Numerical Simulation for Frictional Loss and Local Loss of a 5×5 SMART Rod Bundle

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1. Introduction

During the past decade, 3D CFD codes have been widely applied to NPPs with the aim of examining local thermo-hydraulic phenomena, such as the safety injection flow in the downcomer [1], turbulence due to the incorporation of a mixing vane [2], and subchannel analysis [3]. The results showed good agreement with experimental data and/or reasonable values. However, these results were dependent on computational meshes and turbulence models and it still remains important issues in CFD analysis. The aim of present work is to assess the pressure drop in a 5×5 SMART rod bundle using 3D CFD code with various computational meshes and turbulence models.

2. Numerical Simulation

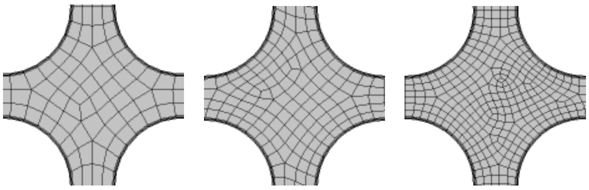
This paper consists of two different numerical simulations.

- Adiabatic simulation of 5×5 bare rod bundle
- Adiabatic simulation of 5×5 SMART rod bundle

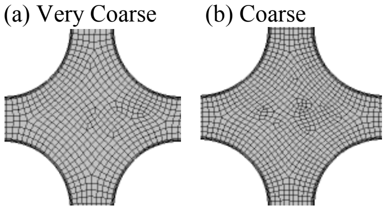
In the present work, steady-state RANs equation for incompressible flow was solved by FVM using CFX 14.5, a commercial CFD code. Three different 2-equation turbulence models with five computational meshes were selected to investigate the adequacy in analyzing thermo-hydraulics in a rod bundle geometry using CFD codes.

2.1 Friction Factor for Bare Rod Bundle

In order to investigate turbulence pressure drop for a bare rod bundle, first, CFD analyses of 5×5 bare rod bundle were carried out with k-ε, RNG k-ε, SST turbulence model and various computational meshes as shown in the Fig. 1. Fig. 2 shows the frictional pressure drop for a bare rod bundle. This result showed that predicted pressure drop are strongly dependent with the turbulence models and the number of meshes. This difference appears to be negligible in the cases of fine mesh and/or very fine mesh. Based on this finding, friction factor was calculated based on the CFD results with fine computational mesh. Fig. 3 shows the prediction friction factor based on CFD result. The friction factor based on k-ε model is nearly identical with McAdams's correlation. While RNG k-ε model underestimates frictional pressure drop and SST overestimates frictional pressure drop in a bare rod bundle based on McAdams's correlation.



(a) Very Coarse (b) Coarse (c) Medium



(b) Fine (e) Very Fine

Fig. 1. Computational meshes.

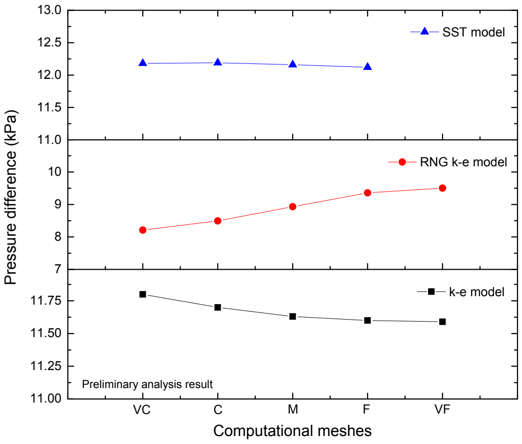


Fig. 2. Mesh sensitivity.

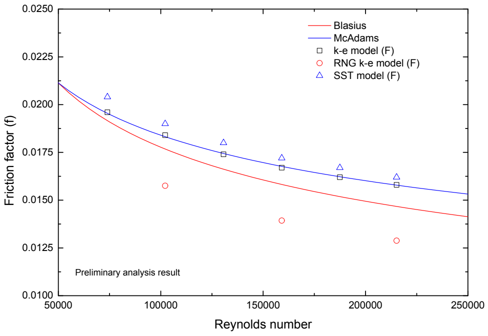


Fig. 3. Friction factor for a 5×5 bare rod bundle.

2.2 Loss Coefficient of Grid Spacer

The 5×5 SMART rod bundle consists of a bottom grid, a top grid, three MV grids and two IFM grids. In the present work, the local pressure drop due to the presence of MV and IFM gird were investigated using 3D CFD code with real grid geometry. Fig. 4 shows the computational domain which includes MV or IFM grid. The inlet boundary was selected at the bottom of computational domain and various uniform velocities were applied at the inlet boundary, which were covered with Reynolds number from 70,000 to 220,000. The outlet boundary is specified at the top of computational domain and it has a relatively pressure of 0 Pa. Three turbulence models were also selected in the simulation, and fine and very fine mesh were used. Fig. 5 and Fig. 6 show predicted pressure loss coefficient, k-factor, of MV and IFM grid based on CFD results. The pressure loss coefficient was calculated by Eq. (1).

$$k = \frac{2\left(\Delta P_s - \Delta P_f\right)}{\rho V^2} \qquad (1)$$

where ΔP_t, ΔP_f, V and ρ are total pressure drop in a rod bundle including single grid, frictional pressure drop, bundle average flow velocity and fluid density, respectively. For all cases, predicted k-factor of MV and IFM grid decrease with increasing Reynolds number and it seems to be nearly constant at high Reynolds number (Re>200,000). The results showed that k-factor predicted by k-ε model was higher than the k-factor based on other turbulence models and SST model predict k-factor lower.

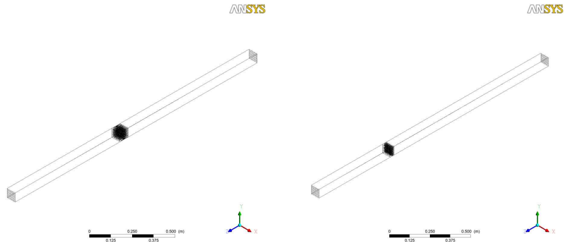


Fig. 4. Computational domains.

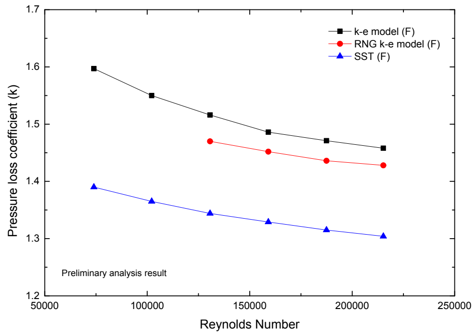


Fig. 5. Pressure loss coefficient of MV grid.

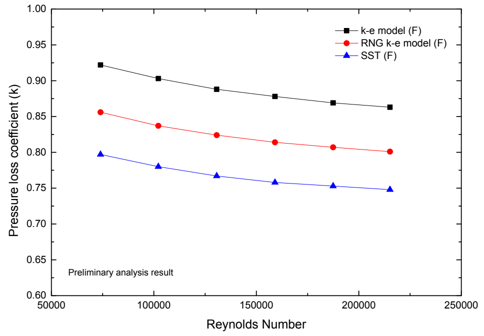


Fig. 6. Pressure loss coefficient of IFM grid.

3. Conclusions

In the present work, 3D CFD code was utilized to investigate pressure drop in a SMART 5×5 rod bundle. The predicted pressure drop was strongly dependent with computational meshes and turbulence models. Based on CFD results in this study, least five of six meshes within the subchannel gap are required to get reliable result which is insensitive to the number of meshes. The friction factor predicted by k-ε model is good agreement with McAdams's correlation while SST model overestimate McAdams's correlation. However, it is difficult to judge performance of turbulence model because of lock of experimental data for a 5×5 SMART bare rod bundle. For nominal condition (Re~194,000) of SMART, SST model predict k-factor of MV and IFM grid as 1.304 and 0.748, respectively. This value is reasonable as compared with designed k-factor, 1.320 and 0.78.

ACKNOWLEDGEMENTS

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