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Preliminary CFD Simulations for an Abnormal Phenomenon in Liquid Zone Control System

Kwangho Lee[a*], Joon-suk Ji[b]
[a] *Korea Electric Power Research Institute, 65 Munjiro Yuseong Daejeon, 305-380 Korea*
[b] *College of Advanced Technology Nuclear Eng., Kyunghee University*
[*] *Corresponding author: khlee1@kepri.re.kr*

1. Introduction

Liquid Zone Control System (LZCS) is one of the reactivity control mechanisms of CANDU reactor intended to regulate the excessive power tilt in a certain zone. The regional power tilt is regulated by controlling the inventory of light water (H_2O) in a compartment, which is used to absorb neutrons. However, when a positive reactivity insertion such as fuel replacement occurs, both local reactor power and water level of the LZCS compartment in the outer top regions of reactor surge, oscillate at a certain frequency for a certain period of time, and drop unstably.

An abnormal phenomenon of the light water hold-up on the Tube Support Plate (TSP) installed in the LZCS compartment was found through the experimental simulation. Then, the feasibility of experimental results is evaluated by computational fluid dynamics analysis in this study.

2. CFD Analysis for an Abnormal Phenomenon

As shown in the experimental simulations, unstable operation in the LZCS compartment is due to the hydrodynamic phenomena associated with the two phase flow of water and air in the reduced-flow area of the tube support plate. Then, CDF analysis is useful to benchmark the experimental results because it is difficult to evaluate the microscopic behavior of two phase flow and the pressure distribution in the compartment by the experiments.

ANSYS CFX software is used in this study, which is powerful to solve multiphase flow problems fast and reliably.

2.1 Governing Equations

The fluid characteristics of water and air in the compartment are simply defined as isothermal, incompressible and turbulent. There is a free surface between water and air in the compartment. Non-homogeneous two-fluid model is applied because each fluid has its own velocity.

In case of low Reynolds number, k-ω based shear stress transport model is used as a turbulence model, which is readily applied to the boundary layer and well-predicted for two phase flow and separation.

① Continuity equation

$$\frac{\partial (r_\alpha \rho_\alpha)}{\partial t} + \nabla \cdot (r_\alpha \rho_\alpha U_\alpha) = S_{MS_\alpha} + \sum_{\beta=1}^{N_p} \Gamma_{\alpha\beta}$$

② Momentum equation

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha U_\alpha) + \nabla \cdot (r_\alpha (\rho_\alpha U_\alpha \otimes U_\alpha))$$
$$= -r_\alpha \nabla p_\alpha + \nabla \cdot (r_\alpha \mu_\alpha (\nabla U_\alpha + (\nabla U_\alpha)^T)) + \sum_{\beta=1}^{N_p} (\Gamma_{\alpha\beta}^{+} U_\beta - \Gamma_{\beta\alpha}^{+} U_\alpha) + S_{M\alpha} + M_\alpha$$

③ Turbulence dissipation equation

- k equation

$$\frac{\partial (\rho k)}{\partial t} + \nabla \cdot (\rho U k) = \nabla \cdot [(\mu + \frac{\mu_t}{\sigma_k}) \nabla k) + P_k - \beta' \rho k w$$

- ω equation

$$\frac{\partial (\rho w)}{\partial t} + \nabla \cdot (\rho U w) = \nabla \cdot [(\mu + \frac{\mu_t}{\sigma_w}) \nabla w) + \alpha \frac{w}{k} P_k - \beta \rho w^2$$

④ Inter-phase momentum transfer

$$M_\alpha = \sum_{\beta \neq \alpha} M_{\alpha\beta}$$

$$M_{\alpha\beta} = M_{\alpha\beta}^{D} + M_{\alpha\beta}^{L} + M_{\alpha\beta}^{LUB} + M_{\alpha\beta}^{VM} + M_{\alpha\beta}^{TD} + M_S + \ldots.$$

2.2 Analysis Modeling

Three dimensional model for ANSYS CFX analysis is written by ANSYS Workbench. 1/2 model of prototype is used and symmetric boundary conditions are applied to save the analysis time.

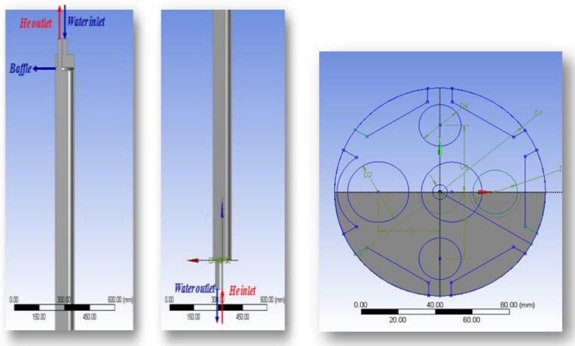

Fig. 1 Models for top, bottom and symmetry of LZC

Tetra meshes for a whole compartment are generated by ANSYS ICEM-CFD and prism meshes for boundary layer are generated to simplify.

2.3 Boundary Conditions and Initial Conditions

One unstable condition from the experimental results of LZCS is selected for boundary conditions and initial conditions. (Fig. 2) Free surface model and multiphase volume coupled model are used in this simulation.

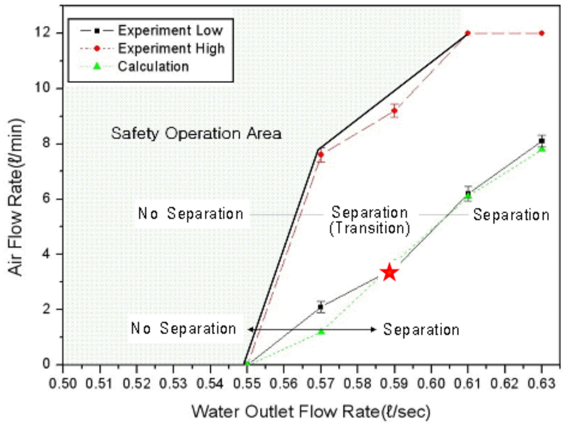

Fig. 2 A Selected condition from the unstable operation region

2.4 Analysis Results

The compartments are initially filled with light water at the level of 2.3m from the bottom and with atmospheric air in the top. Water flows in from the top, along the inner wall and out through the bottom of compartment. Conversely, a certain volume of air flows in from the bottom of compartment and out through the top.

After 6 seconds, air volume starts to stagnate at the bottom of the tube support plate in the compartment. Finally, a certain volume of air is stagnated, that is considered a separation of two fluids, under the tube support plate while the water flow through the tube support plate is continuously decreased. (Fig. 3)

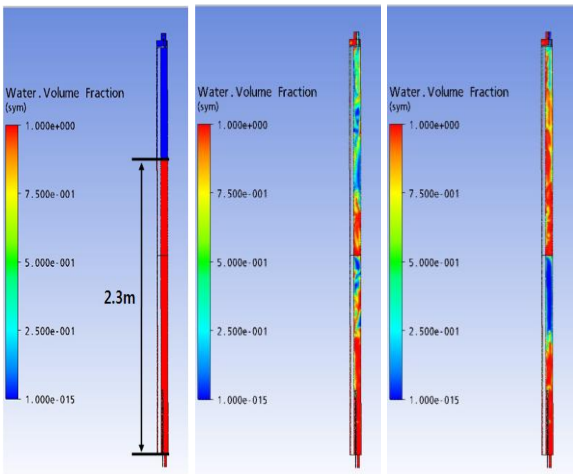

Fig. 3 Variation of water volume fraction

As shown in Fig. 4, it is found that a small amount of water still flows through the tube support plate at 6 seconds. However, there are a less streamlines for outgoing through the tube support plate than ones for incoming from the top. Then, almost no streamline through the tube support plate is shown at 12 seconds and the level of stagnated water in the top of tube support plate increases.

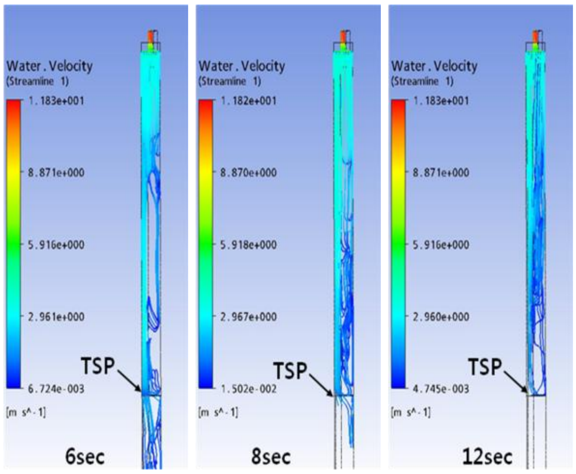

Fig. 4 Water velocity and streamlines

3. Conclusions

The results of ANSYS CFX simulations by using the shear stress transport model are very similar to the experimental simulations, that is water does not flow well through the tube support plate because of air stagnation under the tube support plate. Thus, ANSYS CFX software predicts well the unstable phenomenon occurred in the LZCS compartment.

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