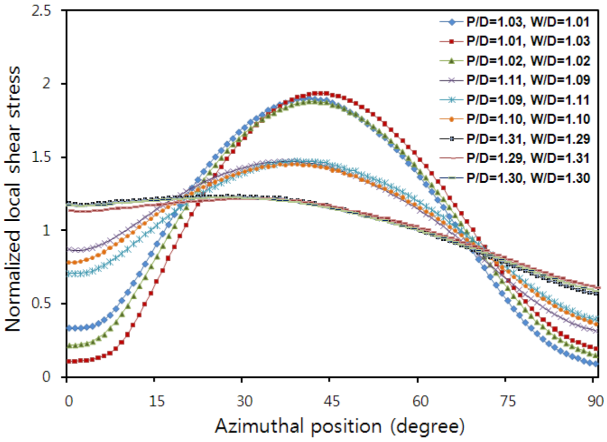


Fig. 3. Wall shear stress variation for side subchannel

Figure 3 shows the normalized wall shear stress profile along the rod surface in the side subchannel. For the representative case of P/D=1.02, 1.10 and 1.30, the values of P/D and W/D are varied with the form that the averaged value of P/D and W/D has the representative value. It is revealed from the figure that the shear stress distribution has the similar shear stress profile only if the averaged value of P/D and W/D is same, although the shear stress distributions shows more deviation as the relative difference of W/D and P/D increases. Hence, the generalized correlation equation of a local shear stress distribution can be developed by defining the equivalent pitch to diameter ratio as follow.

$$\boldsymbol{P^* = \frac{P + W}{2} \ (P \neq W)} \quad (4)$$

That is, for the case that W/D and P/D has the different value, the correlation equation of a local shear stress distribution can be represented by Eq.(3) for each case of P*/D instead of P/D.

The correlation constants a, b and c in Eq.(3) are dependent on the P/D and W/D. These values are deduced from the numerical data. Table 1 shows the values of constants for the case that P/D and W/D has the same value. It is compared with Table 2, which shows the values of constants for the case that P/D and W/D has the different value. The constants a, b, c in Table 2 is revealed to have the similar values with those in Table 1 for each P*/D. It is noted that the slight difference of the correlation coefficient for the same value of P*/D is shown to have the negligible effect on the predicted value of friction factor.

Table. 1. Comparison with the local wall shear stress constants a, b and c for rectangular, side subchannel (P/D=W/D)

	P/D=1.02	**P/D**=1.10	**P/D**=1.30
a	-0.03	0.24	0.30
b	-0.82	-0.40	-0.12
c	0.35	0.10	0.00

Table. 2. Comparison with the local wall shear stress constants a, b and c for rectangular, side subchannel (P/D≠W/D)

	P*/D =1.02		**P*/D** =1.10		**P*/D** =1.30	
	P/D =1.03 W/D=1.01	P/D=1.01 W/D=1.03	P/D =1.11 W/D=1.09	P/D =1.09 W/D=1.11	P/D =1.31 W/D=1.29	P/D =1.29 W/D=1.31
a	0.04	-0.14	0.29	0.16	0.32	0.28
b	-0.81	-0.89	-0.40	-0.44	-0.13	-0.14
c	0.38	0.36	0.11	0.13	0.00	0.00

3. Conclusions

The present study has focused to secure the generalized correlation equation for the shear stress distribution along the rod surface in the side subchannel, irrespective to the difference of P/D and W/D. The comparison results showed that the generalized correlation equation of a local shear stress distribution can be represented by the equivalent pitch to diameter ratio, P*/D for the case that P/D and W/D has the different value.

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