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Numerical Simulation on the Venturi in SMART Reactor Flow Distribution Test Facility

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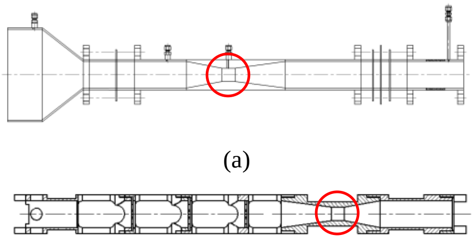
1. Introduction

To identify the flow characteristics of SMART reactor, flow distribution model test and numerical simulation has being performed in KAERI. The test facility is made up major components such as core, and stream generators and reactor internals et al. to simulate the flow distribution and resistance in reactor. Steam generator and fuel assemblies are simulated by using simulators because of the complexity of components.

To predict the flow characteristics in whole test facility more accurately, it is necessary to calculate the characteristics in local components more exactly. In this paper, numerical analysis for the venturi used in steam generator and core simulator is performed to verify the CFD code used in numerical simulation for SMART test facility.

2. Methods and Results

2.1 Geometry and Condition


(a)

(b)

Fig. 1. Geometry of the Steam Generator (a) and Core Simulator (b)

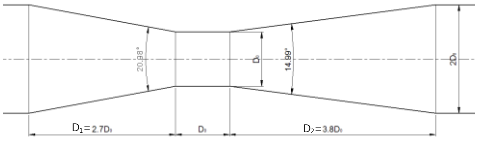


Fig. 2. Geometry of the Venturi

The geometry of the steam generator, core simulator and the venturi included in these components is shown in Fig. 1 and 2.

2.2 Methodology

The pressure loss coefficients calculated by empirical correlation[1] are compared to the numerical results. To calculate the pressure loss coefficient, variables like maximum / minimum cross section area ratio, length / diameter ratio of nozzle, and angle of conical diffuser are considered. Input values required to calculate the flow resistance is shown in table I.

Table I : Problem Description of Venturi

Input Variable	Steam Generator	Core
D_1	$2D_{0,SG}$	$2D_{0,C}$
F_0	$\pi D_{0,SG}^2/4$	$\pi D_{0,C}^2/4$
F_1	$\pi D_{1,SG}^2/4$	$\pi D_{1,C}^2/4$
L_0	$D_{0,SG}$	$D_{0,C}$
L_1	$2.7D_{0,SG}$	$2.7D_{0,C}$
L_2	$3.8D_{0,SG}$	$3.8D_{0,C}$
L_0/D_0	1.0	
α_d	20.98°	
α_k	14.99°	
F_1/F_0	4.0	
Re	1,137,403	372,323

2.2.1. Empirical Correlation

The pressure loss coefficient of venturi is calculated approximately by (1) and (2).

$$\zeta_{cur} = \frac{\Delta p}{\rho w_0^2/2} = k_1 k_2 \zeta_1 + \Delta\zeta \qquad (1)$$

$$\zeta_{rec} = A\zeta_{cur} \qquad (2)$$

Where,
ζ_{cur} : Pressure loss coefficient for curvilinear wall
ζ_{rec} : Pressure loss coefficient for rectilinear wall
$k_1 = f_2(\alpha_d, F_1/F_0)$
$k_2 \approx 0.66 + 0.35 l_0/D_0$ at $0.25 \le l_0/D_0 \le 5$
$\zeta_1 = \begin{cases} f_1(\alpha_d) \ at \ Re \ge 2\times10^5 \\ \zeta_d = f(Re) \ \ at \ Re \le 2\times10^5 \end{cases}$
$\Delta\zeta = f(F_1/F_0, l_0/D_0), \qquad A = f(\alpha_d)$

2.2.2. Numerical Simulation

Numerical simulation is performed using FLUENT 12.0[2] under 100% operation condition. Two-dimensional, axisymmetric, steady-state, ignoring gravity, and constant physical properties such as density and viscosity are assumed. The continuity, momentum equation, and one of the tested turbulence models, Standard k – ε model, are shown in Eq. (3) ~ (6).

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \qquad (3)$$

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_i}{\partial x_j}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \qquad (4)$$

$$\frac{\partial}{\partial x_i}(\rho u_i k) = \frac{\partial}{\partial x_i}\left(\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_i}\right) + G_k - \rho\varepsilon \qquad (5)$$

$$\frac{\partial}{\partial x_i}(\rho u_i \varepsilon) = \frac{\partial}{\partial x_i}\left(\frac{m_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_i}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}G_k - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \qquad (6)$$

A straight pipe is added in upstream and downstream of venturi to simulate the fully developed flow. For each case, mesh sensitivity test and turbulence model test is performed. Standard $k-\varepsilon$, Realizable $k-\varepsilon$, RNG $k-\varepsilon$ and SST $k-\omega$ model are used in turbulence model test, and standard wall function is applied for $k-\varepsilon$ series, and the low-Re correction option is not used for SST.

2.3 Result

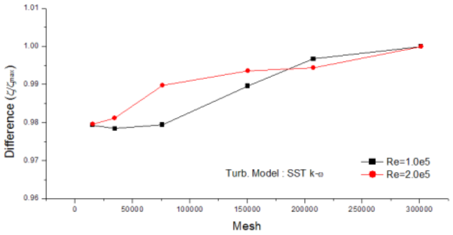


Fig. 3. Loss coefficients variation with grid numbers

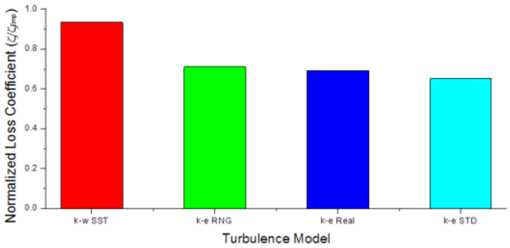
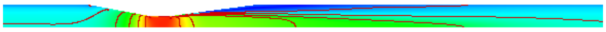
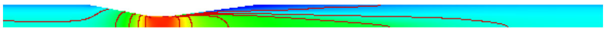


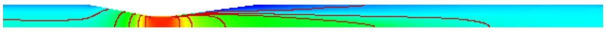
Fig. 4. Loss coefficients variation with turbulence models



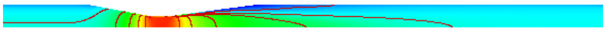
(a) SST $k-\omega$



(b) RNG $k-\varepsilon$



(c) Realizable $k-\varepsilon$



(d) Standard $k-\varepsilon$

Fig. 5. Velocity Distributions for Turbulence Models

Mesh sensitivity test result is shown in Fig. 3. With more than 150,000 cells, the difference of pressure loss coefficient from maximum value is less than 1%.

Turbulence model test results are shown in Fig. 4 and 5. In case of SST, the deviation between empirical correlation and numerical result is smaller than those of the other cases. But other turbulence models show great difference as the pressure loss coefficient is very small and sensitive to flow patterns .

Based on above results, the variation of pressure loss coefficient with Reynolds number is shown in Fig. 6. In this graph, the trend of empirical correlation and numerical result is slightly different each other. In case the Reynolds number is over 200,000, pressure loss coefficient is not a function of Reynolds number but a function of inlet angle of venturi(α_d) in the empirical correlation. Because this discontinuity of pressure loss coefficient is occurred adjacent Re=200,000, it is deduced that the empirical correlation includes some error in this Re region. Nevertheless almost cases have difference less than 7% .

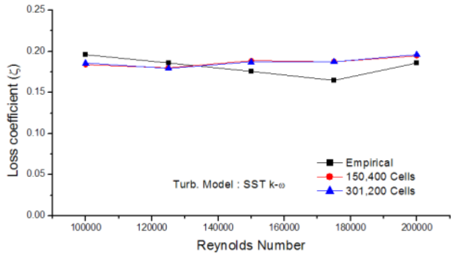


Fig. 6. Pressure Loss Coefficient of Venturi (Steam Generator)

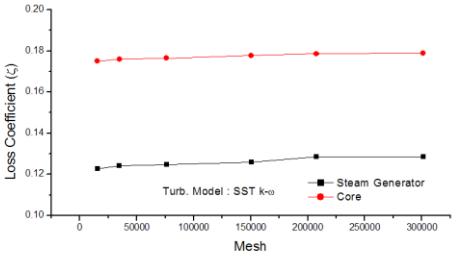


Fig. 7. Pressure Loss Coefficient of Venturi in Test Facility

The analysis result of venturi in 100% operation condition is shown in Fig. 7. The pressure loss coefficient of venturi of steam generator and core simulator is predicted 0.126 and 0.1776 respectively.

3. Conclusions

To identify the flow characteristics of venturi included in the reactor flow distribution test facility of SMART, the empirical correlation and numerical simulation results are compared. In case Reynolds number is below 200,000, the empirical correlation and numerical simulation show very similar results. The deviation between empirical correlation and numerical simulation is less than 7% in SST model. But other turbulence models show great difference.

Acknowledgement

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REFERENCES

[1] I.E. Idelchik, Handbook of Hydraulic Resistance, 3rd Edition, Begell House, pp. 239-329, 2005.

[2] FLUENT 12.0 Theory Guide, ANSYS Inc., New Hampshire, U.S.A., 2009.

[3] M.J. Reader-Harris, W.C. Brunton, J.J. Gibson, D. Hodges, I.G. Nicholson, Discharge Coefficients of Venturi Tubes with Standard and Non-standard Convergent Angles, Flow Measurement and Instrumentation, Vol. 12, pp. 135-145, 2001.