Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Design and Performance Verification of Fuel Assembly Simulators for PGSRF Reactor Core Flow Distribution Evaluation Tests

In-Cheol Chu*, Woo Shik Kim, Hae Seob Choi, Dae Won Cho, Dong Jin Euh
Korea Atomic Energy Research Institute, 989-111 Deadeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: chuic@kaeri.re.kr*

1. Introduction

KAERI (Korea Atomic Energy Research Institute) is developing the PGSFR (Prototype of Generation-IV Sodium-cooled Fast Reactor). The reactor core thermal margin during normal operation and a transient is evaluated based on the core inlet flow rate and core outlet pressure at each fuel assembly. Therefore, an evaluation of the reactor core flow and pressure distributions among the fuel assemblies is necessary to analyze the thermal margin of the PGSFR.

Based on the proposal by Hetsroni [1] in which the Euler number is the utmost important parameter to be preserved for a model test facility to represent the hydraulics of the prototype nuclear reactor, KAERI constructed model test facilities (SCOP and ACOP) for SMART reactor and APR+ reactor, respectively, and performed flow and pressure distribution tests using these test facilities [2-5]. These test facilities had a linear length scale ration of 1/5 against the prototype reactors. One of the key elements for the successful experimental evaluation of the core flow and pressure distribution is the design and performance verification of the fuel assembly simulators.

The detailed design of the main test facility used to evaluate the reactor core flow and pressure distribution of the PGSFR has been completed. This test facility also adopts a linear length scale ratio of 1/5 against the PGSFR, and uses water instead of sodium. To secure the similarity between the model test facility and the prototype reactor, the Euler number is preserved as the key parameter, Reynolds number is placed at a sufficiently high level, and the same internal flow geometry is used except for the reactor core fuel assemblies and intermediate heat exchangers (IHXs).

In this paper, the design approach of the PGSFR fuel assembly simulators and the performance verification test results are described.

2. Design of Fuel Assembly Simulators

2.1 Basic Design Approach

The reactor core of the PGSFR consists of 52 inner core fuel assemblies, 60 outer core fuel assemblies, 9 control rods, 90 reflectors, and 102 B_4C shields. Differently from SMART and APR+, each of the core fuel assemblies is isolated from other core fuel assemblies. That is, a cross-flow among the fuel assemblies does not occur in the PGSFR reactor core. The fuel assemblies have a different flow resistance by which the flow rate through the fuel assemblies is controlled. The pressure drop is determined mainly by the flow resistance of the orfice plates in a receptacle, which is located upstream of each fuel assembly. The 112 fuel assemblies are divided into 9 groups according to the flow resistance.

The design and performance requirements of the fuel assembly simulators are as follows: (1) the simulators have a linear length scale ratio of 1/5, (2) the pressure drop of the prototype fuel assemblies should be strictly preserved based on the Euler number scaling, (3) a device that can accurately measure the flow rate through the simulators should be provided, (4) the pressure at the oulet of the simulators should be measured, and (5) the internal cross-sectional flow area of the fuel assembly should be preserved according to the 1/5 length scale.

In the previous experiments for the evaluation of SMART and APR+ reactor core flow and pressure distribution, the pressure drop of the fuel assembly simulators was adjusted by precisely controlling the hole diameter of the multi-hole orifice plates installed inside the simulators. However, the adjustment of the pressure drop was a very time consuming process because the pressure drop was very sensitive to the small change in a hole diameter and the repeatability of the performance could not be guaranteed owing to an inherent manufacturing tolerance of the multi-hole orifice plate.

To overcome this difficulty, an innovative design of a variable resistance rotating orifice spool (VRROS) was drawn in this study. Figures 1 and 2 show a schematic of the VRROS to explain the principle of the flow resistance adjustment.

As illustrated in Fig. 3, the flow resistance becomes minimum when the two orifice plates are aligned in-line and the flow resistance becomes maximum when the two orifice plates are aligned 45^o out-of-line. By adjusting the rotation angle of VRROS, the flow resistance of the fuel assembly simulators can be finely tuned without changing the orifice plate with a different orifice hole diameter.

Figure 4 shows a picture of the manufactured fuel assembly simulator. A venturi tube is installed at the middle part of the simulator to measure the flow rate through the simulator.

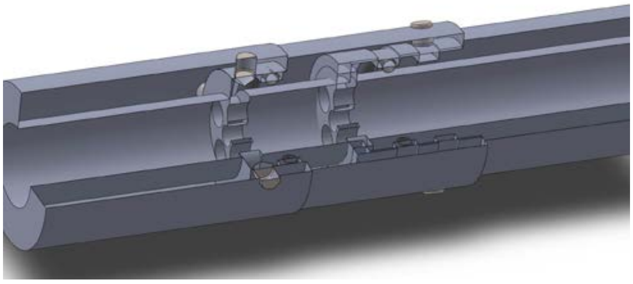

Fig. 1 Schematic of the variable resistance rotating orifice spool (VRROS): two orifice plates with in-line alignment condition

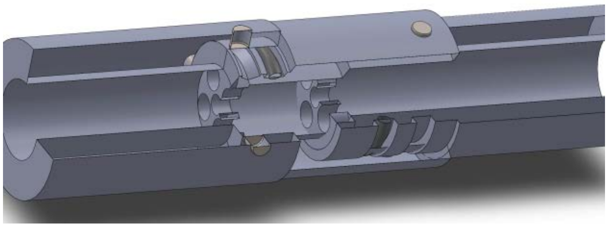

Fig. 2 Schematic of the variable resistance rotating orifice spool (VRROS): two orifice plates with out-of-line alignment condition (45° rotation)

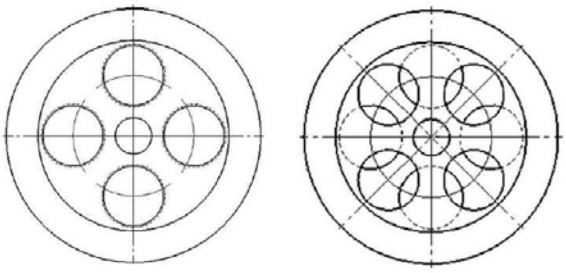

Fig. 3 Front view of the variable resistance rotating orifice spool (VRROS): (left) in-line alignment, (right) 45° out-of-line alignment

Fig. 4 Picture of the fuel assembly simulator

2.2 CFD Calculation for Detailed Design

The commercial CFD code of Star-CCM+ V10 was used to draw the detailed design specifications of the VRROS and venturi tube. Sensitivity studies on the mesh size and turbulent model were conducted.

Figure 5 shows the mesh structure used for the venturi tube design, and Fig. 6 shows the pressure distribution across the VRROS for in-line and 45° out-of-line alignments. Figure 7 shows the pressure drop characteristics across the fuel assembly simulator.

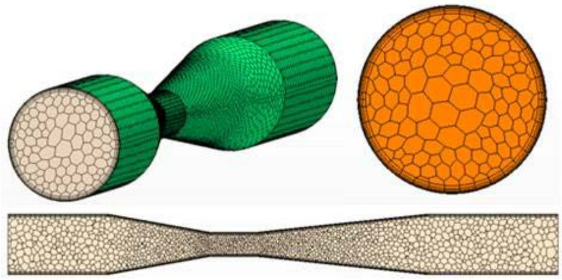

Fig. 5 Typical mesh generation for venturi tube design

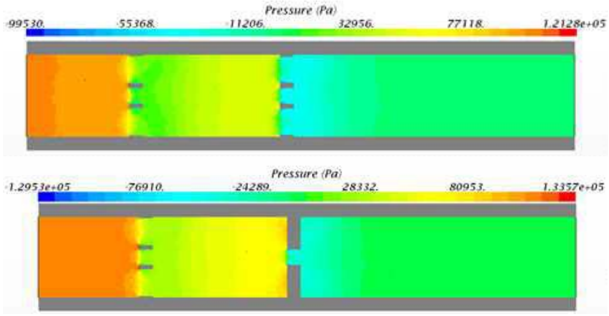

Fig. 6 Typical pressure distribution across the variable resistance rotating orifice spool (VRROS): (top) in-line alignment, (bottom) 45° out-of-line alignment.

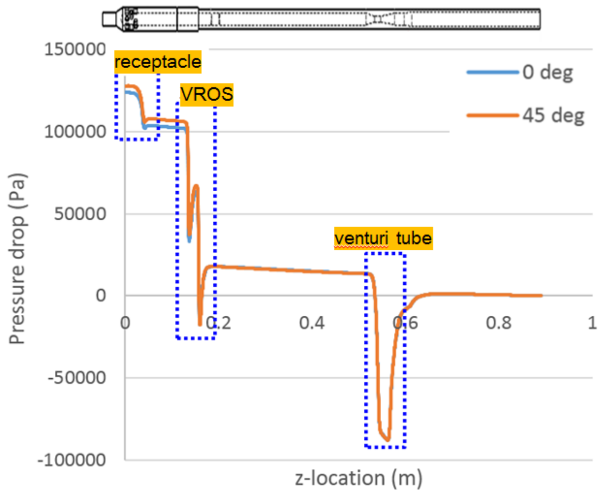

Fig. 7 Typical pressure drop characteristics across the fuel assembly simulator

3. Performance Verification of Fuel Assembly Simulators

CALIP (CAlibration Loop for Internal Pressure Drop) was first constructed for the performance verification of the SMART reactor fuel assembly simulators, and was modified for the PGSRF fuel assembly simulators and IHX simulators (Fig. 8). It is equipped with two test channels each for fuel assembly and IHX simulators, two pumps with a different capacity that control the flow rate by VVVF inverters, four high accuracy Coriolis mass flow meters, two high accuracy pressure transmitters, and twelve high accuracy differential pressure transmitters for a precise measurement of the flow rate and pressure drops across the simulators.

The performance of fuel assembly simulators different designs of VRROS and venturi tube was evaluated in terms of the total pressure drop across the simulator and the pressure drop change with the rotation of VRROS.

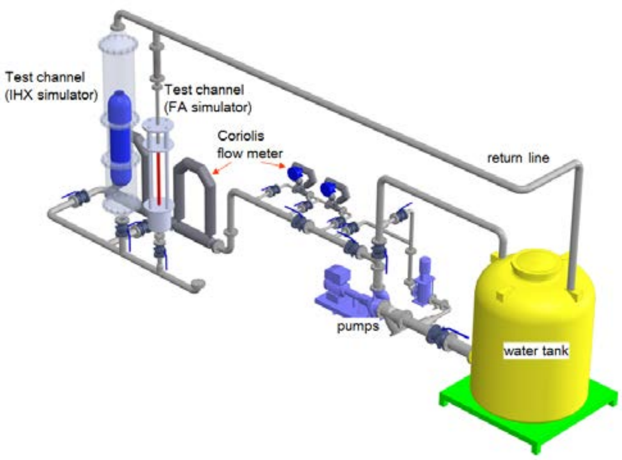

Fig. 8 Schematic of CALIP-SFR facility

There were 5~10% difference in the pressure drop across the fuel assemblies and venturi tube throats between CFD calculation and experimental verification. Figure 9 shows comparison of the pressure drop from the inlet of venturi tubes and the throat of venturi tubes.

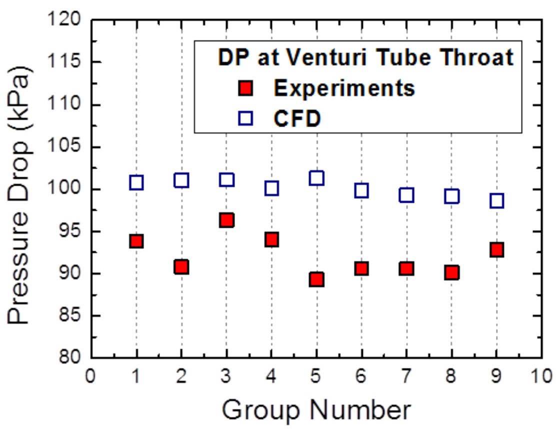

Fig. 9 Pressure drop at the throat of venturi tubes

The specification of the VRROS design was slightly modified based on the first verification test results in order to meet the total pressure prop requirement, and the second verification tests were conducted.

As shown in Fig. 10, six groups of fuel assembly simulators satisfied the total pressure drop requirement. The other three groups of fuel assembly simulators slightly deviated the requirement. The blue solid horizontal line is the target pressure drop and the two green dashed lines are ±1% error boundary which is the pressure drop requirement. The VRROS provided a sufficient margin against the manufacturing tolerance.

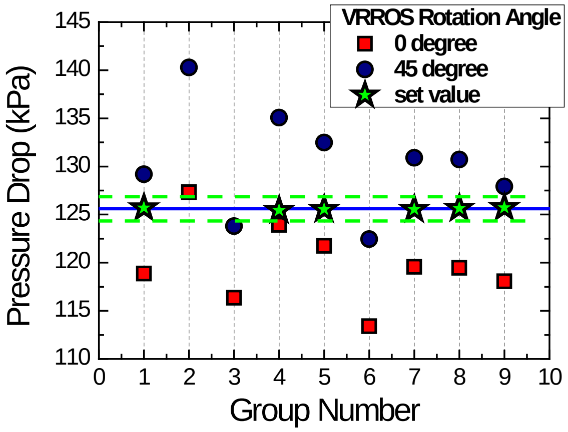

Fig. 10 The total pressure drop of fuel assembly simulators

4. Conclusions

An innovative design of fuel assembly simulators was developed in which the total pressure drop across the simulators can be precisely adjusted with a simple process and the flow rate through the simulators can be accurately measured. A CFD calculation provided a useful basis for a detailed design of simulators that have different flow resistances.

The first phase verification test revealed that six groups of fuel assembly simulators satisfied the total pressure drop requirement. Further modification of the VRROS design will be made for the other three groups of simulators to meet the performance requirement.

REFERENCES

[1] G. Hetsroni, Use of Hydraulic Models in Nuclear Reactor Design, Nucl. Sci. Eng., Vol. 28, p. 1, 1967.

[2] D. J. Euh *et al.*, Hydraulic Characteristics of SMART Reactor for a Nominal Condition, 9th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, Malta, July 16–18, 2012a.

[3] D. J. Euh *et al.*, A Flow and Pressure Distribution of APR+ Reactor under the 4-Pump Running Conditions with a Balanced Flow Rate, Nucl. Eng. Technol., Vol. 44, p. 735, 2012b.

[4] K. H. Kim *et al.*, Experimental Study of the APR+ Reactor Core Flow and Pressure Distributions under 4-Pump Running Conditions, Nucl. Eng. Des., Vol. 265, p. 957, 2013.

[5] D. J. Euh *et al.*, Experimental Identification for Flow Distribution inside APR+ Reactor Vessel and Direction of Internal Structure Design Improvement, J. Nucl.Sci. Eng., Vol. 53, p. 192, 2016.