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Core inlet flow distribution in the APR-Type Reactor under various operating conditions

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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 even under abnormal operation conditions. For example, imbalanced inlet flow for four cold legs has also been assumed to test core inlet flow distribution.

Computational fluid dynamics (CFD) is an effective tool to evaluate and verify reactor design. In this study, the authors investigated core inlet flow distribution in the APR-Type reactor under normal and abnormal operating conditions using CFD analysis. In the normal operating condition of a reactor, the cooling water is supplied throw four cold legs by four pumps. An extremely abnormal operating condition was assumed. In the assumed condition, one of the four pumps supplying the cooling water into four cold legs stopped caused by a certain reason, and there was no fluid flow to the inoperative pump.

2. Materials and Methods

A three-dimensional computer-aided design (CAD) model of an APR-type reactor was developed (Fig.1) [1]. Then, a CFD model was developed using the CAD model.

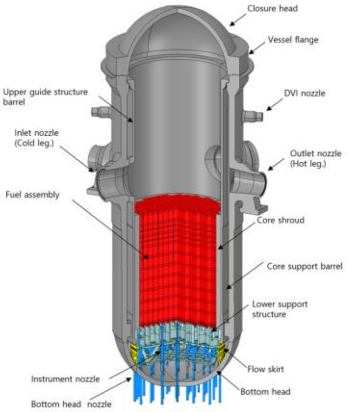
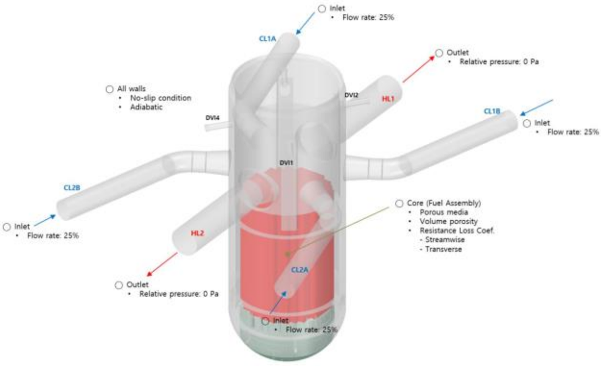


Fig. 1. 3D CAD model of the APR-type reactor

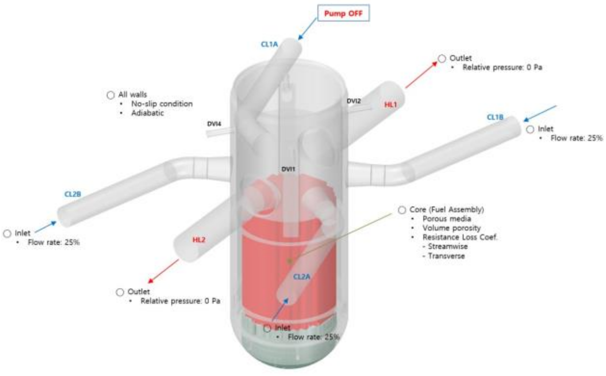
Both tetrahedral and hexahedral grid systems were used for developing the CFD model. The geometry of the fuel assembly was simplified and assumed to be the square bar. The hexahedral grid system was applied, and porous media was used to simply simulate the fluid flow in the core assembly. The tetrahedral grid system was used to depict all other regions with complex geometries. 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.

Since each turbulence model has differences in accuracy and analysis time depending on the number of constitutive equations or processing methods of turbulence terms, the most efficient turbulence model should be selected after identifying the characteristics of turbulence. Therefore, sensitivity analysis was performed in the previous study, and the k-ε model was selected. [2-4].

Core inlet flow distribution was investigated under two operating conditions, normal and abnormal conditions. The normal operation condition of an APR-type reactor, including material properties of the cooling water according to its operating temperature, the flow rate of the cooling water, and outlet conditions of the hot legs was applied (Fig. 2(a)). In the abnormal condition, the cooling water supply for one of the four cold legs was neglected, and all other conditions were maintained (Fig. 2(b)).



(a) Normal operating conditions

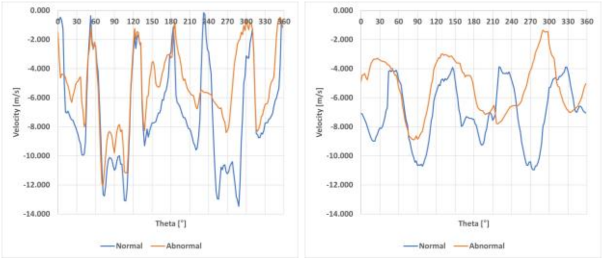


(b) Abnormal operating conditions
Fig. 2. Analysis conditions

3. Results

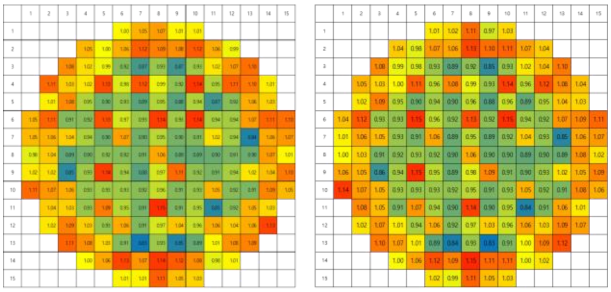
The cooling water introduced through the cold leg pipe sequentially passes through the downcomer, flow skirt, lower plenum, fuel assemblies, upper plenum, and hot leg pipe before being discharged to the outside through the hot leg pipe (Fig. 3). Changes in the flow velocity of the cooling water was predicted in the upper (DC01) and lower (DC02) downcomer of the reactor (Fig. 4). Distinctly different fluid flows in the downcomer region were predicted under two conditions.

Fig. 3. Flow of the cooling water in the reactor (Normal operating conditions)



(a) DC01 (b) DC02

Fig. 4. Velocity of the cooling water in the downcomer



(a) Normal condition (b) Abnormal condition

Fig. 5. Predicted normalized mass flow rate

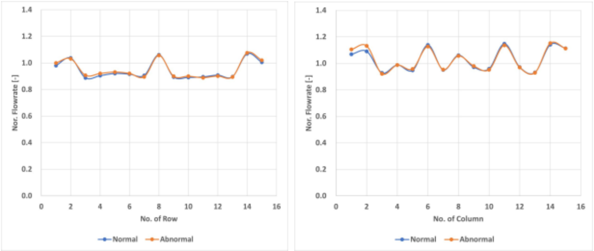


Fig. 6. Predicted normalized mass flow rate in the mid-row and mid-column lines

The standard deviation of velocity in the downcomer decreased by about 1.3 from upstream to downstream in the equilibrium operating condition. It decreased by about 0.7 even in the non-equilibrium operating condition. In other words, it becomes uniform as the cooling water moves downstream.

The core flow distribution was predicted under normal and abnormal operating conditions (Fig. 5 and Fig. 6). Similar normalized inlet flow distribution in the APR-type reactor under abnormal operating conditions was predicted with the flow distribution under the normal operating condition despite different cooling water supply conditions.

4. Conclusions

In this study, the effect of the balanced and imbalanced cooling water supply on the core inlet flow distribution of an APR-type reactor was investigated using CFD analysis. The results of this study showed little changes in the normalized core inlet flow distribution under two conditions, while the velocity of the cooling water was distributed differently in the downcomer, which is the area around the entrance. The complex structure in the bottom area of the reactor (lower structure and flow skirt) may contribute to eliminating the effects of different cooling water supplies. Therefore, in future research, we plan to investigate in detail changes in the flow characteristics before the lower structure region.

Acknowledgement

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