Verification of Flow Blockage Test in the MATRA-S Code

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1. Introduction

1.1 Westinghouse flow blockage test

Flow distribution in the nuclear reactor core is very important. It is the reason why enthalpy distribution, which is related to critical heat flux, follows a fluid behavior.

The flow blockage test of Westinghouse [1] has been operated to estimate flow re-distribution via blockage rate. The test section illustrated in Fig. 1 consists of two 14X14 array rod bundles with a rod diameter of 1.08cm and pitch/diameter ratio of 1.28. From the results, what flow is concentrated in a wide channel and local velocity is higher than average are checked on. These results are caused by pressure drop due to the pressure coefficient of fuel rod.

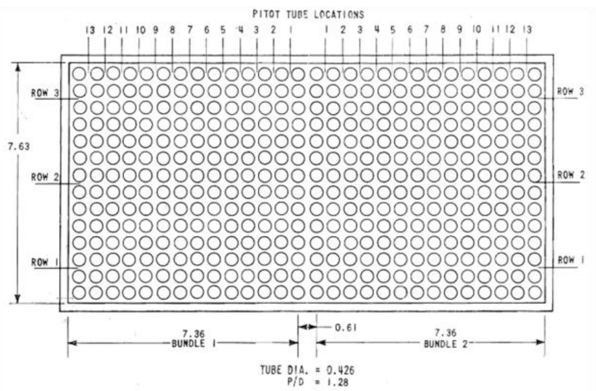

Fig. 1. Test section of blockage test of Westinghouse

1.2 MATRA-S code

The MATRA-S code [2] has been designed for the thermo-hydraulic analysis of a system integrated modular advanced reactor (SMART) core.

1.3 Computational Fluid Dynamics code

Computational fluid dynamics (CFD) analysis is conducted to support the results of the MATRA-S code.

2. MATRA-S Code Analysis

The MATRA-S analysis is conducted to estimate that the MATRA-S simulates the phenomenon of the Westinghouse blockage test properly. Information of the test section shape and boundary condition for analysis is depicted in Table 1. The test section, two bundles, consists of five channels. In order to check the effect of blockage, mass flux ratio is inputted into 1.33, 1.33, 1, 0.67, and 0.67 at channel 1 to 5, respectively. In order to find an effect of area difference because of gap difference, three cases are calculated while changing the area of channel 3. Each case has the same values of, wetted length and heated length.

Table 1. Information for MATRA-S analysis

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
			Gap 1.1 [mm]		
Area [mm^2]	43.31	86.62	62.67	86.62	43.31
			Gap 3.1 [mm]		
Area [mm^2]	43.31	86.62	86.62	86.62	43.31
			Gap 6.1 [mm]		
Area [mm^2]	43.31	86.62	125.68	86.62	43.31
mass flux [kg/m^2s]	2,000	2,000	1,500	1,000	1,000
Pw [mm]	14.922	29.845	29.845	29.845	14.922
Ph [mm]	14.922	29.845	29.845	29.845	14.922

3. CFD Analysis

For the validity of the results of the MATRA-S, computational fluid dynamics (CFD) analysis is conducted with ANSYS CFX [3].

Test section illustrated in Fig. 2 pursues Table 1, and designed by ANSYS Workbench.

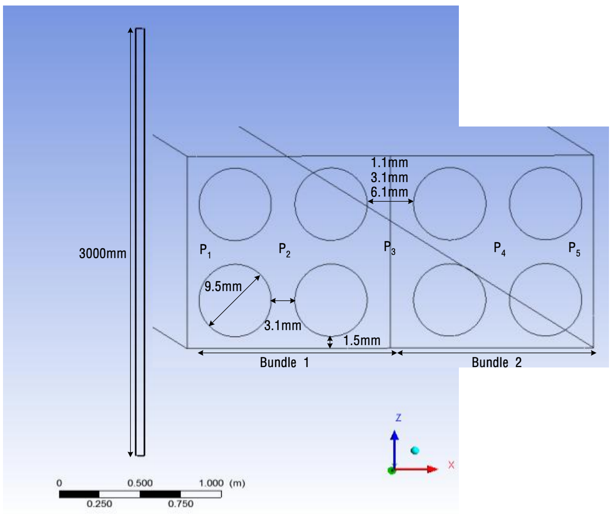

Fig. 2. Three dimensional configuration of test section

3.1 Grid and boundary condition

Grid is generated. The total node number is about 1,110,000 and inflation is generated near a wall or fuel rod.

The energy term, enthalpy, is neglected because the blockage test is for hydraulic analysis. The fluid temperature and pressure are fixed at 25°C and 0.1 MPa for inlet boundary condition, and then, normal speed 2.0

m/s and 1.0 m/s are set. The scheme is applied with high resolution and the shear stress model is selected to transport an equation. The relative pressure of 0 MPa is inputted for the boundary condition of outlet.

3.2 Governing equation

The set of equations solved by ANSYS CFX are the Navier-Stokes equations in their conservation form. For all the following equations, hydrodynamic quantities are given as below;

The continuity equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0$$

The momentum equation

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_i}(\rho u_i u_i)=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i+F_i$$

3.3 Transport equation

The shear stress transport based on the k-ω model of Wilcox [2, 4] is designed as an accurate prediction of the onset and the amount of flow separation under adverse pressure gradients by the inclusion of transport effects into the formulation of the eddy-viscosity. For turbulent flows, the instantaneous equations are averaged leading to additional terms. Te SST model is the same to the k-ε model in the free shear regime. This is the reason why the SST model requires blending factors for performing between k-ε and k-ω.

The standard k-ε model

$$\frac{\partial(\rho k)}{\partial t}+\nabla\bullet(\rho U k)=\nabla\bullet\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\nabla k\right]-\rho\varepsilon$$

$$\frac{\partial(\rho \varepsilon)}{\partial t}+\nabla\bullet(\rho U \varepsilon)=\nabla\bullet\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\nabla \varepsilon\right]-C_{\varepsilon 1}\rho\frac{\varepsilon^2}{k}$$

The Wilcox k-ω model

$$\frac{\partial(\rho k)}{\partial t}+\nabla\bullet\left[\rho\vec{w}k-\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\nabla k\right]=P_k+P_{kb}-\beta'\rho k\omega$$

$$\frac{\partial(\rho \omega)}{\partial t}+\nabla\bullet\left[\rho\vec{w}\omega-\left(\mu+\frac{\mu_t}{\sigma_\omega}\right)\nabla \varepsilon\right]=\alpha\frac{\omega}{k}P_k-P_{\omega b}-\beta\rho\omega^2$$

4. Results

The radial velocity profile is described in Fig. 3 via the axial length and channel area. Red and blue lines are results of the CFX and the MATRA-S, respectively. A fully developed flow regime is vicinity L/De of 130. Channel 3 velocity is lower than other channels in a narrow case. On the contrary, Channel 3 velocity is higher than other channels in wide case. It is clue that the velocity profile is depended on the channel area. Tendency of qualitative analysis is similar, quantitative error is about ±7.3%.

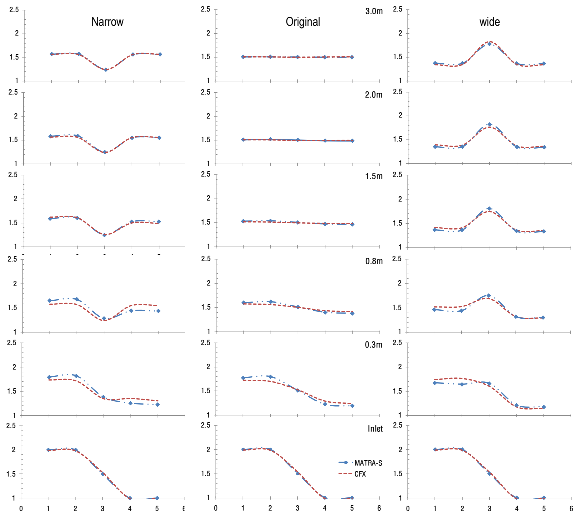

Fig. 3. Comparison results of MATRA-S code and CFX code

5. Conclusion

The MATRA-S code has been simulated the flow re-distribution against blockage. It means that the governing equations, correlation, and models for pressure drop and cross flow is proper in the MATRA-S code.

REFERENCES

[1] H. Chelemer, P.T. Chu, L.E. Hochreiter, “THINC-IV-An Improved Program for Thermal-Hydraulic Analysis of Rod Bundle Cores,” WCAP-7956, Westinghouse Electric Corp., 1973.

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[4] D.C. Wilcox, “Turbulence Modeling for CFD,” DWC industries, La Canada, 1993.