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Characterization of Flow Resistance for the Shell Side of IHX in a Prototype SFR

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1. Introduction

A prototype generation-IV sodium-cooled fast reactor (PGSFR) is being developed at the Korea Atomic Energy Research Institute (KAERI), of which the primary heat transfer system (PHTS) mainly consists of a reactor core, an upper internal structure, two primary heat transfer system mechanical pumps, and four intermediate heat exchangers (IHXs) [1]. As one of the important components in the PGSFR, IHXs are placed between a hot pool and a cold pool to transfer heat from the primary system to intermediate loop to ensure continuous operation without performance degradation or failure. Flow characteristics across the IHX, especially at the shell side, should be investigated and identified to appropriately design the IHX and to accurately analyze the performance and safety of the PGSFR. Due to the geometric complexity of the shell side in the IHX and a wide range of working flow rate conditions, the previous empirical correlations used in the sodium-to-sodium IHX design code (SHXSA) being developed at the KAERI cannot suitably estimate the pressure drop characteristics, which should be improved and validated by using empirical pressure drop results at various flow rate conditions. In the present study, pressure drop characteristics across the shell side of the prototype IHX (p-IHX) by using an experimental apparatus manufactured with appropriate scale laws were investigated. For the pressure drop at the tube bundle regions with the grid plates, an intermediate heat exchanger test loop for PGSFR (iHELP) was constructed based on a 1/29.6 volume scale ratio. The experimental pressure drop results were obtained over a wide range of flow rate conditions. Since geometric characteristics of exit flow channel in the iHELP were not conserved, however, a test section for the exit flow channel (IEC) was built based on a 1/5 linear length scale. The experimental pressure drop results were obtained at various flow rate conditions resulting in fully turbulent flow regimes. Thus, the pressure drop at the shell side of the p-IHX could be determined by combining the pressure drops obtained from the iHELP and IEC experiments.

2. Experimental Setup

The iHELP test section was designed and built to simulate the pressure drop characteristics at the shell side of the IHX, as shown in Fig. 1. The test section maintained the height of the p-IHX and preserved the hydraulic diameter in the tube bundle region and the flow hole area ratio on the grid plates. In addition, the configurations of the heat transfer tubes and flow holes in the p-IHX were preserved in the test section. The test section was slab-shaped and mainly consisted of an entrance region, a tube bundle region, a flow passing region on the grid plate, and an exit flow channel. The experiments were conducted using water (35 ℃, 1 atm) instead of sodium (467.5 ℃, 1 atm) and the flow rate conditions were determined by preserving the Reynolds number in the p-IHX [2]. Several pressure taps connected to the corresponding differential pressure transducers were installed in the test section to investigate the pressure drop characteristics.

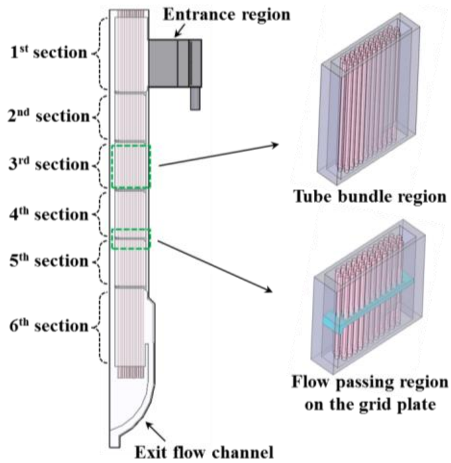

Fig. 1 iHELP test section

Since the iHELP test section was built as a slab form, geometric characteristics were not conserved properly in the exit flow channel. Thus, the IEC test section was designed and constructed with a 1/5 length scale based on the prototype IEC by using Euler number conservation [3]. A 1/8 Reynolds number ratio (1/1 flow velocity ratio) was applied to providing the fully turbulent flow regime for all test conditions. The experiments were conducted using water (60 ℃, 1 atm) instead of sodium (467.5 ℃, 1 atm). The end part of the IEC was a wye symmetrical shape, which caused the distortion of the pressure drop measurement due to the vena contracta effect [4]. Computational results plotted in Fig. 2 clearly show the abovementioned phenomena, which was diminished at around 0.7 m away from the end of the IEC validated by the experimental results. Thus, a 1.5 m-long stainless steel exit flow pipe (EFP) was added to the end of the IEC and the pressure drop was measured by using the pressure taps on the walls of the IEC and the EFP as shown in Fig. 3. Then, the pressure drop of the IEC was determined by subtracting the pressure drop at the EFP from the pressure drop measured by using pressure taps A and B.

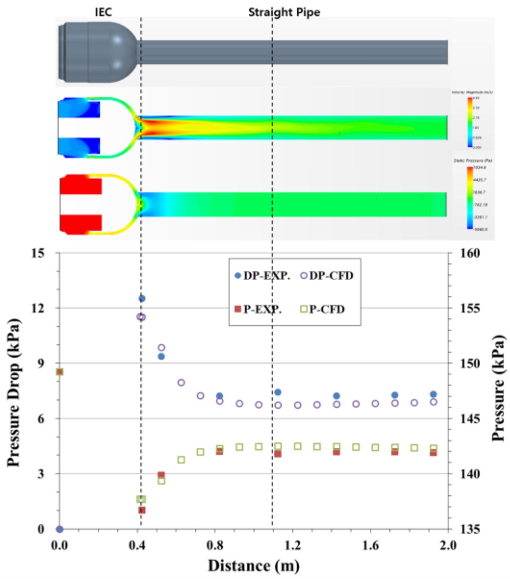

Fig. 2 Pressure drop characteristics at the IEC test section

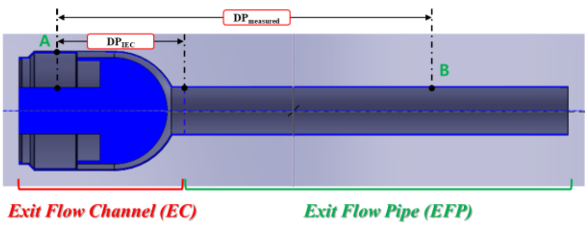

Fig. 3 IEC test section

3. Results

Experiments in the iHELP test facility were performed to identify the pressure drop characteristics at the tube bundle regions with the grid plates (TG). Water (35 ℃, 1 atm) was used as a working fluid and flow rates were determined by preserving the Reynolds number in the p-IHX. All data were recorded using the data acquisition system when physical variables reached a steady state. Figure 4 shows the sectional pressure drop results in the iHELP test section. The experimental results clearly show that the pressure drop increases with the flow rate. The experimental uncertainties ranged from ±0.02 kPa to ±0.25 kPa, satisfying the test requirements [5]. The pressure drop of fluid flowing through the inlet to the middle of the first tube bundle region was relatively smaller than other pressure drops. The pressure drop values across the grid plates were approximately the same, but the pressure drop at the first grid plate was slightly greater than that of the others due to the flow instability. Pressure drop at the TG of the p-IHX could be determined based on the applied similarity between the iHELP test section and the p-IHX.

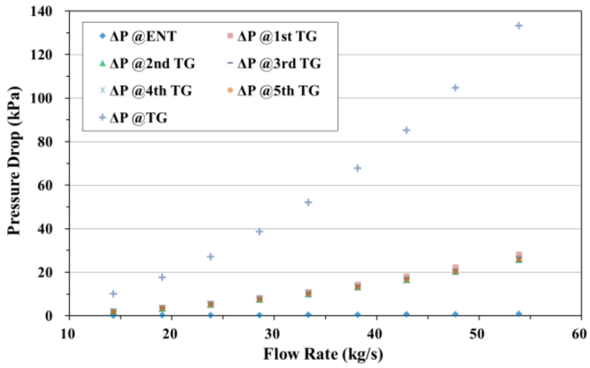

Fig. 4 Pressure drops at the tube bundle regions with grid plates

Experiments in the IEC test facility were conducted to identify the flow characteristics at the exit flow channel. Water (60 ℃, 1 atm) was used as a working fluid and flow rates were determined based on the identical flow velocity condition of the p-IHX. All data were collected when physical variables remained constant during the tests. As plotted in Fig. 5, pressure drop at the exit flow channel increases with the flow rate, which was lower than the pressure drop value obtained in the iHELP test section by up to around 1/9 times. The uncertainty associated for determining the IEC pressure drop was up to ±0.15 kPa, which met the test requirements [5]. Pressure drop obtained from the IEC test facility could be converted based on the similarity between the IEC test section and the prototype IEC for determining the pressure drop at the exit channel of the p-IHX.

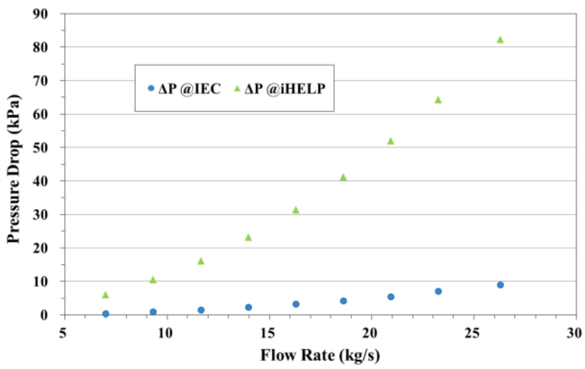

Fig. 5 Pressure drops at the exit flow channel

4. Conclusions

Pressure drop characteristics at the shell side of the IHX in the PGSFR were investigated experimentally in the study by using two different test facilities. An iHELP test section was built for the pressure drop of tube bundle regions with grid plates with a 1/29.6 volume scale ratio by maintaining the height of the p-IHX, hydraulic diameter at the tube bundle regions, porosity of the grid plates, and configuration of the tube bundles. Experiments under identical Reynolds numbers referring to the p-IHX were performed to maintain the hydraulic characteristics of the p-IHX. With respect to the flow resistance of the exit flow channel (EC), an IEC test facility was separately built with a 1/5 length scale ratio and a 1/8 Reynolds number ratio referring to the p-IHX by preserving the flow path of the EC in the p-IHX. The precise pressure drop data for the shell side of the p-IHX over a wide range of flow rates were obtained and would be used to improve and verify the pressure drop correlations in the SHXSA code.

ACKNOWLEDGEMENT

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