Construction of Experimental Facility for SMART Flow Mixing Header Assembly

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has adopted FMHA (Flow Mixing Header Assembly) for SMART (System-integrated Modular Advanced ReacTor) in order to maintain the uniform distribution of the coolant temperature at the core inlet in the case of breakdown in the steam generator or pump. The FMHA which is a key component located between the bottom of steam generator and the CSB (Core Support Barrel) is important to enhance thermal mixing of the coolant so that it is necessary to understand the thermal-hydraulic characteristics of FMHA. Therefore, it is required to perform the CFD (Computational Fluid Dynamics) analysis to confirm the characteristics of flow distribution and thermal mixing capability from the exit of FMHA to the entrance of core. In this study, the scaling and similarity analysis is carried out to design experimental facility using the data such as temperature distribution, pressure distribution and flow rate obtained by CFD analysis. The experimental facility is designed by linear scaling factor, 0.18. The FMHA is a quadruple concentric shell structure, which has lots of coolant flow holes as shown in Figure. 1

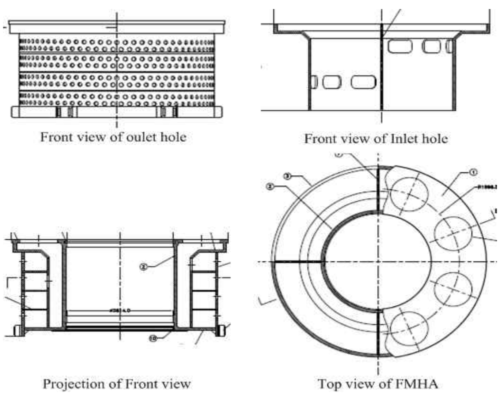

Fig. 1. SMART FMHA.

2. Scaling and similarity analysis

In order to satisfy the similarity criteria between the experimental facility and the actual prototype, they should have same geometric shape and both of the flow patterns should have not only the same Reynolds number but also the Euler number. The prototype shape of SMART FMHA is preserved with linear scaling factor, 0.18(1/5.4) so that the geometric similarity of flow channels from FMHA exit to core inlet is kept. In addition, the thermal-hydraulic similarity should be kept to simulate the similar flow distribution and thermal mixing in the experimental facility of FMHA. Table I gives the main properties depending on the condition of temperature and pressure for SMART prototype and the experimental facility.

TABLE I : Properties for SMART prototype and experimental facility

Property	SMART	Experimental facility		
Pressure [MPa]	15.0	0.1		
Tempature [℃]	295.7	30.0	60.0	45.0
Density [kg/m^3]	734.5	995.7	983.2	990.3
Viscosity [kg/m·s]	0.89E-4	7.97E-4	4.66E-4	5.96E-4

The pressure distribution of the prototype of FHMA and the experimental facility which have a scaling factor, 0.18 (1/5.4) was obtained by using FLUENT code. Figure. 2 shows the analysis results of pressure distribution for the prototype of SMART FMHA and the experimental facility.

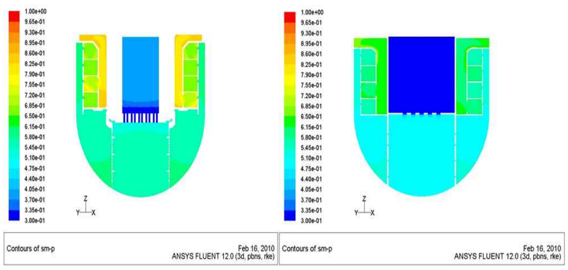

Fig. 2. Pressure distribution of SMART FMHA prototype and experimental facility.

As shown in Fig. 2, there is a little difference of pressure drop between the prototype of SMART FMHA and the experimental facility. As a result of difference in pressure drop, the orifice will be installed at the inlet of FMHA in experimental facility. The ratio of the Euler number could be modified from Eq. (1).

$$\left(\frac{\mathrm{Eu}_{SMART}}{\mathrm{Eu}_{EXP}}\right)_R = \left(\frac{\rho U^2\big|_{EXP}}{\rho U^2\big|_{SMART}}\right) = 1 \qquad (1)$$

By applying each value of density, Eq. (2) can be obtained.

$$\left(\frac{990.3}{734.0}\right)U_R^{\,2} = 1 \qquad (2)$$

(SMART Pressure : 15.0 MPa, Temperature : 295.7℃)
(EXP Pressure : 0.1 MPa, Temperature : 45℃)

where $U_R^{\,2}$ means $\left(\frac{U_{EXP}}{U_{SMART}}\right)^2$ and the values of 990.3 and 734.0 are density(kg/m^3) under the experimental and SMART operation conditions as given in Table II. The value of U_R is 0.8612, which can be calculated by Eqs. (1) and (2). In other words, when the ratio of flow velocity in the experimental facility and SMART prototype is 0.8612, the similarity criteria of the Euler number would be satisfied. Table II gives the ratio of the Reynolds number depending on the ratio of flow velocity.

TABLE II
Ratio of the Reynolds Number

Property	SMART	Experimental facility		
Pressure[MPa]	15.0	0.1		
Temp[℃]	295.7	30.0	60.0	45.0
Ratio of flow velocity	1 : 0.8612			
$Re_{EXP} : Re_{SMART}$	1	0.026:1	0.044:1	0.035:1

3. Experimental configuration

The experimental facility consists of five water tanks, five pumps and test section. Figure. 3 depicts the schematic of the experimental loop and experimental facility.

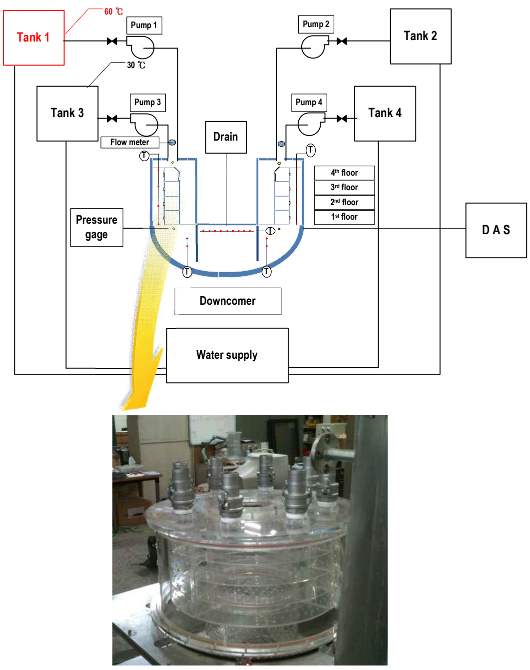

Fig. 3. Schematic of the experimental loop and facility.

The test section was made from acrylic to visualize the flow distribution. The coolant from each tank flows into test section of corresponding header of FMHA through each pump. When the coolant flows into each header, the inlet volumetric flow rate of each header is expected to be 1,100 ~ 1,200 lpm and the flow velocity at inlet FMHA is forecasted to be 2.6 m/s, approximately. Total four differential pressure gauges which have two pressure tap lines in each header are established at the exit of steam generator and downcomer to measure the pressure drop after the coolant passes through the holes of FMHA header. Four flow meters are installed at the inlet of header of FMHA to measure the flow rate of coolant in each header. Total eighty-nine thermocouples are established in the exit of steam generator, outlet hole of FMHA, inside of flow skirt for measuring thermal mixing.

4. Conclusions

The SMART FMHA experimental facility kept geometric similarity criteria of SMART prototype by applying linear scaling factor, 0.18. To preserve the thermal-hydraulic similarity, the similarity of the Euler number which is the standard dimensionless variable is satisfied to design experimental facility. As a result, the SMART FMHA experimental facility which is applied by linear scale factor, 0.18 can be utilized to perform the test of flow distribution capability and thermal mixing phenomenon under the condition of 0.1 MPa and 30 ~ 60 ℃ as the SMART prototype.

In further studies, the thermal-hydraulic parameters will be obtained from a series of experiments such as inlet temperature of FMHA, temperature distribution of flow skirt and pressure drop between inlet and outlet of FMHA, inlet volumetric flow rate of FMHA. Moreover, the other CFD analysis will be conducted to optimize the hole size of FMHA header. Finally, the optimized hole size will be verified by experiments and this study is expected to enhance the thermal mixing efficiency and flow distribution capability of the FMHA.

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