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Design of Fuel Assembly Tube for Flow Distribution Facility of PGSFR

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1. Introduction

Sodium Cooled Fast Reactor (SFR) is one of the most promising options to meet the increasing energy demand in the world, and several countries consider the SFR to be a prime candidate for future large-scale commercial reactors. Korea also speculates on the SFR as a next-generation nuclear power reactor, and KAERI (Korea Atomic Energy Research Institute) has carried out a conceptual design of a Prototype Generation-IV SFR, namely, PGSFR. [1]

In such a pool type reactor, the flow distribution and pressure drop strongly depend on the arrangement and geometrical configuration of the in-vessel components. It is important to estimate these hydrodynamic characteristics for the optimum thermal-hydraulic design of the reactor. In the absence of an analytical model for flow distribution in such a complex geometry, experimental techniques are alternative way to reveal the flow behavior.

For this concern, the experimental approach using a 1/5 down-scaled model with water flow at room temperature was considered to observe the flow characteristics. The purpose of the hydrodynamic test with the down-scaled model is to visualize the flow distribution of the fuel assemblies in the inlet plenum.

In order to simulate the flow distribution in the core of the prototype reactor through the test model, the fuel assembly tubes should be appropriately designed to preserve the hydrodynamic characteristics of the prototype reactor.

In this paper, the methodology for the design and calibration of the fuel assembly tubes which is included the orifice is introduced.

2. Description of PGSFR Core

There are 451 fuel and non-fuel assemblies in the reactor core of the PGSFR, which constitute 13 groups according to the functional classification. Among them, each fuel assembly from groups 1 to 9 (112 fuel assemblies) has 217 fuel rods in a hexagonal duct housing. Most coolant flow in the inlet plenum flows into these fuel assemblies of groups 1 to 9. Thus the flow path through the fuel assemblies belonging to the groups 1 to 9 are simulated in the present test facility, and the flow path through the other assemblies (groups 10 to 13) are simply blocked. The coolant flow passing through the other groups from groups 10 to 13 is merely within 5% of the total core flow.

2. Description of PGSFR Core

The required flow rate and pressure drop of the fuel assembly tube for the test facility were evaluated through the similarity analysis between the prototype and the test facility [2].

The complex flow path of the fuel assembly was simulated by a single tube as shown in Fig 1. The fuel assembly tubes consist of a receptacle, orifice spool, and tube. The outer dimension of the receptacle was reduced by the 1/5 linear scale. The fuel assembly was designed as a circular tube and the receptacle was designed two parts to allow PIV laser beam sheet for visualization of flow.

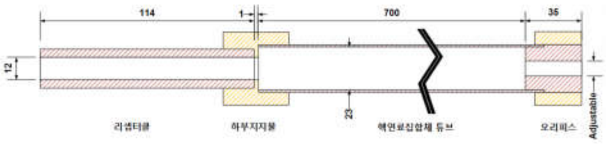

Fig 1. Schematic diagram of fuel assembly tube

The type of orifice spool is thick-orifice. The flow resistance could be precisely varied by adjusting the orifice diameter. The dimensions of the flow holes at the orifice for each group were determined from the comprehensive CFD analysis as introduced in the next section.

The pressure drop across the fuel assembly tube might be different from the designated pressure drop due to the numerical error of the CFD analysis, limitation of correlation for thick-orifice and the manufacturing tolerance. As combination of orifice hole size and hole edge fabrication, the difference between the desired pressure drop and the pressure drop of the each fuel assemblies could be minimized.

To determine the orifice size for each group of nuclear fuel assemblies in the simulated reactor core system, an experimental device capable of measuring pressure drop of a single tube between inlet and outlet is designed.

As shown in Figure 2, Single Fuel Assembly Tube Facility is composed of a pump for controlling the flow rate, a flowmeter for detecting the flowrate into the lower plenum, a differential pressure transmitter from the upper and lower plenums, and a water tank.

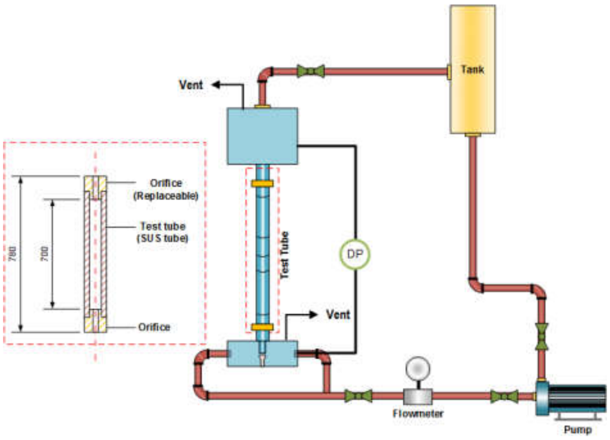

Fig 2. Schematic diagram of Single Fuel Assembly Tube facility

3. Results

CFD analysis is explored for calculation of the fuel assembly differential pressure i.e., diameter of orifice holes and its edge shape for each group.

Orifices can control the pressure drop to some extent by adjusting diameter and edge shape of hole. All bounded pressure drop of fuel assembly tubes included the target pressure drop of 125.6 kPa.

Figure 3 shows CFD analysis result of pressure drop in a case of 9 group orifice. It has 4.9mm diameter orifice and 32mm orifice length. Inner diameter of tube is 23mm long. As water flows from lower plenum to upper plenum, pressure drops mostly occur at inlet to outlet of orifice. There also shows a slight increase of pressure along internal orifice surface. Flow stream is reattached on internal surface of the orifice. Because of this, pressure has minimum value and then recovered at this point.

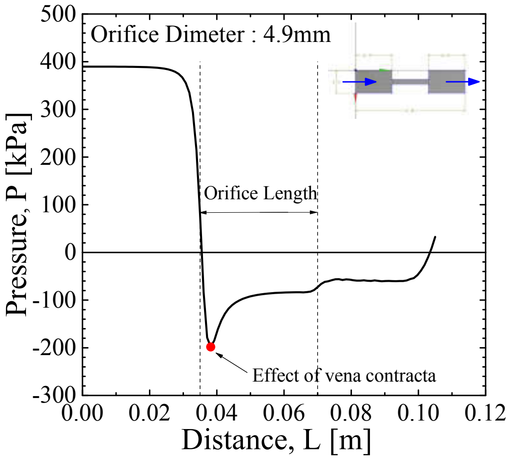

Fig 3. Calculated pressure along orifice

112 fuel assembly tubes of all 9 groups were fabricated according to the dimensions attained from CFD analysis. All fuel assembly tubes were calibrated using the separate test facility, Single Fuel Assembly Tube Facility. While there were slight change of some orifice's hole-diameters and edge shape, it was confirmed that most dimensions of fuel assembly tube were properly designed to have acceptable bounds of the target pressure drop.

The orifice size was carefully adjusted to get a design pressure drop of 125.6 kPa under the condition of the design flow rate at nominal condition. Fig. 3 demonstrates pressure drop curves of orifice as group 1 and 9.

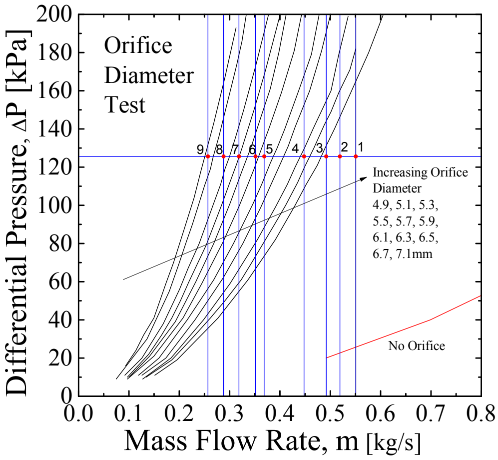

Fig 4. Pressure drops of fuel assembly tube

6. Conclusion

In the present paper, the design procedure of the fuel assembly tube for the flow distribution visualization of PGSFR was introduced. The internal flow path of the fuel assembly simulator was designed as single circular tube with orifice.

A comprehensive CFD analysis was conducted to obtain the dimensions of the holes at the orifices section for 9 groups of the fuel assembly simulators. The calibration test was performed using Single Fuel Assembly Tube facility. During the test, the appropriate diameter and edge shape of orifice were modified to satisfy the desired pressure drop across the tube.

ACKNOWLEDGEMENTS

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