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CFD Analysis on the Core Inlet Flow Similarity between an 1/20 Re model and SMART

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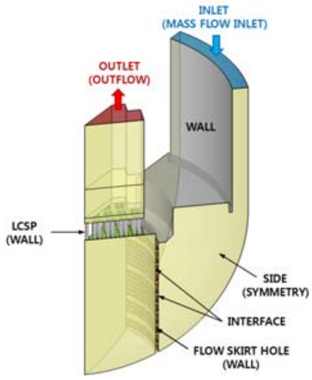
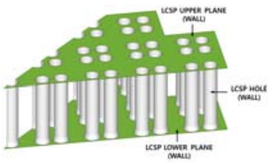
1. Introduction

A reactor flow distribution model test has been being performed using a 1/5 size and 1/20 Re model for SMART since 2009[1]. CFD (Computational Fluid Dynamics) analyses also have been being conducted in parallel for SMART [2~4].

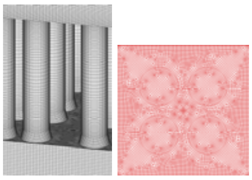
Before the construction of the test facility, several CFD calculations on the core inlet flow distribution to confirm the similarity between the SMART full model and the 1/5 scale-1/20 Re model were performed. The core inlet flow of SMART was investigated in reference [2]. In the process of the similarity calculation, the effects of the core resistance and the flow structure such as the flow skirt of SMART were also investigated. In this paper, the CFD results are discussed and the influence of turbulence models and grids are inspected.



(a) Domain



(b) LCSP



(c) Grid of LCSP holes

Fig. 1. Geometry, BC and grid of computaional domain

2. Methods

2.1 Model description

With the assumptions that the flow pattern is steady and three dimensional (3D) 1/8 symmetry (Fig. 1) and that fluid has constant properties, this simulation is performed using a single precision solver, and the SIMPLE algorithm for pressure-velocity coupling, the 2nd-order upwind scheme for discretization, and the standard wall function for RKE (Realizable *k*-*ε*) and RNG (Renormalization Group *k*-*ε*) turbulence models (the low Reynolds correction option is not applied for SST (Shear Stress Transport *k*-*ω*)).

FLUENT 12 [5], a commercial CFD code, is adopted in this paper. The governing equations for the 3D, incompressible, steady and turbulent flow are as follows:

$$\frac{\partial\langle u_i\rangle}{\partial x_i}=0 \qquad (1)$$

$$\rho\frac{\partial\langle u_i\rangle\langle u_j\rangle}{\partial x_j}=-\frac{\partial\langle p\rangle}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial\langle u_i\rangle}{\partial x_j}+\frac{\partial\langle u_j\rangle}{\partial x_i}\right)-\rho\langle u_i'u_j'\rangle\right] \qquad (2)$$

Turbulence modes such as SST, RNG, RKE are applied in this paper and well summarized in reference [5].

2.2 Configurations and Boundary Conditions

In the experiment, each fuel assembly of SMART having 17×17 fuel rods is simply modeled using a simulator which is fabricated with a venturi and holes. Even though the simplified simulator is applied in the experiment, much computational resources should be required to model the simulators in CFD. To focus on the core inlet flow and simplify the problem, the holes of flow skirt in some cases and the fuel assemblies in all cases are simulated using a porous model in this study.

Figure 1 shows the computational configuration, boundary conditions (BC), and grid. The calculation domain having an inlet and an outlet and two symmetries includes the 45° region (1/8-symmetry) of the reactor core inlet of the 1/20 Re model of SMART. The LCSP (lower core support plate) having 4 holes per each fuel assembly and FS (flow skirt) having many holes are involved in the domain.

The simulation cases for the core inlet region are summarized in Table 1.

Table 1. Case summary

Case	Turb. model	Mesh (million)	Core Resist.	Flow skirt	Mass flow rate	
					Max.	min
A	RKE	22.8	O	holes	1.01	0.98
B	RKE	46.5	O	holes	1.01	0.98
C	RKE	48.0	O	holes	1.01	0.98
D	SST	22.8	O	holes	1.01	0.98
E	RNG	22.8	O	holes	1.01	0.99
F	RKE	47.1	O	porous	1.01	0.98
G	RKE	48.0	X	holes	1.01	0.98

3. Results and Discussion

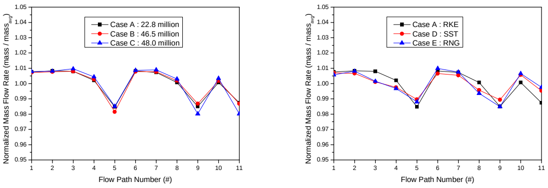
3.1 Grid dependency and turbulence models

As groundwork, the grid independency for the LCSP holes of the test facility and comparison with an empirical correlation are executed in detail in reference [4]. For the orifices similar to LCSP holes, the CFD results of RKE, RNG, and SST are within 10%

deviation from the empirical correlation [6] in reference [4].

Figure 2(a) shows the result of grid test for the 1/20 Re model. The grid test is performed using RKE as turbulence model. The deviations of the mass flows passing through the LCSP are within 1% in the three different grids.

The CFD results for the series using RKE, SST, and RNG are explained in Fig. 2(b). All turbulence models show similar flow distributions within 2% deviation. It can explain that the three models closely estimate the pressure loss passing through the LCSP holes [4].



(a) Grid dependency (b) Turbulence models

Fig. 2. Mass flow rate with meshes and turb. models.

3.2 Effect of flow skirt

The flow skirt is modeled using the real holes in Cases A~E & G and using the porous model in Case F. The variation regarding the modeling method of the flow skirt is very small (<0.5%) as shown in Fig. 3(a). The result describes that the core inlet flow is not sensitive to the change in flow patterns of the flow skirt, as SMART has a large reactor cavity.

3.3 Effect of core resistance

The results simulated without core flow resistance and with that of 1/20 Re model are displayed in Fig. 3(b). As shown in the figure, two cases do not show any remarkable difference (<0.1%). Even though the core flow resistance is not set, that does not make any significant variation of the core inlet flow. This indicates that the LCSP holes play a very important role for the core inlet flow.

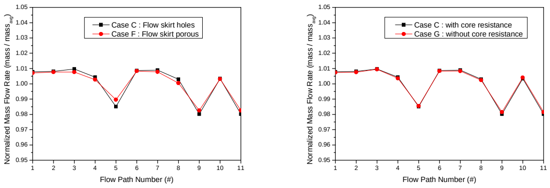
But remember that the core inlet flow characteristics due to flow skirt and core resistance could be different in commercial reactors, as the core inlet geometry of commercial reactors is much different from that of SMART

3.4 Similarity between SMART and the 1/20 Re model

Figure 4 shows the result of the similarity test between the SMART full model and the 1/20 Re model. The mass flows at the LCSP show very similar distributions between two different Re model within 1% deviation.

The mass flow rate becomes small near the wall in all cases. The decease near the wall can be explained that the flow condition near the wall is not uniform compared to the center core. However the deviation compared to average value is not exceeding 2%.

In brief, it can be concluded that it is possible using a 1/5 size and 1/20 Re model to assess the core inlet flow in SMART reactor, as the Re variation within the simulation range make no noticeable difference of the core inlet flow.



(a) Flow Skirt (b) Core resistance

Fig. 3. Mass flow rate with flow skirt and core resist.

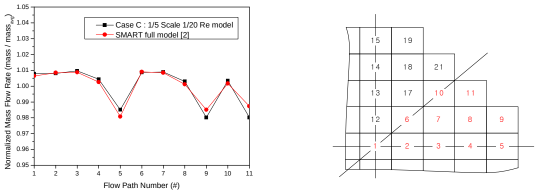


Fig. 4. Mass flow rate with Reynolds number.

4. Conclusions

Numerical analyses using CFD are performed for the core inlet flow of the 1/5 scale 1/20 Re model of SMART. The core inlet flow is not sensitive to the turbulence models. Moreover, the difference of the core resistance or the modeling method of the flow skirt does not make any noticeable variation of the core inlet flow. These indicate that the LCSP holes of SMART play a very important role for the core inlet flow. In conclusion, it is acceptable using a 1/5 size and 1/20 Re model in test facility to investigate the core inlet flow in SMART reactor, as the variation of the core inlet flow with Re is negligible.

Acknowledgement

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