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Conceptual Design of Core Receptacle Performance Test Loop for PGSFR

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1. Introduction

As a next generation nuclear power plant, the Prototype Generation-IV Sodium-cooled Fast Reactor (PGSFR) is under development by Korea Atomic Energy Research Institute (KAERI). In the core thermal hydraulics design of the prototype SFR, the receptacle is designed to properly distribute the primary coolant into each fuel assembly with a predetermined flow rate. The flow rates are assigned to each fuel assembly in order to maximize the thermal safety margin under a designed primary coolant flow rate. The fuel assemblies are divided into 9 flow groups according to the required flow rates which are iteratively derived from the power and thermal distributions evaluation process on the core. The flow rates are regulated by employing orifices inside the receptacle. The orifices are designed to produce proper pressure drop across the receptacle at the given flow rate.

To verify the design of the receptacle and to obtain optimal parameters for the internal orifices, a real scale performance test is going to be conducted in next year. The test results will be utilized to fix the receptacle design and to provide uncertainty evaluation data in the design of fuel assembly inlet flow. In this paper, the conceptual design of the test facility is described including the test requirements, scale analysis for water-based experiment, required flow rate and pressure drop for the test model, and the proposed conceptual test loop facility design.

2. Core Receptacle Design

The receptacle is set up in the inlet plenum beneath the core with accepting the nose-piece of the fuel assembly in the receptacle. The primary coolant in the inlet plenum flows into the inlet hole of the receptacle and then into the inlet hole of the nose-piece of the fuel assembly. Multi-stage multi-hole type orifice plates are installed in the receptacle to provide the required pressure drop at the given flow rate for each flow group of the fuel assembly. The number of receptacle is same with the fuel assembly number since the flow rate of each fuel assembly should be regulated individually.

The pressure drop between the core inlet plenum and the core outlet is all the same for every fuel assembly and its receptacle. Since every fuel assemblies have same geometry, the pressure drop across the fuel assembly depends upon its flow rate. So the key of receptacle design is a precise design of the orifice plates to give exact flow resistance for the given pressure drop and the given flow rate.

The receptacle should support entire weight of the fuel assembly since the nose-piece of the fuel assembly is fixed by the receptacle. Furthermore the reactor core requires extremely precise horizontal/vertical positions near the critical point. Therefore a thick supporting structure is assembled along the vertical axis in the receptacle to provide rigid and reliable supporting function. This constraint makes the orifices to be installed along the annular flow path in the receptacle as shown in Fig. 1. So the shape of the orifice plate is an annular type and the orifice holes are equivalently spaced along the annulus.

The size and number of the holes and the number of orifice plates are roughly designed from empirical formulations in this designing stage. To adjust the pressure drop across the receptacle model, the orifice plates will be designed in a variable resistance rotating orifice spool concept. The detailed parameters such as the rotating angle will be fine-tuned by employing the computational fluid dynamics simulations as well as the hydraulic performance tests.

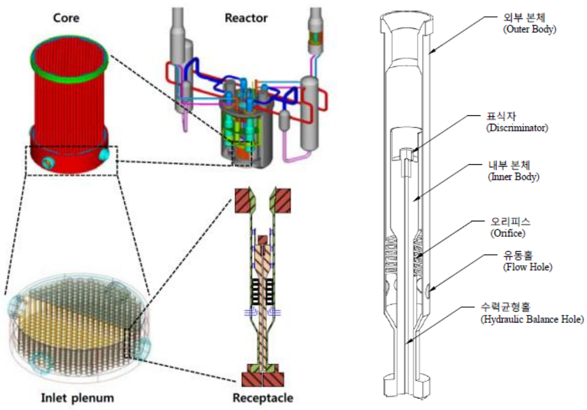

Fig. 1. Location and internal structures of the receptacle.

3. Performance Test Loop Design

3.1 Test requirements

The test requirements are as following:

1) Test model geometry condition should be the same with the design specifications for the receptacle and the orifices.
2) Water is used for the test.

3) Test flow condition should be controlled to maintain the hydrodynamic similitude with the prototype receptacle condition.
4) Measurement uncertainty requirements:
   - Temperature ±1.0℃
   - Flow rate ±2.0% of full scale
   - Pressure ±1.0% of full scale
   - Δ P ±2.0% of full scale
5) Final uncertainty should be evaluated with 97.5% confidence level.
6) All processes involving design, manufacture, test, and report and all procedures of calibration and test should satisfy the quality assurance requirements.

3.2 Hydraulic similitude analysis

The receptacle test model has 1:1 scale geometry to the prototype model. Since the working fluid for the test is water instead of sodium, the Reynolds number of the test should be matched to that of the prototype to maintain the hydraulic similitude. From the same Reynolds number condition, the flow rate ratios and the pressure drop ratios between the model and the prototype can be obtained as following:

$$Re_w = Re_s$$

$$\frac{\rho_w V_w D_{h,w}}{\mu_w} = \frac{\rho_s V_s D_{h,s}}{\mu_s}$$

$$\therefore \frac{V_w}{V_s} = \left(\frac{\rho_s}{\rho_w}\right)\left(\frac{\mu_w}{\mu_s}\right)$$

$$\therefore \frac{\dot{m}_w}{\dot{m}_s} = \left(\frac{\rho_w}{\rho_s}\right)\left(\frac{V_w}{V_s}\right)\left(\frac{A_w}{A_s}\right) = \left(\frac{\rho_w}{\rho_s}\right)\left(\frac{\rho_s}{\rho_w}\right)\left(\frac{\mu_w}{\mu_s}\right) = \left(\frac{\mu_w}{\mu_s}\right)$$

$$\Delta P_w = K_w \frac{\rho_w V_w^2}{2}, \quad \Delta P_s = K_s \frac{\rho_s V_s^2}{2}$$

$$\frac{\Delta P_w}{\Delta P_s} = \left(\frac{K_w}{K_s}\right)\left(\frac{\rho_w}{\rho_s}\right)\left(\frac{V_w}{V_s}\right)^2$$

$$K = \phi(Re, geometry)$$

$$\therefore \frac{\Delta P_w}{\Delta P_s} = \left(\frac{\rho_w}{\rho_s}\right)\left(\frac{V_w}{V_s}\right)^2 = \left(\frac{\rho_w}{\rho_s}\right)\left(\frac{\rho_s}{\rho_w}\right)^2\left(\frac{\mu_w}{\mu_s}\right)^2 = \left(\frac{\rho_s}{\rho_w}\right)\left(\frac{\mu_w}{\mu_s}\right)^2$$

Here, the subscript *w* denotes the model (water) and *s* denotes the prototype (sodium). Overall densities of the sodium and water are similar but the viscosity of sodium is largely smaller than that of water. Since the water viscosity decreases as the temperature increase, the test temperature should be selected as high as possible to decrease the mass flow rate ratio and the pressure drop ratio.

Fig. 2 shows the flow rates and the pressure drop of the receptacle test model according to the flow groups. Here the water temperature is assumed to be 60℃. The pressure drops of the receptacle groups decrease as their flow rates increase. The reason is that the pressure drop of the fuel assembly increases as the flow rate increases but the summation of the pressure drops from the fuel assembly and its receptacle has to be same for every flow group.

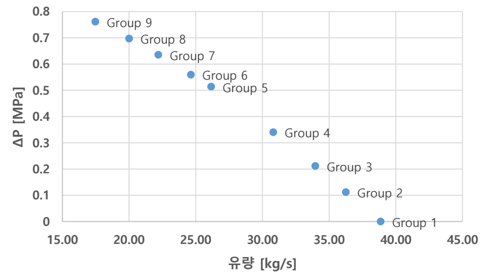

Fig. 2. Estimated flow rates and pressure drops across the core receptacle model for the performance test.

3.3 Conceptual design of the test loop

The conceptual design of the test loop is shown in Fig. 3. The loop consists of the pumps, test section, cooler, cooling tower, and water storage tank with a heater. Major variables to be measured in this test are as followings.

- Inlet/outlet temperatures of the receptacle.
- Inlet/outlet pressures of the receptacle.
- Flow rates through the receptacle.
- Pressure drop between the inlet and outlet of the receptacle.

During the test, the pressure drop of the orifice plates will be precisely adjusted by aligning the angle between adjacent orifice plates. Therefore the test section designed should allow easy adjustment of the rotating angle of the orifice plates. This feature will be considered in the detail design stage.

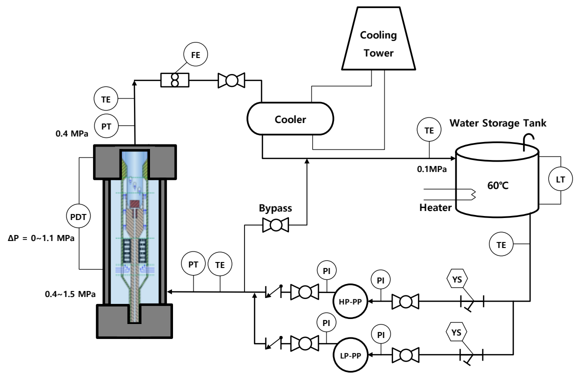

Fig. 3. Conceptual design of the test loop facility.

4. Conclusion

The core receptacle performance test loop for PGSFR is designed conceptually. The test requirements are briefly reviewed and the hydraulic similitude analysis is conducted to estimate the flow rates and the pressure drops for the test model. Finally the conceptual test loop design is presented including the required components and instrumentations.

ACKNOWLEDGMENTS

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REFERENCES

[1] S. R. Choi, Design Report of Core T/H Design, SFR-120-DR-462-001, KAERI, 2016.
[2] N. R. Shin, et al., SFR Prototype Verification Test Plan, SFR-000-DA-471-001, KAERI, 2015.