Experimental Study on Pressure and Core Flow Distribution for PGSFR under High and Low Flow Rate Conditions

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1. Introduction

The performance and safety of the reactor system can be demonstrated based on the accurate thermal hydraulic information of the reactor system. The core thermal margin can be evaluated based on the reference of the boundary conditions of core, which are core flow rate and core outlet pressure at each of the fuel assemblies. The performance and safety analysis of the reactor's transient condition can be performed based on the accurate information of pressure loss along the flow path in the primary system.

Since the primary design feature of the PGSFR (Prototype Gen-IV Sodium Cooled Fast Reactor) are much different from conventional nuclear reactors, it is accordingly expected that PGSFR have unique characteristics of core flow and pressure distribution.

The primary heat transport system of the PGSFR contains major components such as four IHXs, four DHXs, and two PHTS pumps as well as a reactor core with others inside the reactor vessel as shown in Fig. 1. In normal operating conditions, there exits cover gas at the top portion inside the reactor vessel. [1]

To investigate the hydrodynamic characteristics for optimum thermal-hydraulic design of the reactor, the experimental facility using a one-fifth down-scaled test section with water flow at low temperature was constructed, which is named PRESCO (Pressure and Core Distribution for PGSFR). [2] The purpose of the hydrodynamic test with the down-scaled model are 1) to estimate the flow rate distribution of the fuel assemblies in the core, 2) to evaluate the flow resistance across the complex internal structures, and 3) to evaluate the degree of the non-uniformity and asymmetry of the flow in the reactor vessel.

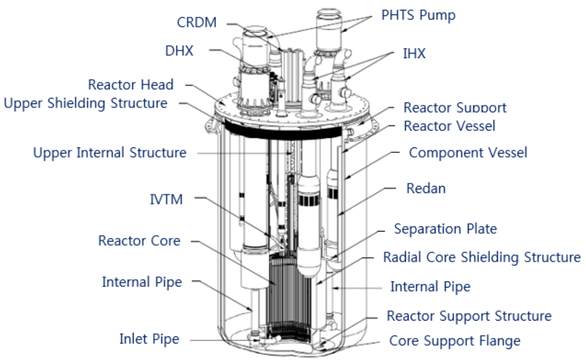


Fig. 1. PGSFR reactor vessel

2. Test Conditions and Results

The reactor flow distribution tests were performed under wide range of flow rate conditions, including 30%, 50%, 80%, 100% and 106.5% of normal operating condition. [3] Among them, two limiting cases were compared in the present paper.

Table I shows the flow rate conditions for two limiting cases with normal operation condition as reference case. The tests were conducted using water as the working fluid at 60°C and below 3 bar temperature and pressure conditions. The flow rates for the present tests were estimated from appropriate similarity analysis between sodium flow and water flow. [2] Table II shows the major scale ratios of PRESCO facility.

Table I: Test conditions

Cases	PGSFR [kg/s]	PRESCO [kg/s]
Normal operation (100% flow rate)	1984.2	46.47
30% flow rate	595.2	13.94
106.5% flow rate	2113.2	49.50

Table II: Major scaling ratios

	PGSFR	Scaling Ratio	PRESCO
Coolant	Sodium	-	Water
Temp. (℃)	467.5	-	60
Press. (MPa)	0.1	-	0.1
Density (kg/m^3)	840.2	1.17	983.2
Viscosity (Pa·s)	2.48×10^{-4}	1.88	4.66×10^{-4}
Length	-	1/5	-
Velocity (m/s)		1/2	
Re (-)	-	1/16	-
Eu (-)	-	1/1	-
Fr (-)	-	~1/1	-

2.1 Core Flow Rate Distribution

The core flow rate distribution of the test facility could be evaluated by utilizing the fuel assembly simulator which has simple flow path with VRROS (Variable-Resistance Rotating Orifice Spool) and venturi geometry for conserving pressure drop characteristic and flow rate measurement, respectively. In advance to assemble the fuel assembly simulator to the test section, pressure drop through the fuel assembly simulator was precisely set by adjusting the rotating angle of VRROS, and the relationship between the differential pressure at the venturi and mass flow rate for each fuel assembly simulator was assessed with aid of CALIP (Calibration Loop for Internal Pressure Drop) facility. [4, 5]

Figure 2 shows the core flow rate distribution for 30% and 106.5% flow rate conditions respectively. In both cases, there showed no significant malditribution or asymmetry of the flow rate distribution. In Fig. 3, group averaged mass flow rate was depicted. For comparison, data for the normal operation condition were drawn together.

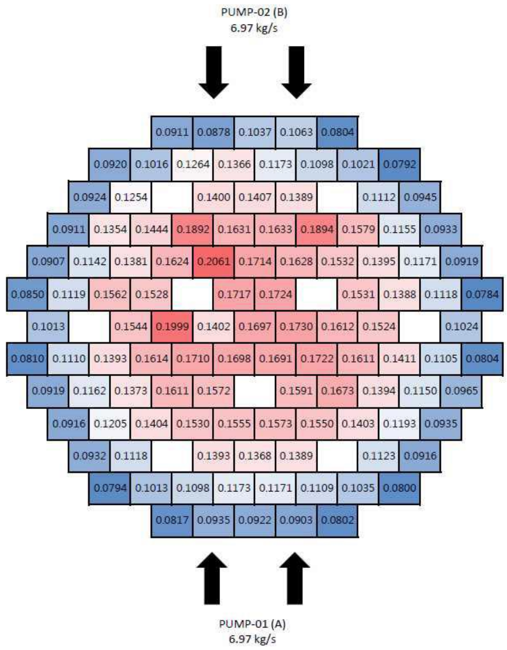
2.2 Pressure distribution along major flow path

The sectional pressure drops were measured along the major flow path. The pressure drop data has important significance for safety analysis of thermal hydraulic system behavior during a transient as well as steady-state conditions of the plant.

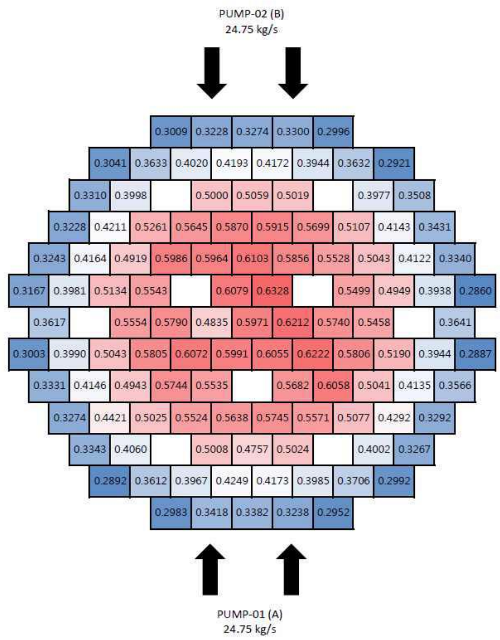
Based on the measured pressure drop data, pressure distribution along major flow path was shown in Fig. 4. The locations for the data was described in Fig. 5. The pressure from the inlet was slightly dropped when passing through the inlet pipes, which provides two branches connecting to the inlet plenum. The pressure in the inlet plenum was remarkably decreased across the core region, which comprises 112 fuel assembly simulators. The pressure drop at the core was measured 12.4 kPa, 140 kPa, 159 kPa for 30%, 100%, 106.5% flow rate conditions, respectively, which are almost 95 % of the total pressure drop along the major flow paths regardless of the flow rate conditions. There showed relatively low pressure drop from core exit to the outlet.

3. Conclusions

In the present study, pressure and core flow distribution for PGSFR was investigated using one-fifth downscaled test model. Among wide range of flow rate conditions, low and high limit cases were compared in the present paper. The core flow rate distribution data were obtained by utilizing uniquely designed fuel assembly simulators. In both limiting cases, no significant maldistribution or asymmetry of the core flow rate distribution was observed. The pressure distribution along major flow path was estimated from the sectional pressure drop measurement data. The pressure drop across the core region has over 95 percent of total pressure drop along the major flow path for all flow rate conditions.



(a) 30% flow rate condition



(b) 106.5% flow rate condition
Fig. 2. Core flow rate distribution

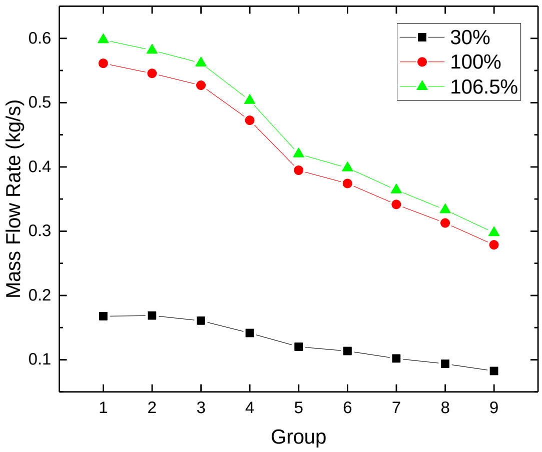


Fig. 3. Group averaged core flow rate

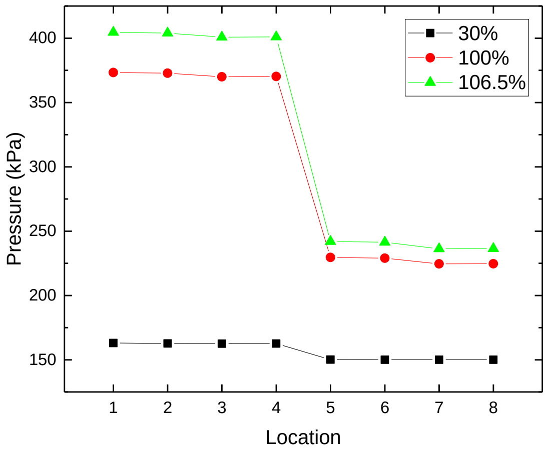


Fig. 4. Pressure distribution along major flow path

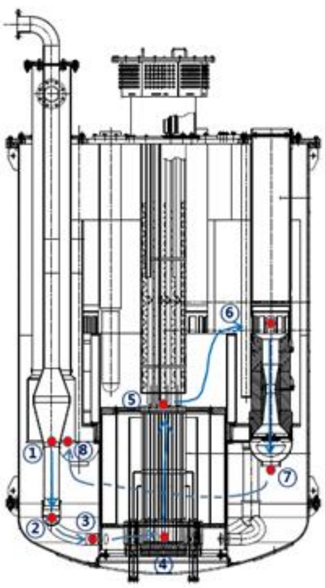


Fig. 5. Pressure drop measurement locations

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