

Multi-dimensional Thermal-hydraulic analysis for PHWR Moderator Experiment by Using MARS-KS and OpenFOAM

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1. Introduction

In the moderator of PHWR (Pressurized heavy water reactor), about 80 MW thermal energy is generated from the D₂O while the high energy fission neutrons slow down to the thermal energy levels to permit further nuclear fission [1]. To remove this heat, the moderator circulates with two moderator pumps. Because there are plenty of structures (380 pressure tubes), complicated multi-dimensional flow is developed in the moderator. In order to analyze this flow system, there have been a lot of researches including experiment and computational code work. In the PHWR plant analysis in MARS-KS [2] which is a system thermal-hydraulic code, the moderator is modelled as a one single volume. However, the single volume method for the moderator have a limitation in checking local phenomenon. For example, it is possible to occur the local boiling phenomena in case of the accident condition. In this study, for the improvement of the moderator analysis system, MultiD module of MARS-KS is adopted for analyzing the multi-dimensional flow system of the moderator. SPEL (Sheridan park experimental laboratory) experiment [3] which is a 1/10 scaled down geometry of the moderator is chosen for the feasibility test of the MARS-KS MultiD. Furthermore, for comparing the local calculation result and detailed flow analysis, CFD (Computational fluid dynamics) calculation is also conducted by OpenFOAM [4] which is an open source CFD toolbox.

2. Features of SPEL Experiment

SPEL is a 1/10 scaled down experiment which was conducted by AECL (Atomic energy of Canadian limited) for the analysis of two-dimensional flow phenomenon of moderator [3]. Fig. 1 represents the geometry of the experiment. Specific dimensions of the experiment geometry is described in the Table I. On the left and right side of the vessel, there are water inlet nozzles which make the water in the vessel circulate. The 52 heat rods generate constant heat by electric conduction. From the conduction heat from the heat rod, natural circulation is developed inside of the vessel. Therefore, because of the momentum of the inlet nozzles and buoyancy from heater, mixed type flow is developed in the vessel. In the SPEL experiment, local temperature of the water was measured to investigate

the flow pattern. Also, various test conditions were conducted with changing the flow velocity of the nozzle and heat power. In this study, the local temperature is compared for mixed type flow condition (Table II) with the MARS-KS and OpenFOAM simulations.

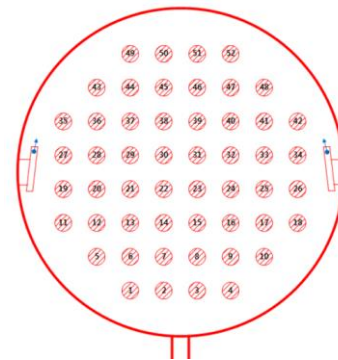


Fig. 1. Schematic diagram of SPEL experiment including 52 heater, inlet and outlet

Table I: Specific dimensions of the SPEL experiment

	Dimension (mm)
Inner dia. of the vessel	737
Vessel length	254
Outer dia. of the heat rods	38
Pitch between the heat rods	75
Inlet nozzle (left and right)	12.7 (width) 127 (length)
Dia. of outlet	25.4

Table II: SPEL experiment condition

	Nozzle inlet velocity (m/s)	Heat flux (W/m ²)
Case 1 (Mixed type flow)	0.065	1,586

3. MARS-KS MultiD simulation

A nodalization for the MARS-KS MultiD simulation is prepared as shown in Fig. 2. In order to model the circle shape of the vessel, the node system is composed of 40 x 40 grids in the Cartesian coordinate system. In case of 52 heat rods, heat structure is applied on the red

cells of the Fig. 2 and the red cells are treated as a porous medium considering the volume of heat rods. However, momentum of the injected water from the inlet nozzle is easily diffused due to the Cartesian coordinate node system. In this study, modification of the form loss coefficient is conducted along the green guide of the Fig. 2 so that the momentum of the injected water can be transferred to the top region of the vessel. Simulation is followed with the condition of the Table II.

Fig. 3 presents the vector plot and temperature contour of the MARS-KS calculation result. In the calculation result, almost symmetrical flow is developed in both temperature and velocity. The water from the inlet nozzle of the both sides flow up through the curved guide until the flow encounter the heated water.

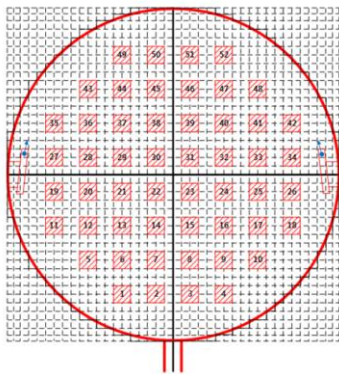


Fig. 2. 40x40 Nodalization of SPEL experiment with MARS-KS MultiD calculation

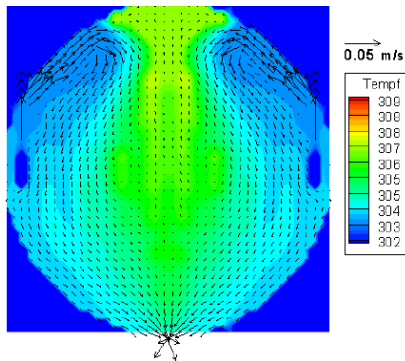


Fig. 3. Vector plot and temperature contour of MARS-KS

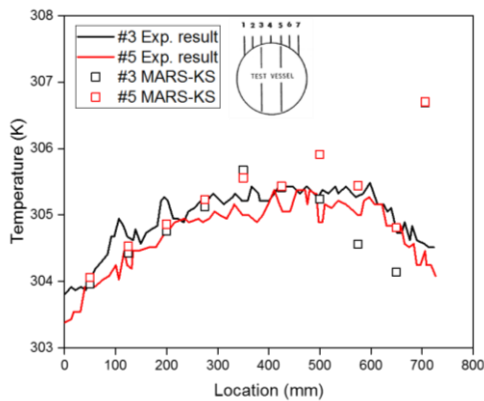


Fig. 4. Comparison of local temperature between experiment result and MARS-KS calculation

The local temperature of MARS-KS calculation is compared with experiment result as shown in Fig. 4. In this paper, port 3 and 5 where the impinged water flow encounter with buoyancy driven flow are chosen for location of temperature comparison. In the lower region of the vessel, MARS-KS could catch the trend of temperature change. However, from the mid-level of the vessel, the discrepancy of MARS-KS and experiment result become larger. Also, while the asymmetric temperature trend was measured, MARS-KS predicted symmetrical temperature trend.

4. OpenFOAM simulation

For the purpose of analyzing detailed flow phenomenon, CFD simulation was conducted by using the OpenFOAM ver. 5.0. Fig. 5 shows the mesh for the CFD calculation. For the boundary layer of the heat rod, prism layer mesh is inserted and base size of the mesh is 4 mm. Total number of mesh was about 45,000.

buoyantBoussinesqSimpleFoam is a solver which was developed for using Boussinesq approximation in case of natural convection analysis [5]. However, many solvers in this code should be modified by user for the appropriate simulation. Also, this solver has limited thermal boundary conditions so that it can only deal with the wall temperature. In order to model the experiment condition properly, heat flux boundary condition is inserted by modifying the library of code system.

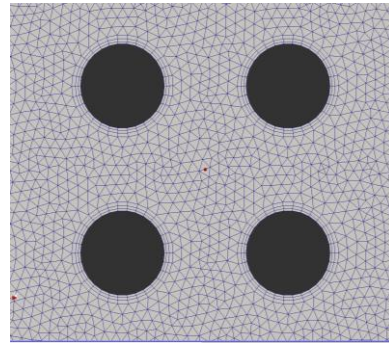


Fig. 5. Two-dimensional triangular and prism layer mesh around heat rod

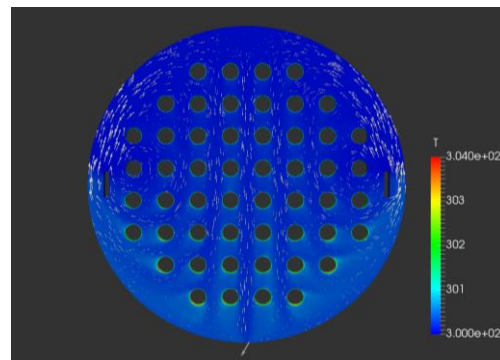


Fig. 6. Vector plot and temperature contour of OpenFOAM calculation

Fig. 6 represents the vector plot and temperature contour of the OpenFOAM calculation. The momentum driven flow is calculated relatively large compared with that of buoyancy flow. Thus, the heated water flow down to the lower region of the vessel. Regarding with this result, the code system will be investigated continuously.

5. Conclusions

Code calculation for the moderator experiment is conducted by using MARS-KS and OpenFOAM. As the complicated flow is developed in the experiment vessel, discrepancy between codes and experiment result are shown. Improvement of code system and extension of calculation will be progressed.

Acknowledgment

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