Preliminary Numerical Study on Core Receptacle Test Model for PGSFR

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1. Introduction

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

To evaluate the conceptual design of the receptacle orifices and to provide basic design parameters, receptacle performance tests are planned in next year. This paper presents preliminary results obtained from the computational fluid dynamics (CFD) calculations in order to evaluate the pressure drop of the roughly designed receptacle in this design stage. As a feasibility test, the receptacle which produces the maximum pressure drop among the 9 flow groups is considered in this study.

2. Core Receptacle in PGSFR

The core receptacle is set up in the inlet plenum beneath the core with accepting the nose-piece of the fuel assembly. The primary coolant in the inlet plenum flows into the inlet hole of the receptacle and then the inlet hole of the nose-piece of the fuel assembly. Inside the core receptacle, multi-stage multi-hole type orifice plates are installed to provide the required pressure drop at a given flow rate. The pressure drop between the core inlet plenum and the core outlet is all the same for every fuel assembly and its receptacle. The pressure drop across the fuel assembly depends upon its flow rate since every fuel assemblies have same geometry. So the precise design of the orifice plates is of importance to give exact flow resistance for the required pressure drop at the given flow rate.

The receptacle has a thick supporting structure along the vertical axis since the weight of fuel assembly is supported by the receptacle. Due to this constraint, the orifices must be installed along the annular flow path in the receptacle. So the shape of the orifice plate is an annular type and the orifice holes are equivalently spaced along the annulus.

To adjust the pressure drop across the receptacle, the orifice plates are designed in a variable resistance rotating orifice concept as shown in Fig. 1. By varying the rotating angle between two adjacent orifices, the pressure drop can be smoothly adjusted. Generally, the minimum pressure drop occurs when the rotating angle is zero and the pressure drop gradually increases with the angle.

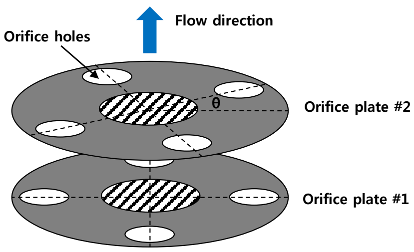

Fig. 1. Typical example of the arrangement of two adjacent orifice plates. θ is a rotation angle for the downstream orifice to the upstream orifice.

Table 1. Parameters of the annular orifice plates.

Parameter	Value
Number of plates	6
Inner diameter	0.05 m
Outer diameter	0.11 m
Number of orifice holes	4
Thickness of plates	0.005 m
Distance between adjacent plates	0.015 m
Tested rotation angles, θ	0°, 5°, 10°

3. CFD Methodology

For the CFD, the geometries and meshes for the core receptacle are produced by the Geometry and the Mesh in the ANSYS Workbench 13.0. The considered receptacle 3d model in this study is the case where the maximum pressure drop occurs. Detailed parameters of the orifice plates are presented in Table 1. The rotation angle θ is tested for 0°, 5°, and 10° cases to check variation of the pressure drop according to the rotation angle. The flow region is extracted from the receptacle 3d model as shown in Fig. 2. The region where the nose-piece of the fuel assembly will be inserted is excluded from the flow region. For the mesh generation, the patch conforming tetrahedrons method and the hexagonal sweep method are utilized. The tetrahedron meshes are adopted for receptacle inlet region and orifices region. The hexagonal meshes are used in the downstream of the orifices. Mesh sizing functions are used to consider the proximity and curvature of the geometry. The minimum and maximum cell sizes are restricted to 0.001 m and 0.005 m, respectively. Number of generated meshes is about 7.2 million.

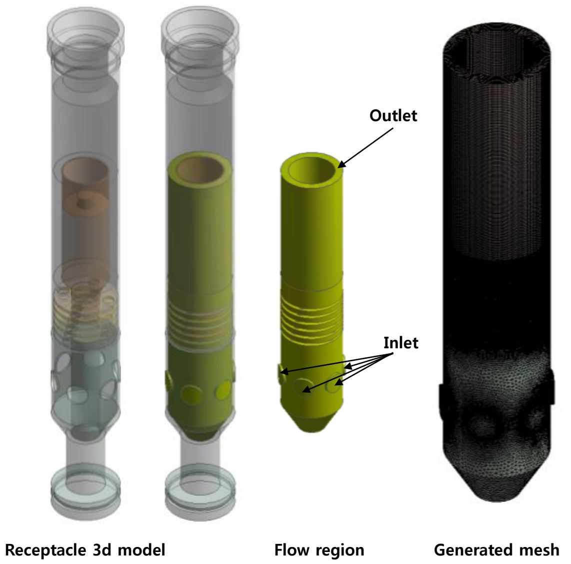

Fig. 2. Receptacle 3d model and the extracted flow region.

The calculation is conducted using the steady solver of FLUENT 13.0. Realizable k-e model with the standard wall function is adopted for the viscous model. For the pressure-velocity coupling, SIMPLE scheme is used with the spatial discretization of second order upwind for momentum and turbulence. Material properties for the sodium at 390℃ are used. The corresponding density and the viscosity are 858.7 kg/m^3 and 2.83e-4 N/m^2, respectively. For the inlet and outlet boundary conditions, mass flow inlet and outflow are used, respectively. The inlet flow rate is set to the design value of 10.59 kg/s.

4. Results and Discussion

The target value of pressure drop for the tested receptacle is 0.32 MPa at the design flow rate of 10.59 kg/s. From the numerical calculations, the pressure drops of the receptacle according to the rotation angles are obtained as presented in Table 2. The pressure drop is minimum when the rotation angle θ = 0° and gradually increases as the θ increases. Since the target pressure drop is between the pressure drops of θ = 0° and 5°, the rotation angle θ should be smaller than 5° to obtain the target value. The pressure drop variation from θ = 0° and 5° is relatively larger than that from θ = 5° and 10°. This indicates that the adjustment of rotation angle might be more robust if the target value lies between θ = 5° and 10° because the pressure drop variation to the unit rotation angle change is smaller in that range. This design idea could be useful for the robust and optimal receptacle design during the detail design stage.

Fig. 3 shows the contour of absolute pressure for the case of rotation angle θ = 10°. Since the contour plane cuts the orifice holes in the first and second plates, local increases of the pressure are observed at the front of the third orifice plate due to the impinging of flow passing the orifice hole and its dynamic pressure conversion. The pressure distribution in the downstream of the third, fourth, fifth, and sixth orifice plates are quite uniform since the contour plane is oblique from the orifice holes. The pressure increase in the downstream of the sixth orifice plate is due to the velocity increase by narrowing the annular flow path.

Table 2. Pressure drops according to the rotation angle θ.

Rotation angle θ	0°	5°	10°
Pressure drop [MPa]	0.078	0.353	0.434

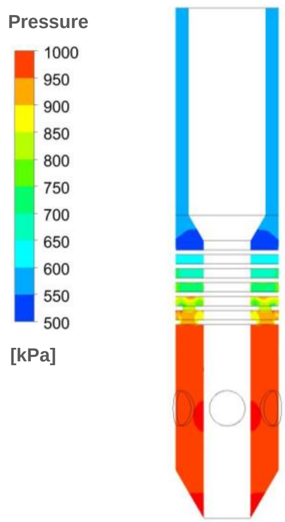

Fig. 3. Contour of absolute pressure in the mid-plane of the receptacle along its central axis. The plane cuts the orifice holes in the first and second orifice plates. The rotation angle is θ = 10°.

ACKNOWLEDGMENTS

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