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Numerical Investigation on Thermal-Hydraulic Characteristics for Inter-Wrapper Flow of PLANDTL-DHX

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1. Introduction

A core model consisting of seven sub-assemblies was installed on the sodium test loop PLANDTL-DHX (PLANT Dynamics Test Loop-Decay Heat Exchanger) to simulate the complex phenomena of a reactor. The core model was connected to the upper plenum in which DHX of a direct reactor auxiliary cooling system (DRACS) was immersed to remove the decay heat. One of the designs of the decay heat removal systems is a direct reactor auxiliary cooling system DRACS. Natural circulation decay heat removal in terms of inherent safety, is one of the most important features of a sodium-cooled fast reactor. When the cold sodium provided by the DHXs penetrates inter-wrapper gaps in the core, the thermal-hydraulic phenomenon called as Inter-Wrapper Flow (IWF) can occur and it may affect the thermal hydraulic behavior in the core. The inter-wrapper gaps filled with sodium were also connected to the upper plenum [1,2,3]. IWF contributes to the reduction of the peak cladding temperature in two ways. The first is direct cooling of the fuel bundles through the wrapper wall, and second is transport of heat to the adjacent fuel bundles [4]. In this study, the temperature in the IWF and assembly was validated with the CFD results using published experimental data. This CFD methodology is based on the innovative grid system developed in previous studies using Jeong and Song's work on the experiment [5], and it is implemented with a RANS-based Menter's Shear Stress Transport (SST) turbulence model.

2. NUMERICAL METHOD

2.1 Test Section Description

The core of PLANDTL-DHX consists of a central 37-pin bundle and six 7-pin bundles around it. All pins are heated by an electric heater, the heated length is 1 m, and the axial power distribution is modeled as a chopped cos distribution. The size of the duct of the 37-pin bundle and the duct of the 7-pin bundle are the same, and the diameter of the rod is different, but the shape of the wire spacer is the same. Fig. 1 shows the modeling domain of PLANDTL-DHX for CFD simulation. Sodium flowing in the assembly is shown in orange parts, and the region flowing by IWF is shown in blue. Coolant temperatures of the core model were measured by K-type thermocouples of 0.3 or 0.5 mm in diameter. The location of the thermocouple is indicated by a red dot in Fig. 1. The transverse temperature distribution was measured along the measurement line at the top of the heated length and middle of heated length [2].

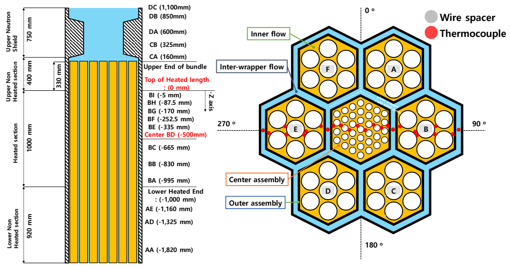

Fig. 1. Schematic of seven subassembly model

Table I. Geometric information of fuel assembly

	Center Assembly	Surrounding Assembly
Number of pins	37	7
Pin diameter	8.3 mm	20.8 mm
Wire diameter	1.5 mm	1.5 mm
Wire lead pitch	165.0 mm	165.0 mm
Pin pitch	9.9 mm	22.4 mm
Inter-wrapper gap width	7mm	
Wrapper tube thickness	4mm	
Heated length	1000 mm	
Total length	2250 mm	

2.2 Computational grid system

In PLANDTL-DHX experiments, thermocouples were used to measure the temperature of the wire, so accurate simulation of the helical wire spacer shape is important. As shown in Fig. 2, an innovative grid generation method using Fortran-based in-house code was applied [5].

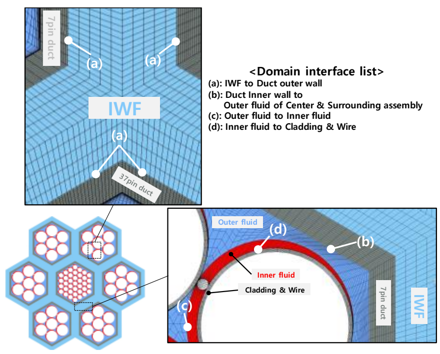

Fig. 2. Mesh configuration

2.3 CFD analysis Method

Table I. shows the boundary conditions of each experiment in the report. The inlet temperature of the IWF and assembly is 300°C, and the heater power and flow rate of each assembly are shown in Table I.

Table I. Boundary conditions of PLANDTL-DHX [1]

Case No.	Heater Power [kW/Ass]		Flow Rate [L/min/Ass]	
	Center	Surrounding.	Center	Surrounding.
ST-043	144.3	144.0	49.0	49.0
ST-049	144.3	116.0	49.0	49.0

3. RESULT

Each case is an experiment that evaluates isothermal, heated, and cooled heat transfer based on the center assembly. Fig. 3, 5 shows the CFD results of ST-043, ST-049 and the heat of the center assembly is transferred to the surrounding assemblies by the inter-wrapper flow. Fig. 4. 6 compares the CFD results calculated on the transverse line with the experimental data measured by the thermocouples. In the ST-043 analysis result, the average relative error is 2.22% and in the ST-049 analysis result, the average relative error is 5.28%.

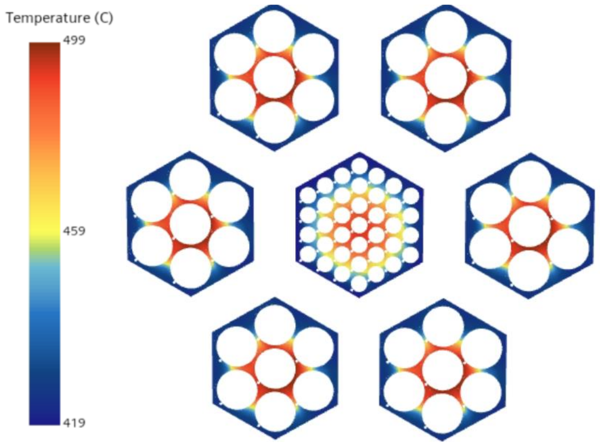

Fig. 3. CFD result Temperature contour of ST-043

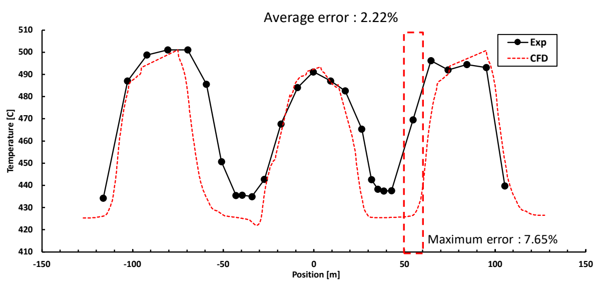

Fig. 4. Comparison of experimental results and CFD for the top of the heated section in ST-049

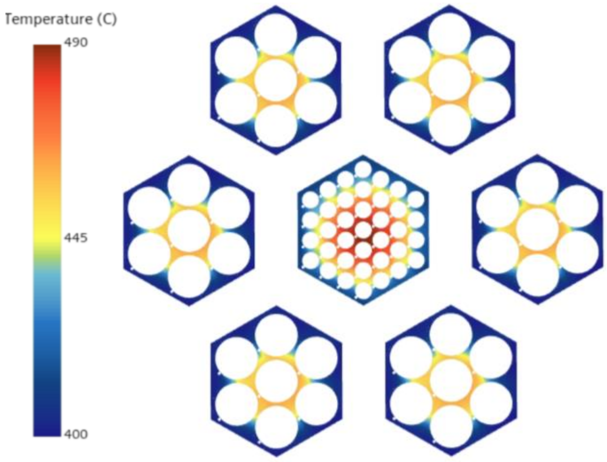

Fig. 5. CFD result Temperature contour of ST-049

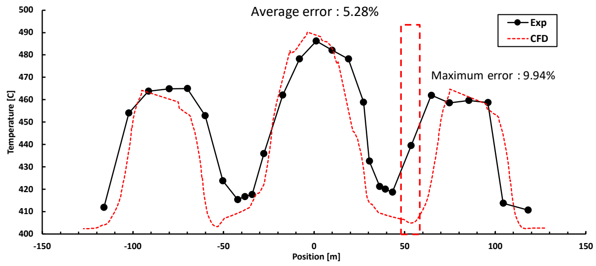

Fig. 6. Comparison of experimental results and CFD for the top of the heated section in ST-049

4. CONCLUSION

The inter-wrapper flow is an important phenomenon in SFR that can affect the performance and safety of the reactor. However, the uncertainty factor of IWF in SFR can depend on a variety of factors such as the specific reactor design, operating conditions, and measurement techniques, etc. Another source of uncertainty is related to the modeling of IWF in reactor simulations. While CFD simulations can provide detailed information on the flow patterns and heat transfer in SFR, there are subject to various sources of uncertainty, such as the choice of turbulence model and numerical discretization scheme. Overall, the uncertainty factor of IWF in SFR can vary depending on the specific reactor design and operating conditions, as well as the measurement and modeling techniques used to quantify this phenomenon. Follow-up studies will conduct thorough sensitivity analyses and validation studies to quantify the uncertainty and ensure the safety and performance of SFR.

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