Investigation of Effect of ECC Core Barrel Duct on Core Flow in APR-Type Reactor : A Comparative Study of Numerical and Experimental Results

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1. Introduction

The distribution of flow within a reactor core is crucial for the safe and efficient operation of nuclear power plants. Consequently, reactors are designed to obtain an optimal core flow distribution. Then, the designs are evaluated using experimental and numerical methods to validate the core flow distribution. Scaled-down models are commonly used for experimental study, and computational fluid dynamics are generally used for the numerical approach.

APR+ (Advanced Power Reactor Plus) is being developed in Korea as an improved nuclear power reactor with 1,500 MW [1, 2]. In the reactor, an ECBD (ECC (Emergency Core Cooling system) Core Barrel Duct) has been designed to minimize the direct bypass of safety injection flow to the break during the late reflood phase [3]. While the ECBD was designed for emergency conditions, it should not disrupt core flow distribution. In this study, we investigated changes in core flow distribution caused by the installation of ECBD.

2. Materials and Methods

Two distinct Computational Fluid Dynamics (CFD) models of the APR-type reactor were developed using high-fidelity three-dimensional Computer-Aided Design (CAD) models that accurately represent the reactor's geometry. **These CAD models were converted into computational meshes suitable for CFD analysis. After the convergence test, approximately 40 million tetrahedral meshes were used for modeling [4]. In regions where complex fluid flow was expected, such as the flow skirt and lower plenum, finer meshes were used for more accurate analysis.** The first model excluded the ECBD to establish a baseline flow distribution, while the second model included the ECBD to analyze its impact on core flow (Fig. 1).

The choice of turbulence model is critical for accurate simulation of flow within nuclear reactors. For this study, the K-epsilon turbulence model was selected based on its balance between computational efficiency and accuracy in predicting turbulent flow characteristics [4]. Simulations were conducted using the commercial CFD software package ANSYS-CFX 18.0. The core flow distribution was predicted under normal operating conditions of the APR-type reactor using two different CFD analysis models. The results were then compared with experimental data obtained from **a small-scale model. A small-scale hydraulic test model of the APR-type reactor was developed, incorporating 177 fuel assemblies. Hydraulic tests were conducted to investigate the flow distribution to these assemblies, and these tests were performed under scaled normal operating conditions that mirrored those used in the numerical analysis.**

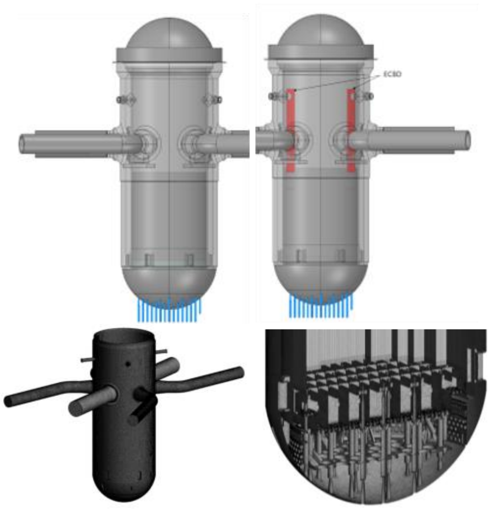


Fig. 1. 3D CAD and CFD models of the APR-type reactor

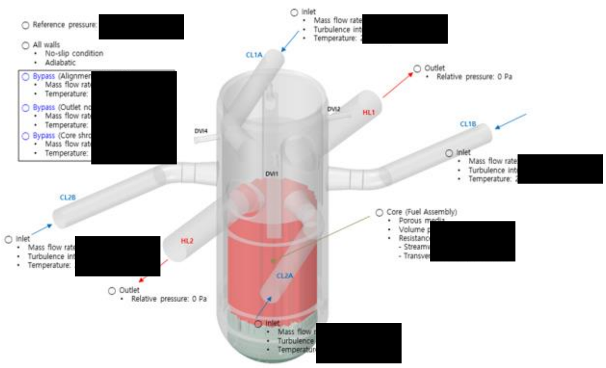


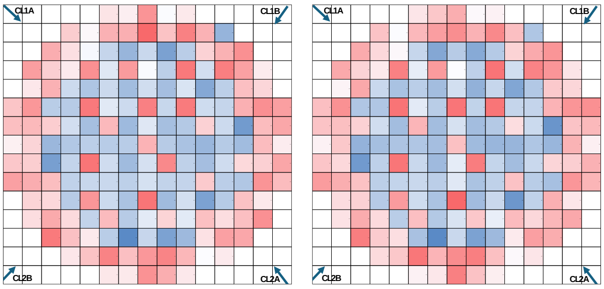
Fig. 2. Analysis conditions for simulating normal operation condition of the APR-type reactor
(Some values were hidden due to confidentiality issues.)

3. Results

When the ECBD was not installed, the predicted flow velocity on the outer region was higher compared to the velocity in the center region. The maximum velocity was higher than the average value by 16%, and the minim value was lower than the average by 16%. The standard deviation of the core flow velocity was about 8% (Fig. 3, left). The similar core flow distribution was predicted in the model with ECBD (Fig. 3).

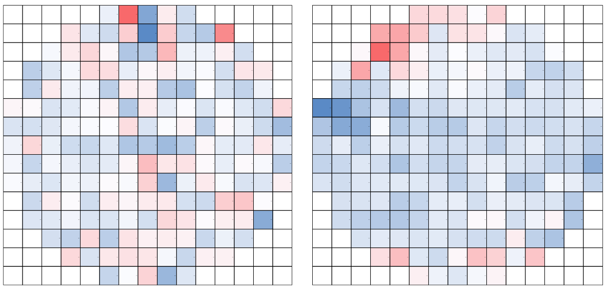
Installation of the ECBD results in slight changes in core flow distribution. The maximum increase and decrease of core flow caused by the installation of ECBD were only 5% and 4%, respectively. Also, 1.1% of the standard deviation was predicted in the difference in core flow by installing ECBD in CFD results. The experimental results showed similar results. Maximum increase and decrease of core flow were 3% and 2%, respectively. Only 0.6% of the standard deviation in the changes in core flow by installing ECBD was calculated (Fig. 4).

Three channels showed differences greater than 3% between the two models when ECBD was installed in the CFD analysis results. Of the 177 channels, 122 exhibited differences of less than 1%. Experimental results showed that less than 1% of differences were measured in 161 of 177 channels (Fig. 5). Both CFD analysis and experimental results showed little effect of ECBD installation on core flow distribution.



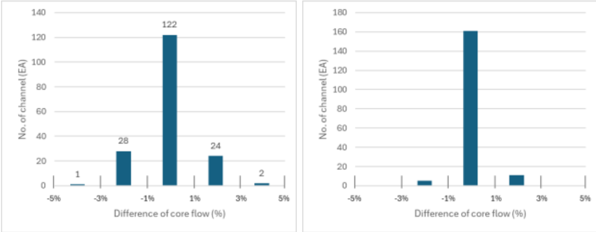
Without ECBD With ECBD

Fig. 3. Distribution of the normalized core flow in the models without ECBD (left) and with ECBD (right)



CFD Experiment

Fig. 4. Changes in core flow caused by installation of ECBD, CFD (left) and experiment (right)



CFD Experiment

Fig. 5. Predicted normalized mass flow rate in the mid-row and mid-column lines using five different grid systems

4. Conclusions

In this study, core flow distribution was predicted using CFD analysis in the APR-type reactor models with ECBD and without ECBD. The results showed that ECBD doesn't affect core flow distribution. The experimental study using a small-scale model also revealed that the ECBD effects were neglectable on the aspect of core flow distribution. Thus, the numerical results showed good agreement with the experimental results, and the core flow is well distributed in the APR-type reactor regardless of the installation of the ECBD. These results could be useful for designing the APR-type reactor as well as the installation of ECBD in different types of reactors.

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