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Sensitivity Analysis of the Core Flow in the APR-Type Reactor : A Comparative Study of Grid System and Turbulence Model

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1. Introduction

In-reactor core flow distribution is important for the safety and efficient operation of nuclear power generation. Thus, the reactors are designed to generate a good distribution of the core flow. Computational fluid dynamics (CFD) could be used to verify reactor design on the core flow distribution aspect. However, various factors in the modeling and analysis could affect the results of CFD.

In this study, a CFD model for simulating fluid flow in the APR-Type reactor was developed. Then, the effects of mesh size and turbulence models on the core flow distribution at the inlet plane of the nuclear core assemblies were investigated.

2. Materials and Methods

2.1 3D CAD model and mesh system

In order to analyze the flow distribution of the reactor core, the three-dimensional geometry of the APR-type reactor was developed (Fig.1). Then, a grid system was created using the model.

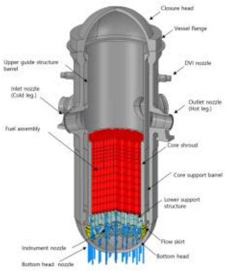

Fig. 1. 3D CAD model of the APR-type reactor

Since the analysis results can vary depending on the quality of the grid, a total of five levels of grid models were created (Fig.2) and sensitivity analysis was performed. In this study, both tetrahedral and hexahedral grid systems were used. The core assemblies were simplified using porous media and the hexahedral grid system was used for them. The tetrahedral grid system was used for all other regions.

The fine grid system was used for the region of the downcomer, the flow skirt, the lower support structure, and bypass flow, where changes in physical quantities are expected to be large, to ensure the accuracy of the analysis. To perform the grid sensitivity evaluation, five different grid system were developed from Level 1 to 5. From the grid system for Level 1, the models for Level 2 to 5 were developed by increasing the number of grids by 10%, 20%, 25%, and 30%.

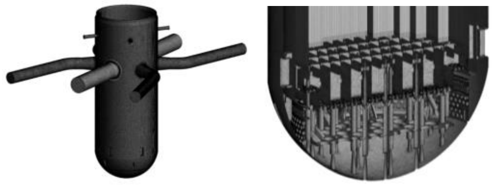

Fig. 2. Grid system of the APR-type reactor (Level3)

2.2 Analysis method

A three-dimensional steady-state CFD analysis was performed to numerically simulate the core flow distribution in the reactor under normal operating conditions. To calculate the behavior of the coolant in the reactor vessel, the continuity equation and the momentum equation were considered. Inside the fuel assembly, the fuel rod, top nozzle, fuel alignment plate, intermediate support, etc. are complexly composed. For the efficient analysis, the porous media model was applied for the fuel assemblies.

Since each turbulence model has a difference in accuracy and analysis time depending on the number of constitutive equations or the processing method of turbulence terms, the most efficient turbulence model should be chosen by identifying the characteristics of turbulent flow. Four turbulence models were chosen based on the previously published studies in which core flow distribution analysis has been analyzed, and were used for the sensitivity analysis [1-3]. Four chosen turbulence models are k-ε, SST, RNG k-ε, and LRR Reynolds stress.

2.3 Analysis conditions

In order to perform core flow distribution analysis, boundary conditions were established and shown in Fig. 3.

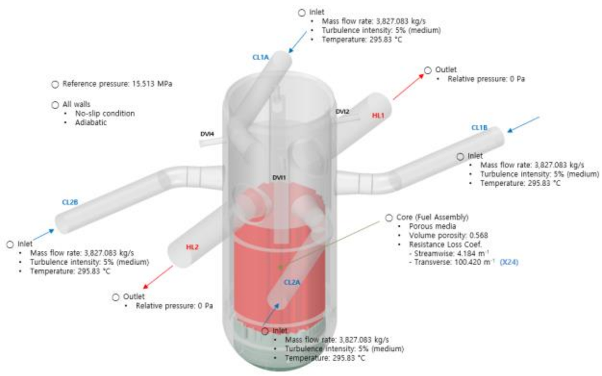

Fig. 3. Analysis conditions

3. Results

3.1 Flow in reactor

The coolant introduced through the cold leg pipe sequentially passes through the downcomer, flow skirt, lower plenum, fuel assemblies, upper plenum, and hot leg pipe before being discharged to the outside through the hot leg pipe.

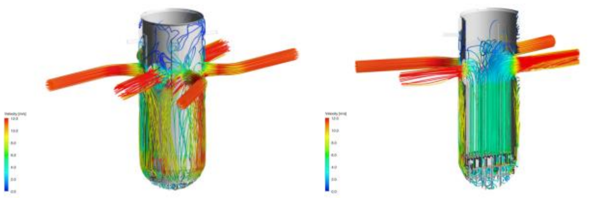

Fig. 4. Flow of the coolant in the reactor

3.2 Grid sensitivity analysis

Sensitivity analysis using Level 1 to 5 grid systems was performed on the aspect of core flow distribution. All models showed similar distributions for the core flow. (Fig. 5).

The normalized mass flow rate was calculated using the mass flow rate flowing into each core inlet. The normalized mass flow rates in the mid-row and mid-column lines of the core inlet plane were compared with each other. All models showed similar distributions, and the maximum differences in the mid-row and mid-column lines were 0.018 and 0.027, respectively (Fig. 6).

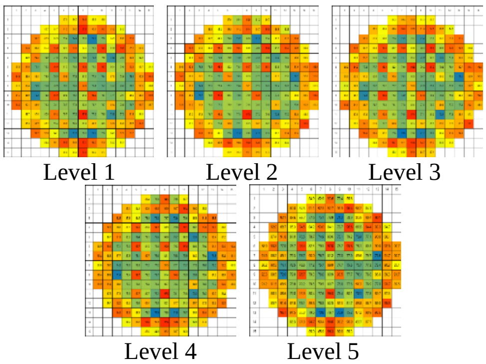

Fig. 5. Predicted core flow distribution using five different grid systems

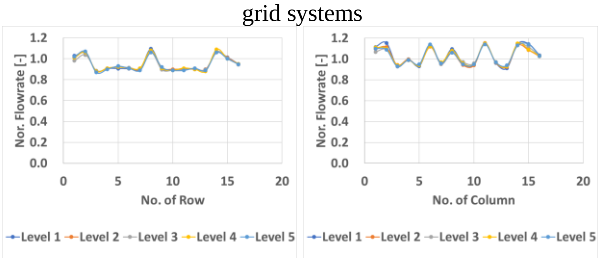

Fig. 6. Predicted normalized mass flow rate in the mid-row and mid-column lines using five different grid systems

3.3 Turbulence model sensitivity analysis

Sensitivity analysis of the turbulence model using k-ε, Shear stress transport, RNG k-ε, and Reynolds stress model turbulence models was performed. All turbulence models showed similar core flow distribution (Fig. 7). Slight difference was shown in the normalized mass flow rate in the mid-row and mid-column line predicted using four different turbulence models (Fig. 8).

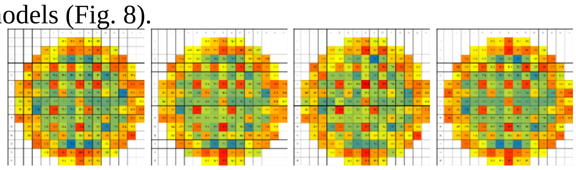

Fig. 7. Predicted core flow distribution using four different turbulence models

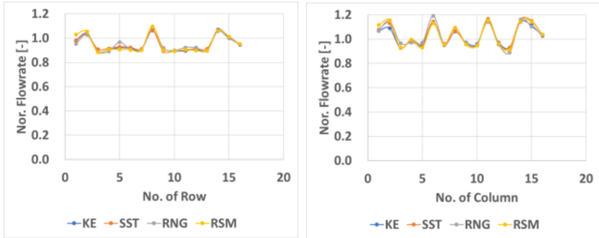

Fig. 8. Predicted normalized mass flow rate in the mid-row and mid-column lines using four different turbulence models

4. Conclusions

This study investigated fluid flow in the APR-type reactor using CFD analysis and the effects of the grid system and turbulence models on the core flow distribution. The results of this study showed that five different grid systems and four different turbulence models predicted similar core flow distribution on the core inlet plane. The modeling factors considered in this study, five levels of the grid system and four different turbulence models, did not affect the distribution of core flow. The complex structure in the bottom area of the reactor (lower structure and flow skirt) may contribute to eliminating the effects of the modeling factors considered in this study on the core inlet plane. Therefore, in future research, we plan to investigate changes in the flow characteristics before the lower structure region.

Acknowledgement

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REFERENCES

[1] B. Kutuk, and I. H. Guzelbey, Computational fluid dynamics analyses of a VVER-1200 nuclear reactor vessel for symmetric inlet, asymmetric inlet, and LOCA conditions, Int. J. Press. Vessels Pip., 187, 2020

[2] L. Wang et al., Numerical simulation of temperature heterogeneity inside the AP1000 upper plenum and hot leg, Nucl. Eng. Des., 362, 2020

[3] R. Puragliesi et al., Steady-state CFD simulations of an EPR™ reactor pressure vessel: a validation study based on the JULIETTE experiments, Nucl. Eng. Des., 300, 2016