CFD analysis for an axial annular radial diffuser

Y.G. KIM [a*], J.K. Kong [a], Y.M. BAE [a], Y.I. KIM [a], Y.J. Jeong [a], C.T. Park [a], S. Choi [a]
[a]*Korea Atomic Energy Research Institute. P.O.Box 105, Yuseong, Daejeon, 305-600, KOREA*
[*]*Corresponding author: kimyeonggil@kaeri.re.kr*

1. Introduction

A Reactor Coolant Pump (RCP) is being developed in SMART. The head loss of Reactor Coolant System (RCS) is greatly concerned with the RCP design, and the flow path of the RCP discharge is one of the major parts of RCS pressure loss. Before calculating the loss coefficient in the flow path of the RCP discharge using a CFD code, the CFD analysis results are compared to an empirical correlation similarly to the flow path of the RCP discharge. In this study the commercial software, FLUENT 12.0 code, is adopted for the numerical analysis.

2. Approaches

2.1 Empirical correlation

Figure.1 shows the geometry of diffuser in diagram 11-10-(c) of reference [4] similarly to the flow path of the RCP discharge.

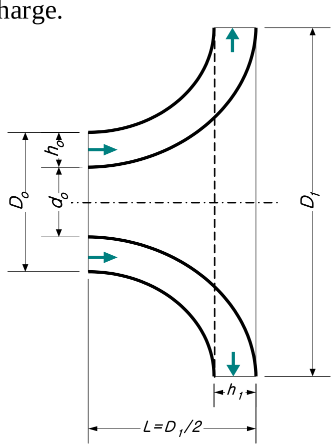


Fig.1 Free discharge from axial annular radial diffuser

The loss coefficient of empirical correlation regarding Figure.1 is as following formula (1) and Table.1

$$\zeta = f(h_1/h_0, \overline{D_1}, \overline{d_0}) = \frac{\Delta P}{\rho v^2/2}, \ \overline{D_1} = \frac{D_1}{D_0}, \ \overline{d_0} = \frac{d_0}{D_0} \quad (1)$$

$$\zeta = 0.54$$
$$(\text{in this paper}, \ h_1/h_0 = 1.2, \ \overline{D_1} = 2.1, \ \overline{d_0} = 0.7)$$

In case that, the shape of h_1/h_0, $\overline{D_1}$ and $\overline{d_0}$ is fixed, the loss coefficient is constant in this empirical correlation.

Table.1 Loss coefficient in the empirical correlation [4]

Values of ζ

$\overline{D_1}$	h_1/h_0								
	0,8	0,9	1,0	1,1	1,2	1,4	1,6	1,8	2,0
1,5	0,85	0,78	0,73	0,70	0,69	0,67	0,66	0,66	0,66
1,8	0,72	0,66	0,63	0,61	0,61	0,62	0,63	0,64	0,65
2,1	0,31	0,55	0,52	0,52	0,54	0,57	0,59	0,61	0,62

2.2 Numerical analysis Method

In this numerical analysis, it is assumed that the flow is 2D-axisymmetric and steady state, and the fluid is incompressible. And gravity is not considered and material properties (density, viscosity) are not changed with pressure.

The Fluent 12.0 code is applied to analyze incompressible Navier-Stokes equation as following formula (2), (3) and (4)

Conservation of mass (continuity equation)

$$\frac{1}{r}\left[\frac{\partial}{\partial x}(r\rho U) + \frac{\partial}{\partial r}(r\rho V)\right] = 0 \quad (2)$$

Conservation of U-momentum

$$\frac{1}{r}\left[\frac{\partial}{\partial x}(r\rho U^2) + \frac{\partial}{\partial r}(r\rho UV)\right]$$
$$= -\frac{\partial P}{\partial x} + \frac{1}{r}\left\{2\frac{\partial}{\partial x}\left[r(\mu+\mu_t)\frac{\partial U}{\partial x}\right] + \frac{\partial}{\partial r}\left[r(\mu+\mu_t)\left(\frac{\partial V}{\partial x} + \frac{\partial U}{\partial r}\right)\right]\right\} \quad (3)$$

Conservation of V-momentum

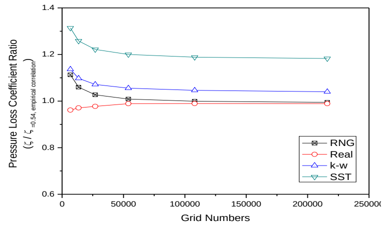
$$\frac{1}{r}\left[\frac{\partial}{\partial x}(r\rho VU) + \frac{\partial}{\partial r}(r\rho V^2)\right]$$
$$= -\frac{\partial P}{\partial r} + \frac{1}{r}\left\{\frac{\partial}{\partial x}\left[r(\mu+\mu_t)\left(\frac{\partial V}{\partial x} + \frac{\partial U}{\partial r}\right)\right] + 2\frac{\partial}{\partial r}\left[r(\mu+\mu_t)\frac{\partial V}{\partial r}\right]\right\} - 2\frac{(\mu+\mu_t)V}{r^2} \quad (4)$$

RNG k-ε, Realizable k-ε, Standard k-ω, SST k-ω turbulence models[5] are investigated in this study. And the CFD analysis is performed using following methods.

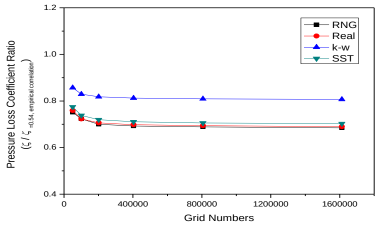
- Wall mesh and option: enhanced wall treatment (without low-Re-corrections option for k- ω)
- Discretization: second order upwind (momentum, turbulence), Standard (pressure)
- Pressure-velocity coupling: SIMPLE algorithm
- Solver: double precision solver

2.3 Grid independence

Grid independence test is conducted for all turbulence models used in this simulation. With increasing the grid numbers, the loss coefficients are converged to constant values as following Figure.2.



(a) Re=10^5



(b) Re=5×10^6

Fig.2 Grid sensitivity

3. Result and Discussion

In comparison between results from the CFD analysis and the empirical correlation, the loss coefficient is predicted within 2.5% deviation at Re=10^5. But the deviation increases to 30% at Re=5×10^6. The loss coefficients tend to be smaller in all turbulence models as Reynolds number increases. Figure.3 shows the variation of loss coefficient with Reynolds number for RNG k-ε turbulence model. As shown in Figure.3, the loss coefficients are very similar to the empirical correlation at Re=10^5. But the deviation is increase as the Reynolds number increase. In general, experiments generating empirical correlations are performed in the range that Reynolds number is not too much large for economical efficiency. It is deduced that the empirical correlation is not effective in the very large Reynolds number; it will overestimate the loss coefficients.

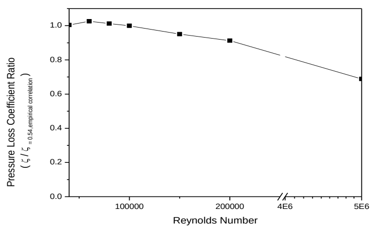
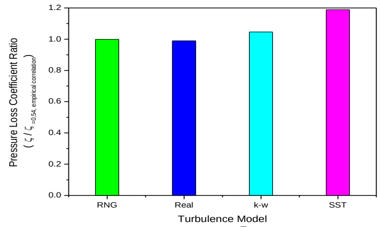
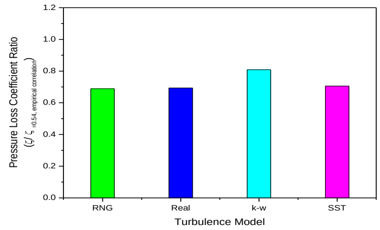


Fig.3 Loss coefficient with Reynolds number

Figure.4 shows loss coefficient corresponding to Re=10^5 and Re=5×10^6. And Figure.5 shows the contour of velocity magnitude for RNG k-ε model is applied.

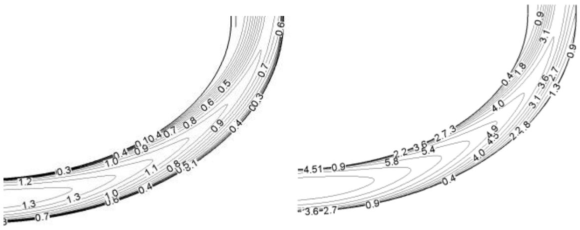


(a) Re=10^5



(b) Re=5×10^6

Fig.4 Loss coefficient



(a) Re=10^5 (b) Re=5×10^6

Fig.5 Contours of velocity magnitude

4. Conclusions

Numerical analysis is conducted to investigate the FLUENT 12.0 code applicability for the flow path of the RCP discharge in SMART. The loss coefficients are very close to the empirical correlation in the low Reynolds number region. But the deviation increases as the Reynolds number increase in all turbulence models investigated. It is deduced that the empirical correlation is not effective in the very large Reynolds number. Based on this study, FLUENT 12.0 code is applicable for the flow path of the RCP discharge.

REFERENCES

[1] Y.I. Kim, Y.G. Kim, Pressure loss calculation for the flow path of the RCP discharge in SMART, 100-NH301-014, Korea Atomic Energy Research Institute, 2010.
[2] Comparison of CFD analysis to empirical data in a commercial vortex tube, International Journal of Refrigeration 29(2006) 71-80, H.M. Skye, G.F. Nellis, S.A. Klein.
[3] Prediction of a heat transfer to CO_2 flowing in an upward path at a supercritical pressure, Nuclear Engineering and Technology, Vol41, no7, B.H.Cho, Y.I.Kim, Y.Y.Bae, Korea Atomic Energy Research Institute,2008
[4] I.E. Idelckik, Handbook of Hydraulic Resistance, 3rd, Begell house, 2000, Index 11-10-(c).
[5] ANASYS, Inc., Fluent 12.0 Manual, 2009.