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Design and Performance Verification of Fuel Assembly and Steam Generator Simulators for SMART Reactor

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Abstract

The SMART reactor has been developed at KAERI, for the generation of electric power and also for seawater desalination. In order to verify the performance of the SMART design with respect to flow and pressure distribution, an experimental test facility named SCOP has been developed. For the purpose of preserving the flow distribution characteristics, SCOP is linearly reduced with a scaling ratio of 1/5. A CFD analysis was carried out to draw basic design parameters of the venturi tube and the perforated plates in a fuel assembly simulator. A CALIP, which is a flow and pressure drop calibration test facility, has been constructed to evaluate the pressure drop characteristic of fuel assembly and steam generator simulators. This paper shows the results of the actual performance verification and evaluation of fuel assembly and steam generator simulator, were evaluated using a CALIP.

Introduction

Reactor Flow Distribution Test Facilities for SMART, named SCOP (**S**MART **Co**re Flow & **P**ressure Test Facility), installed 57 fuel assembly simulators and 8 steam generator simulators. The flow distribution at the inlet of 57 fuel assembly simulators and 8 steam generator simulators was measured at SCOP. A venturi tube was installed at the front part of the fuel assembly and steam generator simulators in order to measure the flow rate through the channel. It has a perforated plate to preserve the total pressure drop. Hence, the calibration tests were required. A flow and pressure drop calibration test facility, CALIP(**Ca**libration **L**oop for **I**nternal **P**ressure Drop), was constructed to evaluate the pressure drop characteristics of fuel assembly simulators and steam generator simulators which will be used in SCOP.

In this paper, the performance of the fuel assembly simulators and the steam generator simulators were verified using CALIP. These simulators will be used in SCOP to evaluate the flow and pressure distribution of SMART reactor.

1. Design of core simulator

To measure the axial flow rate of each fuel assembly, a venturi flow meter was installed at the front part of the core simulator. The total axial pressure drop of the core simulator was adjusted by an orifice during a calibration process. Each side of the core simulator had several cross flow holes simulating the cross flow between adjacent fuel assemblies. The design feature and performance evaluation of the core simulator was performed using proven CFD packages.

1.1 Pressure drop at a single simulator

The total axial pressure drop of the core simulator was adjusted using three orifices installed at the downstream section during the calibration process. The fluid volume of a core simulator was considered for current CFD analysis with polyhedral mesh, as shown in Figure 1.

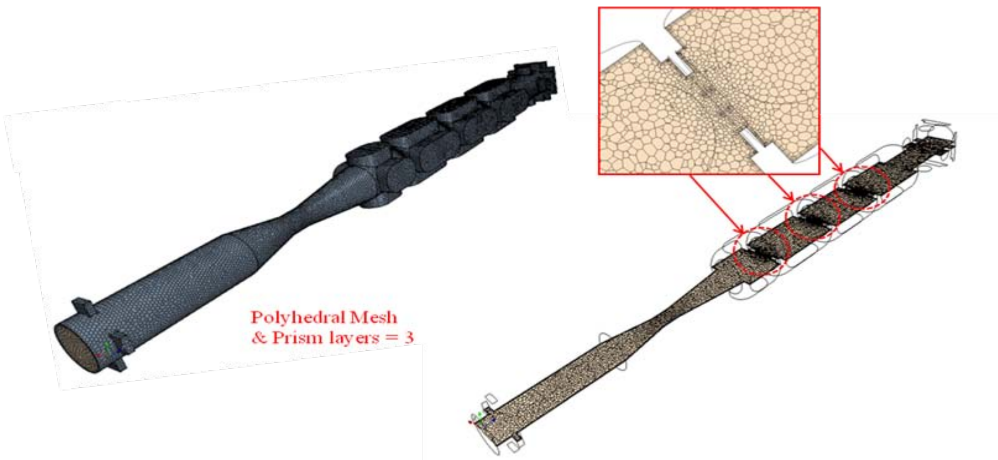


Figure 1 CFD analysis with a polyhedral mesh

An orifice type was selected with a perforated plate having same size holes.

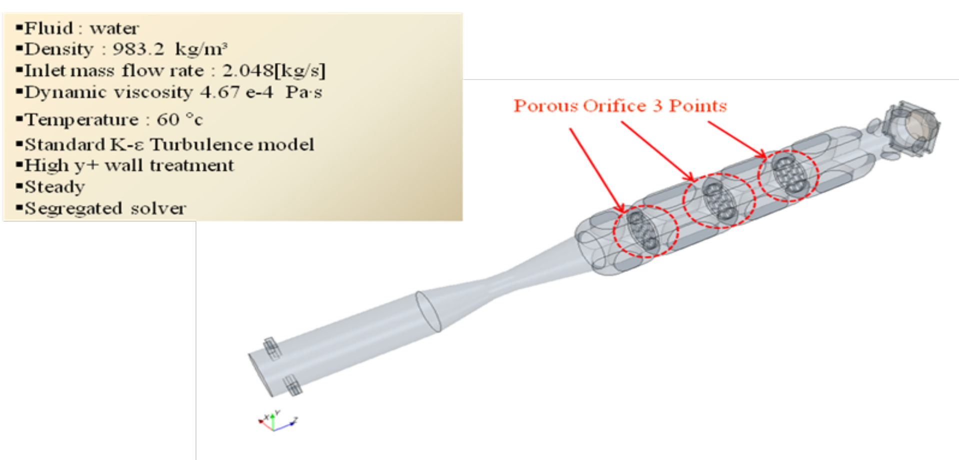
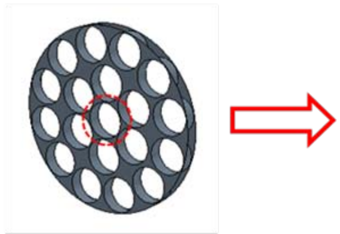


Figure 2 Three orifices at three points

The best fitting hole diameter was found to be about 5.81mm, which matched the desired pressure drop($\Delta P \approx 27.24$ kPa).



Hole Diameter (mm)	Pressure (kPa)
5.75	28.645
5.78	27.838
5.79	27.772
5.8	27.534
5.81	27.244
5.83	26.774

Figure 3 The hole diameter matched the desired pressure drop

1.2 Side holes sensitivity tests

For the simulation of a cross flow effect between fuel assemblies, the cross flow holes were designed on both the sides of the core simulator. Three paralleled core simulators were configured for the sensitivity test of the side hole as shown figure 4(a).

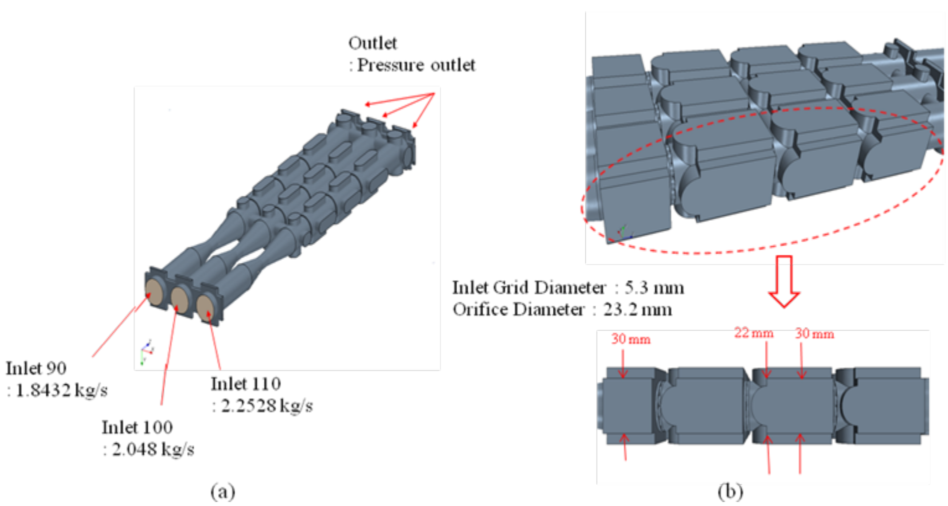


Figure 4 A cross flow hole shape design

In this simulation, the axial velocity difference was tested at about 90%, 100% and 110%. Table 1 shows calculated results at the interfaces between each core simulator along the flow proceeds. Figure 4(b) shows the cross flow hole design.

	Mass Flow Rate at outlets(kg/s)	Magnitude of difference(%) with 2.048 kg/s(100%inlet)
90% inlet	2.033	0.74
100% inlet	2.046	0.09
110% inlet	2.065	0.83

Table 1 Inlet grid hole size 5.3 mm & 3 grid hole sizes 5.3 mm, side hole size 30 mm

A CFD analysis was carried out to draw basic design parameters of a venturi tube and the perforated plates in the fuel assembly simulator.

2. A calibration tests using CALIP

In order to preserve the flow characteristics, the SMART design is linearly reduced with a scaling ratio of 1/5 and the flow geometry was design to be conserved. Table 2 shows a summary of the scaling relations adapted in the CALIP facilities with respect to the SMART reactor.

	SMART	Scaling Ratio	CALIP
Geometrical Length Ratio	1	l_R	1/5
Euler No.	1	1	1
Density Ratio	1	ρ_R	1.4
Velocity Ratios	1	V_R	1
Viscosity Ratio	1	μ_R	5.53
DP Ratio	1	$\rho_R V_R^2$	1.4
Core Re Ratio	1	$\frac{\rho_R V_{CR} D_{CR}}{\mu_R}$	1/0.98

Table 2 Summary of Scaling of CALIP

Figure 5 shows the schematic of the CALIP test facility. It consisted of a calibration (test) section, a flow supply and measurement section, a water reservoir, and a control and data acquisition section.

A calibration test condition of the core simulator and steam generator simulator adopted the same conditions for the SCOP test.

- Density : 983.2 kg/m^3
- Calibration flow rate : 40 ~ 140 % of reference flow rate
- Temperature : 60 ℃
- Pressure : 0.1 ~ 0.2 MPa

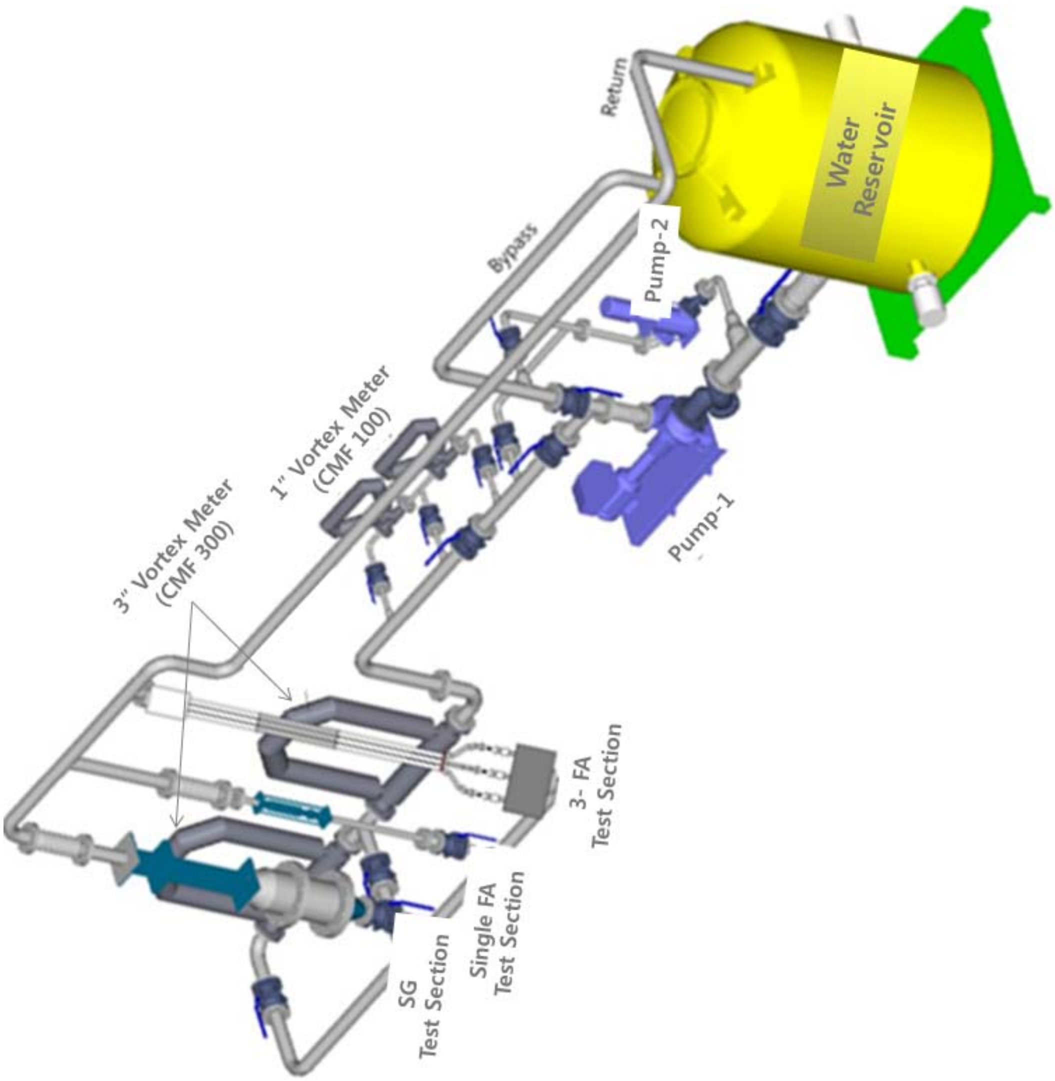


Figure 5 Schematic of CALIP Test facility

2.1 A calibration test of single core simulator

Figure 6 shows the fuel assembly simulator of SCOP. A venturi tube was located at the front part, three perforated plates were installed downstream of the venturi tube(figure 7). Also sixteen large openings were installed downstream of the venturi tube in order to preserve the cross flow characteristics between neighboring fuel assemblies.

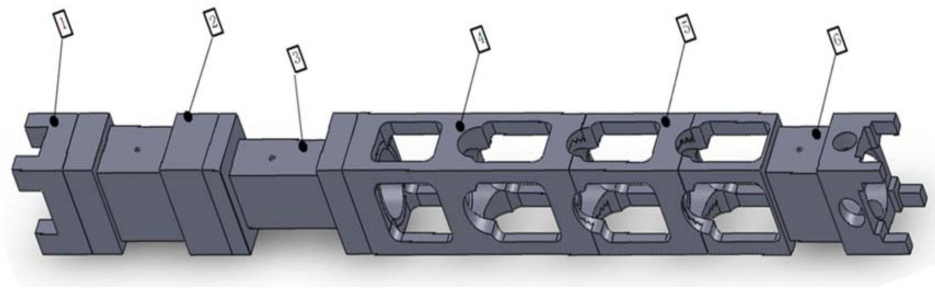


Figure 6 The fuel assembly simulator of SCOP

Ultra precise grade differential pressure(DP) transmitters were installed to measure the pressure drop of the whole fuel assembly simulator and/or single perforated plate as well as the discharge coefficient of the venturi tube.

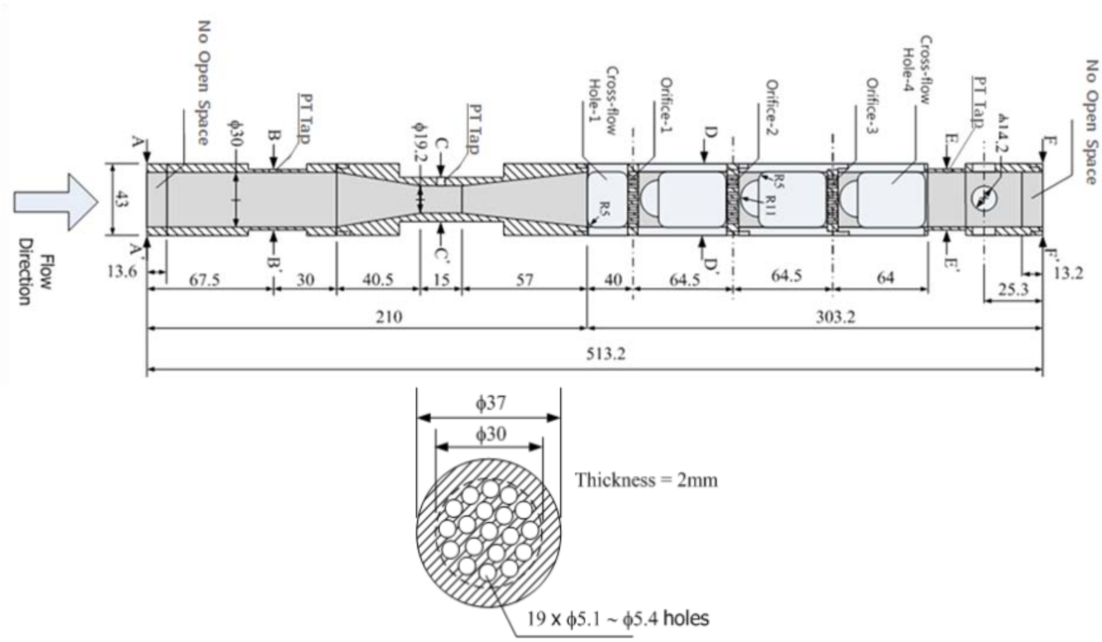


Figure 7 The shape of the fuel assembly simulator for calibration test

The pressure drop characteristics of the front perforated plate and the rear perforated plates were evaluated at a nominal flow rate and density conditions for SCOP experiments.

2.2 A calibration test of steam generator simulator

A cylinder with inner dia. of 260mm and length of 300mm was installed at the front part of steam generator simulator to assure the flow stability. Also, mesh plates for effective flow stability were installed at the front and rear of the cylinder. Figure 8 shows the steam generator simulator. The steam generator simulator had a venturi tube at the front part to measure the flow rate through the channel. The total axial pressure drop of the steam generator simulator was adjusted using one orifice installed at the downstream section.

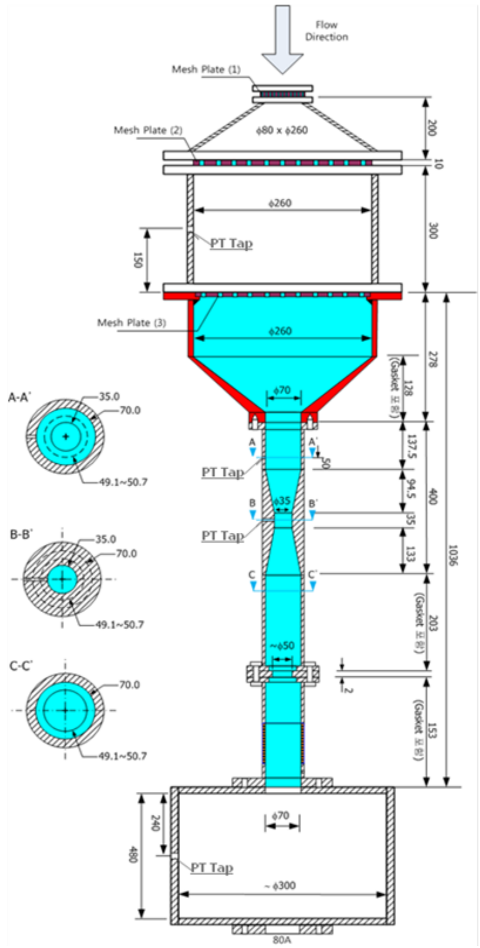


Figure 8 The steam generator simulator

2.3 Measurement and data acquisition

In order to evaluate the calibration test results, the flowing parameters were selected and analyzed.

- The inlet flow rate of the simulator
- The inlet coolant temperature
- The total pressure drop of the simulator
- The inlet/outlet pressure of the simulator
- The pressure drop of the venturi tube

The flow rate of the water supplied to the calibration(test) section was measured by coriolis mass flow meters, and the flow rate was controlled by adjusting the rotation speed pump impeller using VVVF inverter. Ultra precise grade differential pressure(DP) transmitters were installed to measure the pressure drop of the whole simulator. The water temperature was adjusted constant at about 60℃ by PID controller. CALIP was equipped with the DP transmitters and flow meters having two different measurement ranges, and measurement redundancy was secured by providing two DP transmitters and two flow meters for each measurement range.

The measurement system of CALIP consisted of the measurement instruments and devices with the highest accuracy. In addition, redundancy of the measurement instruments was secured for key parameters in order to prevent a false signal was acquired by chance due to damage and/or malfunction of a single instrument.

The data acquisition and processing system was established based on NI PXI system and LabVIEW software, enabling: (1) acquisition of measurement signals and conversion to engineering quantities; (2) monitoring, saving, and post-precessing of the measurement signals; and (3) controlling of rotating speed of pumps and heater powers.

3. Results

3.1 Result of fuel assembly simulator calibration test

3.1.1 Total pressure drop characteristic

The total pressure drop of each fuel assembly simulators was evaluated at the calculation test condition. Figure 9 shows the results of the pressure drop error of the respective fuel assembly simulators.

The pressure drop error of the fuel assembly simulator was as follows.

- The average error(Absolute value) : 0.42 %
- Minimum/Maximum error(Relative value) : -0.94 % / 1.01 %
- Standard deviation of error between simulators : 0.29 %

FA-01 ~ FA-57, the fuel assembly simulators will be used in the Reactor Flow Distribution Test Facilities for SMART(SCOP).

FA-58 ~ FA-60, the fuel assembly simulators were used for calibration test for evaluation of cross flow between adjacent fuel assemblies.

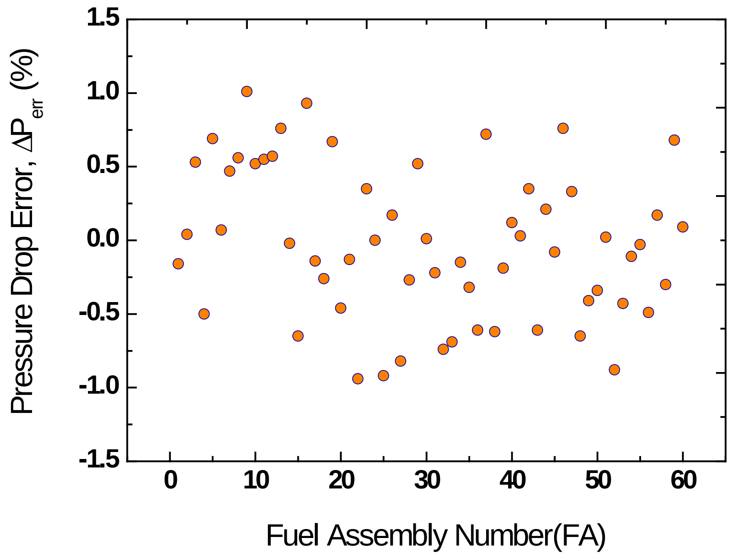


Figure 9 The pressure drop error of 60 fuel assembly simulators

3.1.2 Venturi tube discharge coefficient

Venturi tube discharge coefficients were different from among fuel assembly simulators. Also, a venturi tube discharge coefficient depends on the Reynolds number even the same fuel assembly simulator. Figure 10 shows the dependence of discharge coefficient of the venturi tube with regard to the Reynolds number.

Main calibration results of venturi tube discharge coefficient were as follows.

- The average discharge coefficient (C_D) : 0.9758 (flow rate 100%)
- Minimum discharge coefficient (C_D) : 0.9309 (flow rate 100%)
- Maximum discharge coefficient (C_D) : 1.0151 (flow rate 100%)
- Standard deviation of discharge coefficient (C_D) between simulators : 0.0189 (flow rate 100%)

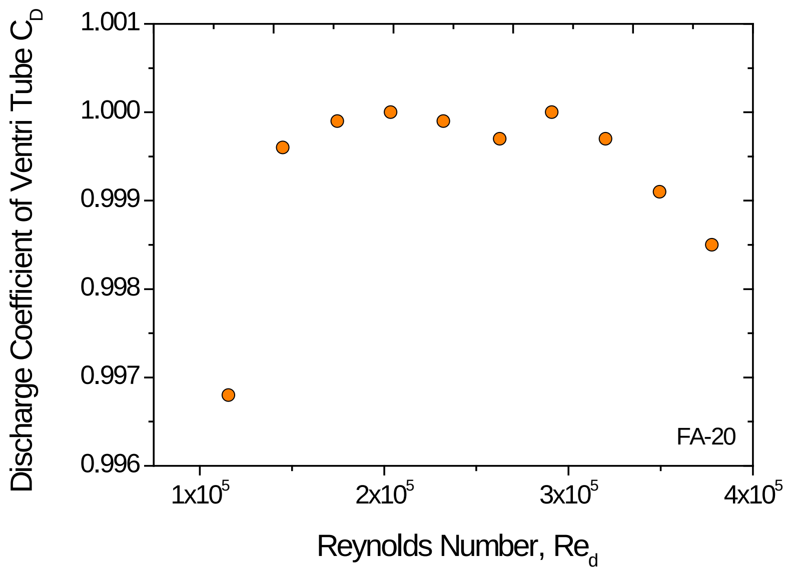


Figure 10 Discharge coefficient of the venturi tube installed in the fuel assembly simulator

3.2 Result of steam generator simulator calibration test

3.2.1 Total pressure drop characteristic

The total pressure drop of each steam generator simulator was evaluated at the calculation test condition. Figure 11 shows the results of the pressure drop error of the respective steam generator simulators.

The pressure drop error of the steam generator simulator was as follows.

- The average error(Absolute value) : 0.26 %
- Minimum/Maximum error(Relative value) : -0.49 % / 0.39 %
- Standard deviation of error between simulators : 0.31 %

SG-01 ~ SG-08, the fuel assembly simulators will be used in the Reactor Flow Distribution Test Facilities for SMART(named SCOP).

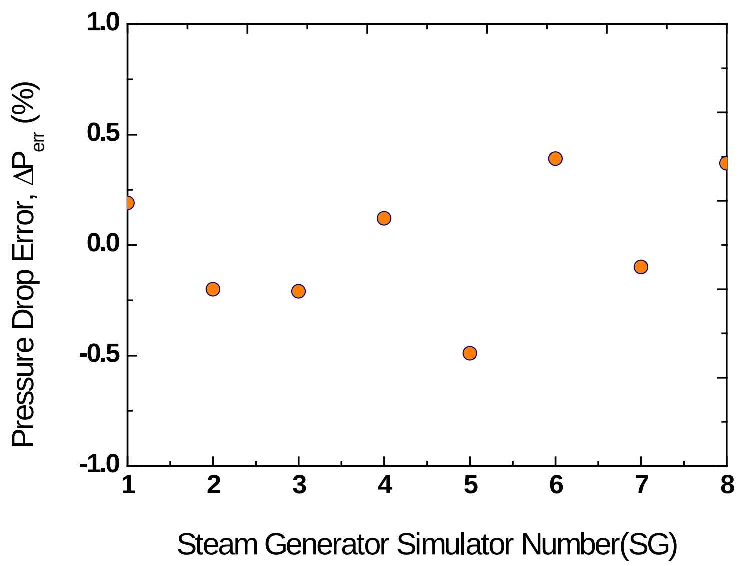


Figure 11 The pressure drop error of 8 steam generator simulators

3.2.2 Venturi tube discharge coefficient

Venturi tube discharge coefficients were different among steam generator simulators. Also, a venturi tube discharge coefficient depends on the Reynolds number even the same steam generator simulator. Figure 12 shows the dependence of discharge coefficient of the venture tube with regard to the Reynolds number.

Main calibration results of venturi tube discharge coefficient were as follows.

- The average discharge coefficient (C_D) : 0.9758 (flow rate 100%)
- Minimum discharge coefficient (C_D) : 0.9309 (flow rate 100%)
- Maximum discharge coefficient (C_D) : 1.0151 (flow rate 100%)
- Standard deviation of discharge coefficient (C_D) between simulators : 0.0189 (flow rate 100%)

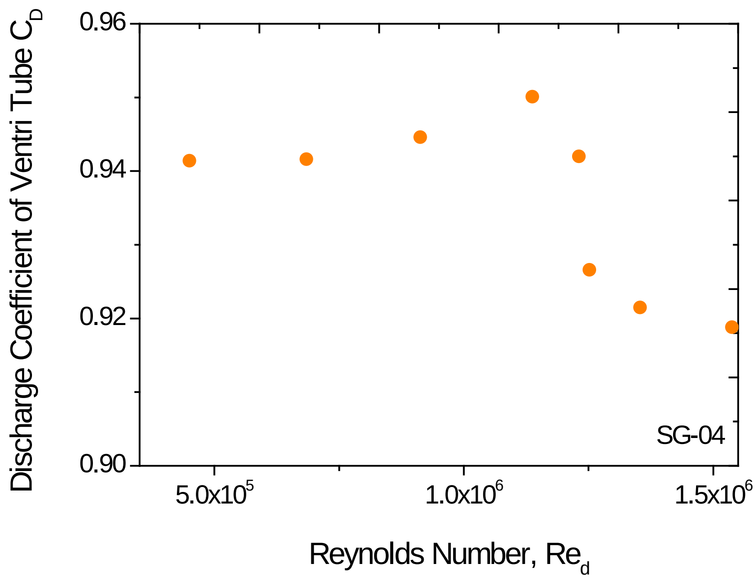


Figure 12 Discharge coefficient of the venturi tube installed in the steam generator simulator

4. Conclusions

The pressure drop and discharge coefficient of the fuel assembly simulator and the steam generator simulator for the SCOP were precisely measured and evaluated using CALIP test facility. Adjustment of the total pressure drop to the design value was made for 57 fuel assembly simulators and 8 steam generator simulators. The discharge coefficient of each simulator was evaluated for the flow rate of 40~140% of the reference value.

Compared with the design reference values, the maximum error of the total pressure drop for all simulators was lower than ±1.1%. For all fuel assembly simulators and steam generator simulators, the measurement uncertainty of the discharge coefficient of the venture tube was in the range of ±0.3% ~ ±0.6%, and the measurement uncertainty of the Reynolds number was in the range of ±1.113% ~ ±1.16%.

Final performance evaluations will be carried out for all 57 fuel assembly in the SCOP experiments. Then, the identical performance evaluations will be carried out for all 8 steam generator simulators for SCOP experiments.

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