A CFD Simulation of a 1/5 Linear-Scaled Steam Generator Simulator

Hwang Bae [a*], Dongjin Euh [b], Incheol Chu [b], Youngin Kim [a], Jung Yoon [a], Young-jong Chung [a], Wonjae Lee [a]
[a]*Korea Atomic Energy Research Institute, Deparement of SMART development, 150-1, Dukjin-dong, Yeusung-Gu, Daejeon, Korea*
[a]*Korea Atomic Energy Research Institute, Thermal-Hydraulic Safety Research Division, 150-1, Dukjin-dong, Yeusung-Gu, Daejeon, Korea*

[*]*Corresponding author: hbae@kaeri.or.kr*

1. Introduction

A 1/5-scaled test facility, called SCOP(SMART Core flow and Pressure Test Facility), was built for the flow test of System-integrated Modular Advanced ReacTor (SMART) [1,2]. Its overall layout is illustrated in Fig.1. To simulate the pressure drop induced by helical steam generators, a 1/5-scale steam generator simulator composed of a header, a venture and an orifice is installed. The orifice used for pressure loss calibration is settled in the lower part of the simulator. The calibration data for the venture is utilized to measure the flow rates passing through the SG simulators.

In this paper, the flow characteristics of the SG simulator is evaluated by the numerical analysis. The numerical results are compared with the empirical correlation and the experimental calibration data.

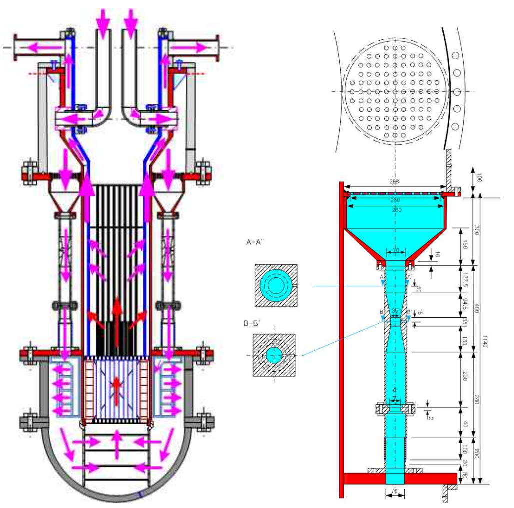

Fig.1 Overall layout of SCOP and SG simulator

2. Modeling & Scaling Methodology

2.1 Steam Generator Simulator

The SG simulator was designed by 1/5 linear scale method [3]. It consists of a perforated plate for the cover, a cone-shaped contraction part, a venturi and an orifice. The exit of the SG is connected to the flow mixing head assembly (FMHA) which takes part in assisting the flow stability well. The flow ratio was 1/17.9. Various turbulent models were applied to evaluate the pressure drop.

2.2 Numerical Model

A commercial CFD code of Fluent version 12 was applied for this simulation. The continuity, momentum equation and various turbulent models are applied. They are the realizable k-ε, RNG k-ε, standard k-ω and SST k-ω model. The steady-state numerical solution was applied in the pressure drop simulation. The mesh dependency had been investigated before the model dependency was calculated. The two types of the exit were embedded. One is a long straight pipe enough to fully develop the exit flow and the other is the FMHA. The holes of the SG cover are aligned with 1/8 symmetry. Except the FMHA exit, the computational domain was based on the 1/8 symmetric geometry. The tetra mesh is constructed for all calculation domains as shown in Fig.2.

<u>Boundary condition</u>
Inlet (mass flow rate) : 14.6 kg/s
Outlet (pressure) : 0 Pa

<u>Water Properties</u>
Density : 983.2 kg/m^3
Viscosity : 4.67e-4 Pa-s

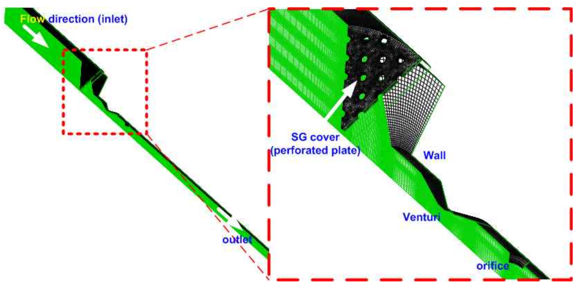

Fig. 2 Mesh construction

The working condition of the test facility was about 60^{o}C and 0.1 MPa whereas operating condition of SMART was 323^{o}C and 15 MPa. The different temperature causes a different density which was 983m^3/kg at 60^{o}C and 670m^3 /kg at 323^{o}C. The ratio of water density was about 1.4 times greater than that of SMART330. Therefore, the ratio of pressure drop was increased by the density ratio. The pressure drop in the SG of SMART is about 43 KPa for design value. To compensate the scaling distortion, the scaled pressure drop was set to 65KPa.

3. Results and Discussion

The computation domain and the numerical results are shown in Fig. 3. The pressure and velocity in the two Dimensional-plane domains represent the reasonable distribution. The static pressure decreases in the venturi and orifice while the velocity increases. The pressure profile repeats the loss and recovery consistently through the venturi and orifice along the center line of the SG simulator as shown in Fig.4.

The pressure loss between the inlet and the outlet of the SG is summarized in Table1. The total pressure loss of the SG simulator appears about 65 kPa, except the SST k-ω model. The mesh of the model 6-A was constructed by the model 1-A of 1/8 symmetric mesh and the SG exit is connected to the FMHA. Therefore, the mesh density of the SG simulator in the model 6-A is the same as that in the model 2-A. The total pressure loss is less than 1% between the different types of the exit formed like a long straight pipe or FMHA. It could be considered a non-dependency of the exit type.

The numerical solutions coincide with the empirical correlation and the calibration data. It reveals that the SG simulator designed by the linear scale represents the real phenomena of its internal flow. It is different slightly the actual orifice size embedded in the calibration test and the calculation. It caused the deviation of the pressure loss between these two results. It would be expected that the deviation decreases under the same size.

4. Conclusion

The 1/5-scale steam generator simulator was developed. To simulate the pressure and velocity distribution of the simulator, the numerical analysis for four turbulence models was carried out under the same condition with that of the SG calibration test. The pressure loss through the simulator agrees well with the empirical correlation and the calibration data within the deviation of ±3% except the SST k- ω model. The SG simulator is expected to simulate the real flow distribution of SMART SG.

Acknowledgement

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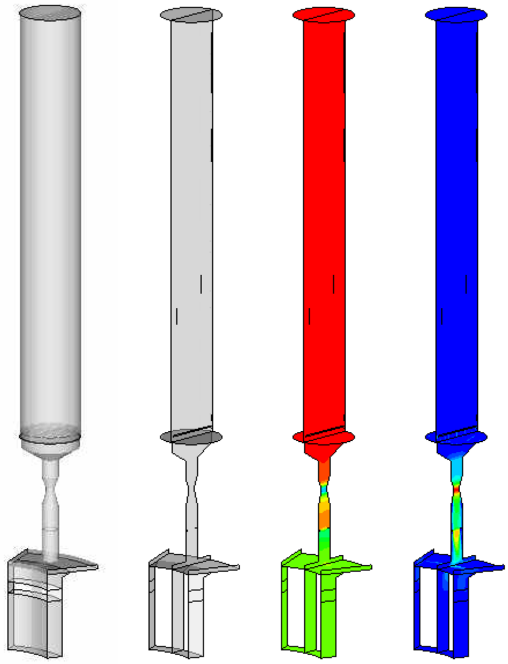

Fig.3 Calculation domain: (a), (b)calculation domain ; (c) Pressure distribution (d)velocity distribution

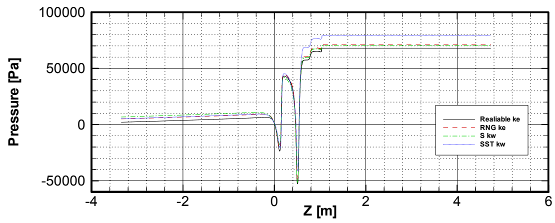

Fig.4 pressure distribution along the axial center line

Table 1. Pressure loss and pressure loss coefficient
A : Realizable k-ε model, B : RNG k-ε model, C : standard k-ω model, D : standard k-ω model, E : empirical correlation, F : calibration data, dP : pressure loss ζ : pressure loss coefficient

model	Mesh No.	dP	ζ	Deviation, %	
				/ E	/ F
1-A	999,520	65,904	-	2.28	9.74
2-A	14,449,080	64,045	0.56	-0.60	6.64
3-B	14,449,080	65,969	0.57	2.38	9.85
4-C	14,449,080	75,595	0.66	17.32	25.87
5-D	14,449,080	64,327	0.56	-0.17	7.11
6-A	11,697,740	64,192	0.00	-0.38	6.89
7-E	-	64,434	-	-	7.29
8-F	-	60,056	-	-	-