Changes in hydraulic characteristics of APR type core simulators in different simulation conditions

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1. Introduction

Tens of or hundreds of fuel assemblies are installed in the nuclear reactors. For example, the APR+ reactor core consists of 257 fuel assemblies, the APR1000 reactor core is composed of 177 assemblies, and the SMART core has 57 fuel assemblies [1~3]. Because the geometries of the fuel assemblies are too complex, simply designed core simulators, which are designed to simulate the resistance of the axial flow as well as cross-flow characteristics of the real fuel assembly, are used in the experiments.

A core simulator has been developed for a 1/5 scaled experimental reactor model of APR+ in which 60℃ water is used as the working fluid. The hydrodynamic characteristics of the simulator have been investigated via experimental studies [4]. In this study, the authors investigated how the hydraulic characteristics, especially changes in the cross-flow characteristics, are varied according to the boundary condition of the CFD (computational fluid dynamics) model as well as the operating condition.

2. Methods and Results

2.1 CFD model of three core simulators

In this study, a core simulator for APR+ was used developed by KAERI (Korea Atomic Energy Research Institute) [4]. Three APR+ core simulators aligned in a line were assumed to investigate cross-flow characteristics among three simulators (Fig. 1). Fine mesh with 3,851,701 nodes and 13,037,718 cells were adopted to the developed CFD model of the core simulators (Fig. 2).

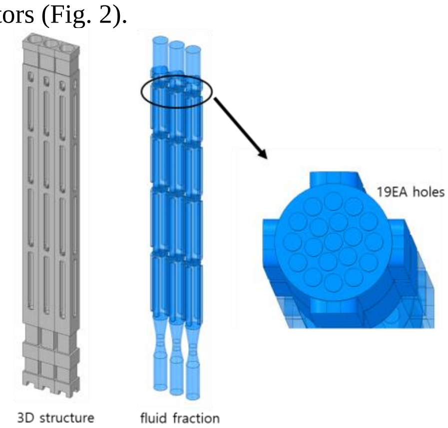

Fig. 1. Three core simulators aligned in a line and its fluid fraction for developing CFD model

2.2 Analysis conditions

Flow rates simulating ARP+ and APR1000 were calculated considering the difference in density caused by the different temperatures of the working fluid (water) as well as geometric scale, and those were 2.278 kg/s and 2.353 kg/s, respectively. To generate cross-flow in the core simulator assembly, 90% and 110% of the calculated flow rate was applied on the left (Channel A) and right (Channel C) core simulators.

In the experiment for three core simulators, the experimental models are inserted into a chamber. Thus, the exterior surfaces of the fluid fraction of the core simulators should be constrained in CFD analysis for simulating the experiment using a boundary condition such as “no-slip wall condition”. However, most of the fuel assemblies are connected to other assemblies in the real reactor. Thus, “symmetry wall condition” seems to be more appropriate for simulating real assemblies using CFD analysis. In this study, two different wall conditions, "no-slip wall condition" and "symmetry wall condition", were applied and their effects on the changes in hydraulic characteristics of the core simulator were investigated.

Mass flow boundary conditions were used to provide a prescribed mass flow rate at inlets. Also, pressure outlet boundary conditions with 0 Pa were used to define flow outlets. Flow rates at seven points of three core simulators were predicted and compared with each other (Fig. 2). For CFD analysis, a commercial CFD solver (Ansys CFX, Ansys, Inc., Canonsburg, PA, USA) was used. A widely used standard k-ε turbulence model was adopted, and changes in the flow rate of each core simulator were investigated using steady-state CFD analysis.

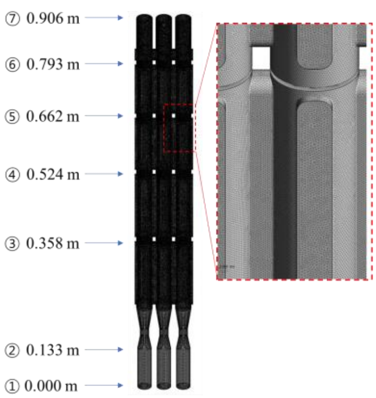

Fig. 2. Grid system of fluid fraction of the three core simulators and location at which flow rate was predicted

3. Results

While flow rate at the center (Channel B) showed little changes in flow rate in three different analysis conditions, flow rates in both left and right converged to the flow rate of the center one. Flow in the center simulator compensated the flow in the left one which started with 90% of the flow rate of the center one, and the flow at the right simulator supplemented the flow at the center one (Fig. 3).

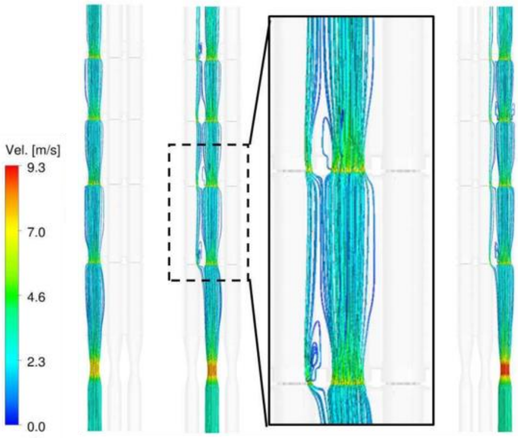

Fig. 3. Streamline flow in three aligned core simulators with APR+ operating condition and no slip wall condition

Table I: Mass flow rate at the vertical locations

(a) APR+ operating condition with no slip condition

Location (m)	Channel A (kg/s)	Channel B (kg/s)	Channel C (kg/s)
0.906	2.276	2.272	2.278
0.793	2.276	2.273	2.277
0.662	2.272	2.271	2.283
0.524	2.260	2.267	2.300
0.358	2.197	2.267	2.363
0.133	2.048	2.276	2.503
0.000	2.048	2.276	2.503

(b) APR+ operating condition with symmetry condition

Location (m)	Channel A (kg/s)	Channel B (kg/s)	Channel C (kg/s)
0.906	2.271	2.279	2.277
0.793	2.273	2.278	2.275
0.662	2.271	2.273	2.283
0.524	2.261	2.270	2.295
0.358	2.197	2.269	2.360
0.133	2.048	2.276	2.503
0.000	2.048	2.276	2.503

(c) APR1000 operating condition with no slip condition

Location (m)	Channel A (kg/s)	Channel B (kg/s)	Channel C (kg/s)
0.906	2.350	2.347	2.354
0.793	2.350	2.350	2.352
0.662	2.346	2.347	2.359
0.524	2.336	2.342	2.373
0.358	2.270	2.341	2.440
0.133	2.115	2.351	2.585
0.000	2.115	2.351	2.585

Two different boundary conditions applied on the exterior wall surfaces of the fluid fraction of the core simulator resulted in little changes in hydraulic characteristics of the core simulator. RMSE (root mean square error) between the results was about 0.003 kg/s. It's only 0.1% of the flow rate of the center simulator (Table I).

Two different operating conditions also showed little changes in the flow rate of the three core simulators. RMSE of the normalized flow rate of the left core simulators was 0.2 % between APR+ operating condition and APR1000 condition, and also 0.2% was shown in the right one.

4. Conclusions

The results of this study showed that the boundary conditions of the wall surfaces ("no-slip wall condition" vs "symmetry wall condition") didn't affect the hydraulic characteristics including the cross-flow phenomenon among the channels of the core simulator. Moreover, two different flow conditions resulted in the same cross-flow characteristics of the simulator. Therefore, the authors could conclude that geometry, as well as resultant pressure resistance in the channel, are the dominant factors determining hydraulic characteristics, including cross-flow characteristics, of the simulator. In this study, the effects of the limited parameters were investigated. Thus, in the future, the effects of turbulence models as well as the temperature of the water will be studied.

Acknowledgement

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