Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, October 21-22, 2010

Numerical Analysis for SG flow distributions at RCP Abnormal Conditions of SMART

J. K. Kong*, Y. G. Kim, H. Bae, Y. I. Kim, C. T. Park, Y. J. Chung, W. J. Lee
Korea Atomic Energy Research Institute, 150 Dukjin-Dong, Yusong-Gu, Daejeon 305-353, Korea
**Corresponding author: jkkong@kaeri.re.kr*

1. Introduction

Reactor Coolant Pumps (RCP) and Steam Generators (SG) of an integral type reactor, SMART, are arranged differently compared to those of a loop type reactor. The RCPs are connected in the open annulus space with the SGs in SMART as shown in Fig.1, but those are arranged inline in the loop type reactor. So the flow distribution characteristic between the SGs is different. The reactor flow distribution test is being performed using a prototype model with 1/20 Reynolds number and 1/5 length scale of SMART in KAERI. This study is performed to confirm the flow passage design between RCPs and SGs and to investigate the flow distribution characteristic of SGs.

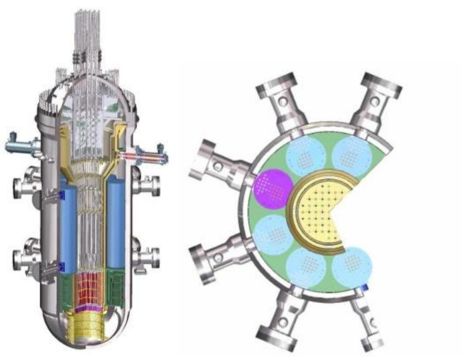


Fig. 1 SMART RCPs and SGs arrangement

2. Methods and Results

The commercial CFD code, FLUENT 12.0 is adopted to solve incompressible Navier-Stokes equation. The governing equations are described as follows:

Continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (1)$$

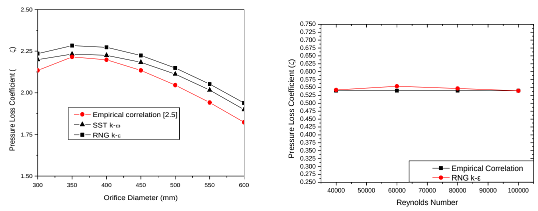
Momentum equation

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

For the CFD simulation of the SMART test facility, the realize k-epsilon model is selected as a turbulence model. The 2nd order upwind scheme is used for spatial discretization scheme and SIMPLE algorithm is applied for pressure-velocity coupling [1].

2.1 Turbulence model evaluate.

The SMART RCPs are installed horizontally in the reactor vessel and discharge the RCS coolant to the open cavity located in the upper region of the SGs. Flow resistance is expected to be large at the discharge section. A cap with many flow holes is installed at each SG inlet. Three turbulence models [1], RNG k-ε, Realizable k- ε, SST k-ω are investigated in references [2, 3]. The CFD results were compared with empirical correlations similar to the hole of SG cap or the RCP discharge flow path. The deviation between the turbulence models and empirical correlation is less than 10% as shown in Fig. 2 [2, 3].



(a) Orifice [2] (b) annulus diffuser [3]

Fig. 2 Comparison between empirical correlations and CFD calculation results

2.2 geometry and mesh structure modeling

Four RCPs and eight SGs are installed in the annulus flow passage. Abnormal conditions in Table 1 were simulated using 1/2 symmetry geometric model as shown in Fig. 3.

Reactor coolant passes through the shell side of the SG tubes and the Flow Mixing Header Assembly (FMHA) having many flow holes. Two SGs and a header of the FMHA are connected inline. The flow resistance of the SGs and the FMHA affects the flow distribution of the SGs. The SG tube region is modeled using a simplified simulator in the SMART flow model test.

The SMART flow model test is simulating the actual shape of the FMHA with various flow hole sizes. But in this analysis, the FHHA is simulated using a porous media model simulating only the flow resistance due to the complicated geometry and lack of computing power. Even though the real geometry of the FMHA is not considered the real geometry, as the flow resistance of the FMHA is small. The impact on flow distribution characteristic is negligible.

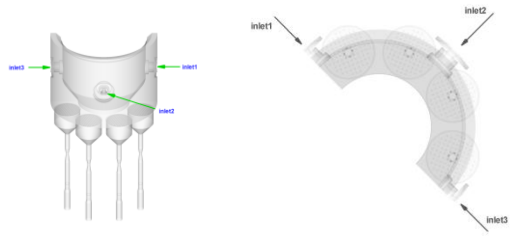


Fig. 3 Test section geometry

2.3 Simulated condition

Abnormal conditions such as the maximum RCPs flow deviation of 10% or one pump stop as shown in Table 1 are assumed to analyze the characteristic of the SG flow rate distribution. The RCPs and The SGs are at hot region of SMART. So constant properties (viscosity and density) at 323℃ and 15MPa are applied. Inlet flow rates on each operating condition are shown in table 1. Here, the 100% condition means the flow rate at 1/20 Reynolds number of SMART.

Table 1: Simulated conditions

	Inlet 1	Inlet 2	Inlet 3	Inlet 4
Case 1	100%	95%	90%	95%
Case 2	100%	100%	100%	0%

2.4 Results

Maximum 10% flow rate deviation condition (Case1)

As shown Fig. 6, the flow rate deviation among SGs is very small at this condition. Fig. 4 shows flow distribution at the SG entrance section. As shown in Fig. 4, the symmetrical flow distribution is presented even though the RCP flow rates are not uniform.

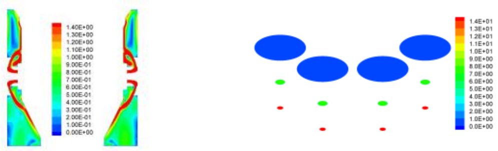


Fig. 4 Pressure & velocity distribution

One pump interrupted condition (Case2)

An analysis is performed under one pump stop condition. Due to the decrease of overall flow rate, the pressure drop is also decreased. As shown in Fig. 6, when one RCP is not working, the SG flow rate is very uniform within 2%. Fig. 5 shows flow distribution at the SG entrance section. As shown in Fig. 5 the symmetrical flow distribution is predicted, in spite of the fact that one RCP is stopped.

The reason can be explained as follows: First, the four RCP outlets are connected with an open annulus place. The small deviation induced from RCPS rapidly diminishes as the pressure is spread easily in the open space. Second, the discharging flow from RCPs that has large momentum is separated to small pieces by the SG hole caps. Third, the flow and pressure deviations produced at the SG upper region are reduced by large flow resistance of the SG.

Fig. 5 Pressure & velocity distribution

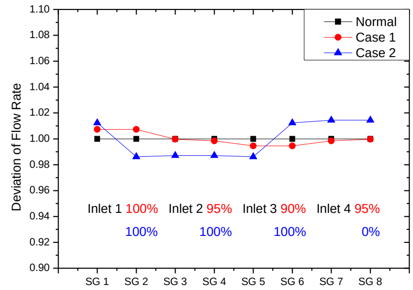


Fig. 6 Deviation of flow rate at SGs

3. Conclusions

The numerical analysis shows that uniform flow is distributed even in abnormal RCP conditions. When one RCP is stopped, the deviation is less than 2%. The reason of appearing these phenomenon is that SMART has the opened RCP outlet and the SG hole cap for flow stabilization. Also, the SG flow resistance is very large compared with the upper flow disturbance.

REFERENCES

[1] ANASYS, Inc., Fluent 12.0 Manual, 2009
[2] Y.I. Kim, SMART Steam Generator Orifice Size Calculation, KAERI/100-NH301-003/2010, Korea Atomic Energy Research Institute, 2010.
[3] Y.I. Kim, Y.G. Kim, SMART Reactor Coolant Pump Diffuser Pressure Loss Calculation, KAERI/100-NH301-014/2010, Korea Atomic Energy Research Institute, 2010.
[4] I.E. Idelckik, Handbook of hydraulic resistance, Third edition, Begell house, 2000.