Development of Lateral Loss Coefficient Model on Heterogeneous Gap of Mixed Core

Hyuk Kwon [a*], S. J. Kim, D. H. Hwang, and W. J. Lee
[a]*Reactor Core Design Division, Korea Atomic Energy Research Institute*
, 989-111, Daedeok-daero, Yuseong, Daejeon, 305-353, Korea
[*]*Corresponding author: kwonhk@kaeri.re.kr*

1. Introduction

Fully Ceramic Microencapsulated(FCM) fuel is a heterogeneous fuel that contained dispersed TRISO particles in SiC-matrix. Diameter of FCM fuel is indispensably enlarged to load the sufficient heavy metal in comparison with the fuel rod diameter of conventional PWR. The enlargement of diameter depends on the rod array in assembly. Rod diameters of FCM fuel on the 12 by 12 and 16 by 16 array increased as large as 1.5 and 1.05 times diameter of reference assembly, respectively.

Heterogeneous gap is appeared, provided that mixed core is consisted of FCM fuel assembly and reference fuel assembly. An additional model on lateral loss coefficient model in conventional PWR that is crucial parameter to evaluate the cross flow is not needed due to the homogeneous gap. In conventional thermal-hydraulic design, lateral loss coefficients use the constant or Idel'chik's Reynolds number dependent model that is not considered on the P/D effect.

In order to develop a lateral loss coefficient model applied to the heterogeneous gap in mixed core, 2-D CFD analysis is performed to calculate the pressure distribution and velocity field. MATRA code, subchannel code developed by KAERI, adopted the model is used to estimate the compatibility of FCM assembly with the reference fuel assembly of the conventional PWR.

2. Methods and Results

2.12-Dimensional CFD Analysis

Cross flow is induced by the axial pressure difference caused by lateral flow resistance across subchannels. In order to estimate the effect of lateral loss, 2-D model considering lateral direction only was implemented.

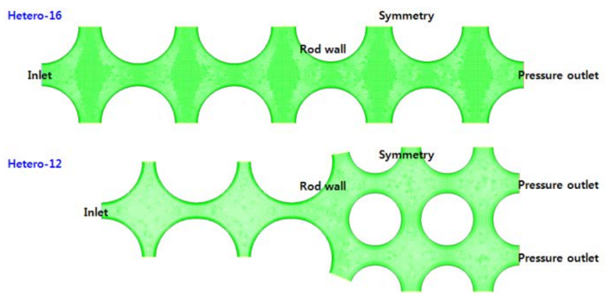


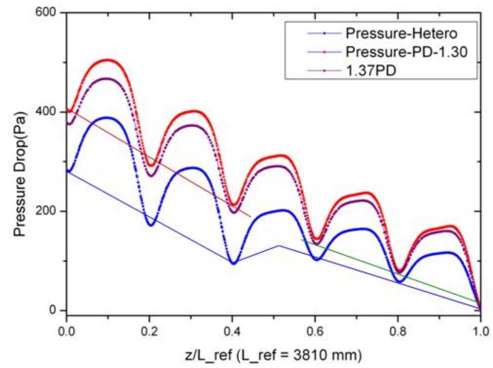
Fig.1. CFD model on FCM 12by12 and FCM 16 by 16 with conventional 16 by 16 assembly

Flow field and pressure distribution on heterogeneous gap are investigated with the 2-dimensional CFD model as shown in Fig. 1. Inlet mass flow, outlet pressure, and symmetry condition are applied as boundary condition. Sensitivity analysis was performed to select the optimum mesh and turbulence model. Table 1 shows the selected optimum model.

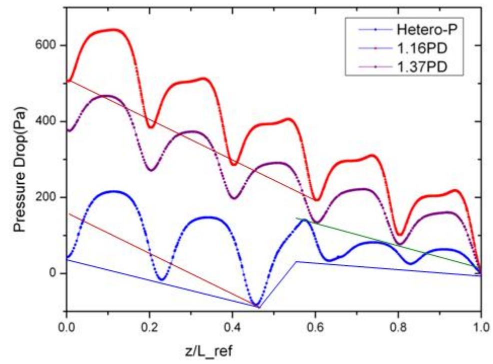
Table 1. Optimized model description

Turbulence model	standard k-e
Mesh information	conformal Hex with 10-boundary layers
Mesh number	30000
Y^+ value	10~15
Wall function	Non-equilibrium type

Lateral pressure distribution according to gap is affected by the geometry of stream direction and mass flow rate. Pressure distribution of individual assembly and mixed core are investigated as shown in Fig. 2.



a) Pressure drop for Hetero-16



b) Pressure drop for Hetero-12

Fig.2. Pressure drop distributions on mixed core having FCM assembly and conventional assembly

In this figure, the straight line describes the pressure gradient due to the form loss and frictional loss.

The Pressure gradient line of Hetero-16 case shows the preserving pressure gradient of each assembly due to the slight difference rod diameter. Hetero 12 case with different rod array assembly shows that the pressure gradient is strongly affected by static pressure change by flow area at the upstream and downstream. Lateral loss coefficient considering heterogeneous gap should apply the pressure change due to the flow area.

2.2 Lateral Loss Coefficient Model

Thermal-hydraulics core design of conventional PWR has used the constant value or Ide'lchik's inline tube bank model [1] in Eq. (1).

$$K_G = A\mathrm{Re}_{lateral}^{-0.2}, \quad A = 1.52\left[\frac{P}{\mathrm{D}} - 1\right]^{-0.5} \tag{1}$$

,where Reynolds number is defined by the rod diameter and lateral velocity. P is rod pitch, D is rod outer diameter.

A heterogeneous gap was established at the interconnection of two assemblies with different rod diameter or different rod array. Idel'chik model using the single pitch to rod diameter (P/D) ratio cannot be applied on the mixed core with the heterogeneous gap.

Zukausukas model [2] that has been used on the performance analysis of heat exchanger can consider various P/D effect on inline tube bank.

$$K_G = 0.52\left(\frac{P/D - 0.8}{P/D - 1.0}\right)^{1.5} \mathrm{Re}^{-r}, \quad r = 0.12\left(\frac{P/D\big|_{row} - 1.0}{P/D\big|_{column} - 1.0}\right)^{0.5} \tag{2}$$

Present model is developed based on Idel'chik model considering the P/D correction of Zukausukas model in Eq. (2).

$$K_G = A\mathrm{Re}_{lateral}^{-r} \tag{3}$$

,where

$$A = 1.52\left[\frac{P_{in} + P_{out}}{\mathrm{D}_{in} + D_{out}} - 1\right]^{-0.5}, r = 0.2\left(\frac{P/D\big|_{out} - 1}{P/D\big|_{in} - 1}\right)^{0.5}$$

Where subscript 'in' means the flow upstream direction and 'out' is flow downstream.

2.3 Results and Discussions

Present loss coefficient model was compared with the CFD results and Idel'chik model. As shown in Fig.3, this model is slightly under-predicting CFD results but improve the accuracy about 20% in comparison with Idel'chik model.

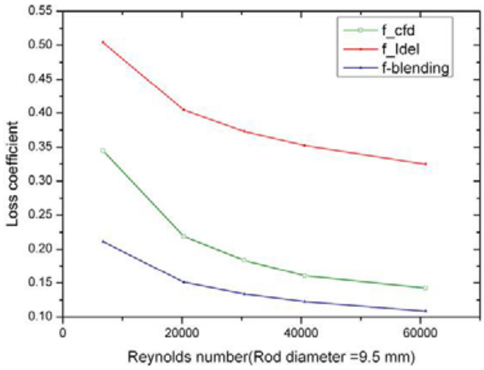


Fig.3. Comparisons of lateral loss coefficient model

Subchannel analysis using MATRA code was performed on the 1/4 assembly having FCM fuel assembly and conventional 16 by 16 assembly. As shown in Fig.4, relative mass flux at MDNBR location was compared according to the lateral loss models such as Idel'chik model(blue line) and present model(red line). In different from Idel'chik model, flow distribution applying present model is affected on upstream effect at intersection region at 0.5 of relative width.

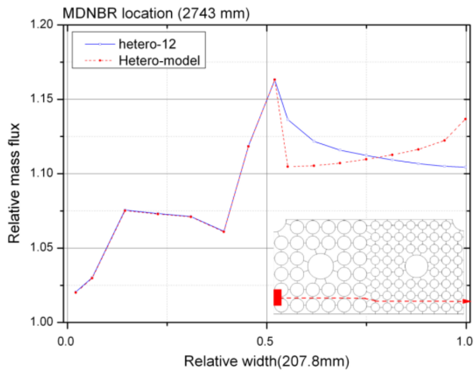


Fig.4. Axial flow distribution on Hetero-12 case

3. Conclusions

Lateral loss coefficient model was developed considering the heterogeneous gap in mixed core that is consisted of conventional 16 by 16 and FCM assembly. Developed model implemented in MATRA code was well applied on the subchannel calculation of mixed core.

REFERENCES

[1] I. E. Idel'chik, Handbook of Hydraulic Resistance, AEC-TR6630, (1966).

[2] A. Zukauskas and R. Ulinskas, Heat Exchanger Design Handbook, Vol. 2 Fluid mechanics and Heat Transfer, Hemisphere, (1983).