CFD Analysis on the Lower Core Support Plate at the Core Inlet of SMART Test Facility

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1. Introduction

The lower core support plate (LCSP) having four flow holes per a fuel assembly is installed bottom of the SMART core. The reactor coolant enters into the core inlet region through the LCSP composed of many holes. In general, the LCSP has a strong effect on the flow distribution of core inlet.

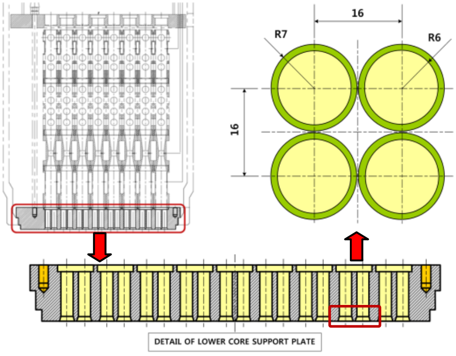


Fig. 1. Configuration of LCSP (1/5 scale)

Since 2009 the reactor flow distribution model test has been being performed using a prototype model with 1/20 Re and 1/5 scale of SMART as shown in Fig. 1. As groundwork for the CFD analysis for the core inlet flow, a numerical analysis for the flow similarity between the local hole in LCSP of SMART and that of test facility is performed in this paper. The accuracy of turbulence models and grid effect are also investigated in this paper.

2. Methods and Results

2.1 Model description

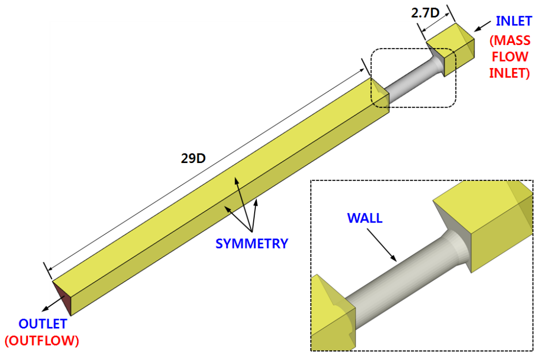


Fig. 2. Schematic of computational domain for LCSP

In this numerical simulation, it is assumed that the flow is in a steady state and 3D-1/8 axisymmetric in the reactor and that the fluid is incompressible. In addition, the steady-state simulations are carried out with a single precision solver, SIMPLE algorithm for pressure-velocity coupling, second order upwind scheme for discretization, and standard wall function for near wall treatment (without low Reynolds correction for SST *k*-*ω* turbulence model), while the working fluid with constant density and viscosity is applied. The commercial CFD code, Fluent 12.0, is applied to solve governing equations [1], for example given in the *k*-*ε* turbulence model as follows:

Continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

Momentum equation

$$\rho u_j \frac{\partial u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \mu \frac{\partial^2 u_i}{\partial x_j^2} + \rho \frac{\partial}{\partial x_j}\left[\frac{c_\mu k^2}{\varepsilon}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \tag{2}$$

Figure 2 illustrates a typical computational domain used in the simulation and shows corresponding boundary condition. In order to remove the effect of geometrical uncertainties in the comparison with an empirical correlation, a straight tube which has approximately 3D and 30D of the LCSP flow hole is installed at the entrance and discharge of the hole as shown Fig. 2.

2.2 Empirical correlation

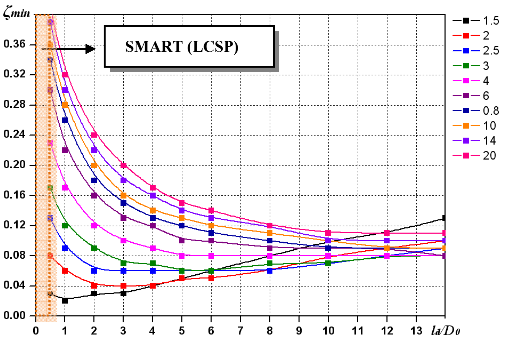


Fig. 3. Loss coefficient regarding the outlet chamfer [2]

The loss coefficient calculated using an empirical correlation [2] is used to confirm the accuracy of Fluent 12.0 code. The CFD results for orifices, which have no outlet chamfer, are in good agreement with the empirical correlation within 10% [4, 5]. Figure 3 shows the relation between configuration of orifice outlet chamfer and loss coefficient. As shown in Figure 3, the pressure loss coefficient is greatly influenced by the shape of outlet chamfer, particularly at the small value of chamfer. Even when the ratio (l_d/D_o) of chamfer length (l_d) to orifice diameter (D_o) is less than approximately 0.5, the empirical correlation is out of the range of valid values. Unfortunately, the LCSP of SMART is in the invalid region. Therefore, comparison with an empirical correlation is performed for an orifice which has no outlet chamfer [4].

2.3 Grid sensitivity and turbulence model test

The investigation into grid dependency for a LCSP hole with chamfer is conducted using hexagonal meshes generated by Gambit. As shown Table 1, approximately 18~470 thousand nodes are used for the cases. The fine grids are applied near the walls and around the flow holes of the LCSP, where the maximum $\mathbf{y}^+$ values are set less than 80 for all cases. As shown in Table 1, the deviations between C cases and D cases are less than 1.5% in all turbulence models. It is also seen in Fig. 4 that between Case C1 and Case D1, the local deviation of static pressure along the central axis of flow does not exceed 3%. Based on the present grid test result, the grid of the C Cases is applied for following analysis of LCSP.

In addition, the deviation between SST and RNG is less than 3%, and between SST and RKE, the deviation is less than 5%. Therefore, three turbulence models are all valid.

Table 1 Case summary [3]

Case	Mesh (#)	Turb. model	Pressure difference (Pa)	Deviation (%) (Emp. correl.)
A1	18,242	RKE	6,623	7.9
B1	39,590	RKE	6,427	5.1
C1	103,887	RKE	6,296	3.1
D1	466,688	RKE	6,257	2.5
A2	18,242	SST	7,168	14.9
B2	39,590	SST	6,914	11.7
C2	103,887	SST	6,599	7.5
D2	466,688	SST	6,499	6.1
A3	18,242	RNG	6,695	8.9
B3	39,590	RNG	6,538	6.7
C3	103,887	RNG	6,428	5.1
D3	466,688	RNG	6,394	4.6
Empirical correlation			6,102	(1)

(1) An estimated value form ref.[2] and CFD results[4]

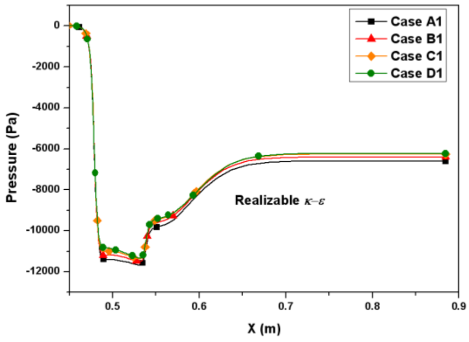


Fig. 4. Grid sensitivity test using RKE [3]

2.4 Comparison with the LCSP of SMART

The loss coefficients of the 1/5 scale & 1/20 Re model and the SMART full model are compared in Table 2 for the SST turbulence model, as SST was applied at the LCSP of SMART full model [4].

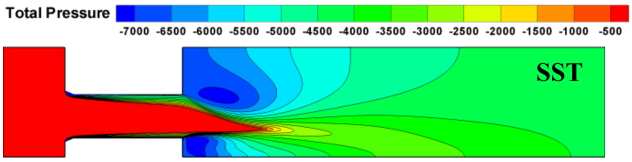
The loss coefficient calculated using the empirical correlation is not much different between the 1/20 Re model and the SMART full model, and the deviation is caused by the friction factor variation with Re and is approximately 6%. In addition, the results of the CFD and the empirical correlation are slightly different within approximately 5%. There is some limit of $\mathbf{y}^+$ values in applying fine grids near the wall in the 1/20 Re model having small Re, as the wall function is used in this study.

However, the differences caused by the friction factor variation and grid limit are not noticeable between two models. And when compared with the Case C2 and Case E of total pressure at the symmetry region, there are no significant differences between them. Consequently, according to simulation results, there are similarity between the 1/5 scale & 1/20 Re model and the SMART full scale model.

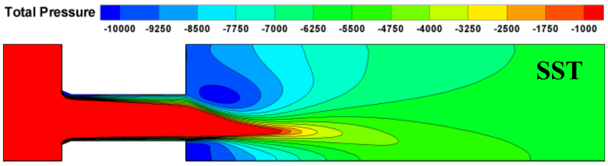
Table 2. Comparison between the 1/20 Re model and SMART

CASE	Mesh number	Turbulence model	Loss coefficient	
			Empirical (1)	CFD
C2	0.1M	SST	0.68	0.65
E	9M	SST	0.64	0.59

(1) ζ_{emp} is an estimated value form ref.[2] and CFD results[4]



(a) CASE C2 (1/20 Re model)



(b) CASE E (SMART full model)

Fig. 5. Contours of total pressure on the symmetry plane (SST)

3. Conclusions

Several numerical simulations are performed using the FLUENT 12.0. The simulation results between SMART full model and the 1/5 scale & 1/20 Re model of SMART show very similar flow pattern. Therefore we can conclude that the flow characteristics of SMART LCSP is not significantly affected by the Reynolds number variation in the range where Reactor flow model test is being performed.

Acknowledgement

This study has been performed under a contract with the Korean Ministry of Educational Science and Technology.

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