Grid Sensitivity Test for STERN Experiment by using the CUPID Code

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1. Introduction

When the cooling system of fuel channel fails in CANDU reactor, the moderator may function as to remove decay heat which occurs in the fuel. During a LOCA, the pressure tube could strain to contact its surrounding the Calandria tube, leading to sustained C/T dry out in the case of low subcooling in the moderator system. So, precise prediction of the flow in the Calandria vessel of a CANDU reactor is very important. But, it is possible to measure the local temperature only in the inlet/outlet region of the moderator of the Calandria vessel. Therefore, in order to predict the local temperature, the extensive experiments and calculations have been conducted [1].

In previous study, the CUPID code was validated against the STERN experiment using a two-dimensional grid. In this study, the previous two-dimensional analysis was extended to a three-dimensional analysis and, thus, a grid sensitivity calculation was performed. The three-dimensional grid was based on the two-dimensional grid. The nominal case of experiment performed at STERN Laboratories Inc. was used in this calculation.

2. Mathematical Model

2.1 Governing Equations

To simulate two-phase flow, CUPID code adopts a transient two-fluid, three-field model. The three-fields represent the liquid, droplet and vapor. The mass, energy, and momentum equations are established as each field separately and each field is linked by the interfacial mass, energy, and momentum transfer models. The continuity, momentum, energy and conduction equations for the k-phase are given by [2]

$$\frac{\partial}{\partial t}(\alpha_k \rho_k) + \nabla \alpha_k \rho_k \underline{u}_k = \Gamma_k \tag{1}$$

$$\frac{\partial}{\partial t}\alpha_k \rho_k \underline{u}_k + \nabla \cdot (\alpha_k \rho_k \underline{u}_k \underline{u}_k) = -\alpha_k \nabla P + \alpha_k \mu_k \nabla \underline{u}_k + \alpha_k \rho_k \underline{g} + S_k \tag{2}$$

$$\frac{\partial(\alpha_k \rho_k e_k)}{\partial t} + \nabla \cdot (\alpha_k \rho_k e_k \underline{u}_k) = -P\frac{\partial \alpha_k}{\partial t} - P\nabla \cdot (\alpha_k \underline{u}_k) + \alpha_k k_{c,k} \nabla T_k + E_k \tag{3}$$

where α_k, ρ_k, u_k, P, Γ_k, and e_k are the k-field volume fraction, density, velocity, pressure, an interface mass transfer rate, and energy transfer rate, respectively. S_k represents the interfacial momentum transfer due to a mass exchange, a drag force, and non-drag forces. E_k includes the phase change, interfacial heat transfer, wall heat transfer, and volumetric heat source. For a mathematical closure of the system of equations, constitutive relations and the equation of state are included.

2.2 Frictional Pressure drop model

Pressure drop model for a porous media zone is needed to accurately simulate the flow behavior in the Calandria vessel. The hydraulic resistance consists of two factors: the attack angle between the flow direction and the tube axis. In the tube bundle region, the frictional pressure drop for the cross flow is represented as follows [3];

$$PLC = \frac{\Delta P}{N_f \cdot \rho \cdot v_{fs}^2/2} = 4.54 \cdot Re^{-0.172} \tag{4}$$

where $V_{fs} = \varepsilon V = \varepsilon\sqrt{\sum u}$

$$\left.\frac{\Delta P}{\Delta L}\right)_{CROSS-FLOW} = \frac{PLC}{p \cdot cos\theta} \cdot \rho \frac{(\gamma V)^2}{2} \cdot (s_v/s_{90})$$

where the ratio of the pressure drop of (s_v/s_{90})can be expressed as a function of attack angle. For axial flow, the hydraulic resistance could be expressed by the conventional correlations for the pressure drop in a cylindrical pipe;

$$\left.\frac{\Delta P}{\Delta L}\right)_Z = \frac{\Delta P}{\Delta z} = \frac{f\rho u_z^2}{2D_e} \tag{5}$$

where $f = 0.316Re^{-0.25}$.

3. Modeling of the STERN Experiment

The moderator test vessel of the STERN facility is a cylinder with a diameter of 2 m and width of 0.2 m as depicted in Fig. 1. In the core region, there is a matrix of 440 inconel heating elements with a total power of 100kW. The coolant inlet nozzle is 6 mm in width and the outlet nozzle is 15 mm in width.

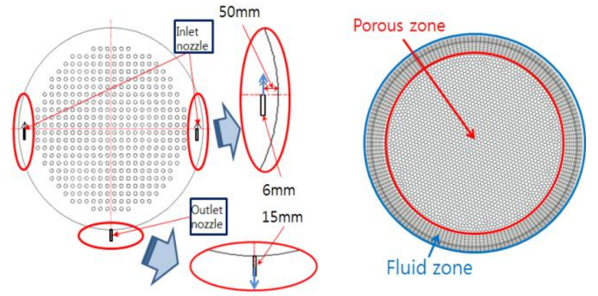

Fig. 1. Schematics of STERN experiment and grid omputation

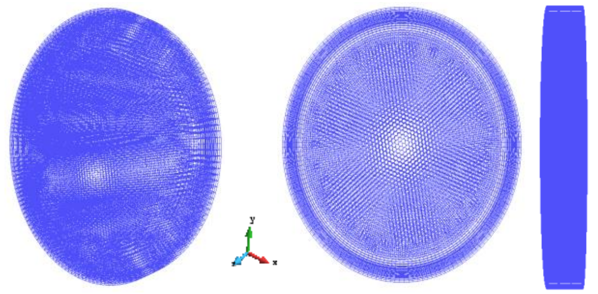

Fig. 2. 3D grid system for STERN experiment

In this study, the three-dimensional grid was developed using a two-dimensional grid of the previous study[4,5,6]. In order to calculate the grid sensitivity, the number of the grid is consists of 4000, 7000, 10000 as two-dimensional and 3~5 layers in the thickness direction, which is a combination of polyhedral mesh and bent structured mesh as shown in Fig. 2. The porosity of the porous media region is 0.832.

4. Results and Discussion

The calculation of grid sensitivity was performed at the nominal condition. For the nominal condition, the total flow rate at the inlet nozzle is 2.4 kg/s, the corresponding inlet velocity is 1 m/s, and the inlet temperature of moderator is 55 ℃. And total thermal power of the heaters is 100 kW.

The grid sensitivity analysis for the cross section (x-y plane in Fig. 2) and the layer (z-direction in Fig. 2) was carried out.

The results of the grid sensitivity calculation for the cross section indicated that the calculated temperature using 7000 meshes converges in the same trend as the previous two-dimensional calculation. For the layer, the low overall temperature distribution was formed when using the 3 layers. And when the number of layer was greater than 5 layers, the calculated maximum temperature was corresponded with the different data regardless of the number of the grid in the cross-section. It is based on the flow on the axial direction. In two-dimensional analysis, a hydrodynamic resistance is only considered for the cross-flow. However, in the three-dimensional analysis, although the mesh of the cross section is smaller than in the two-dimensional analysis,

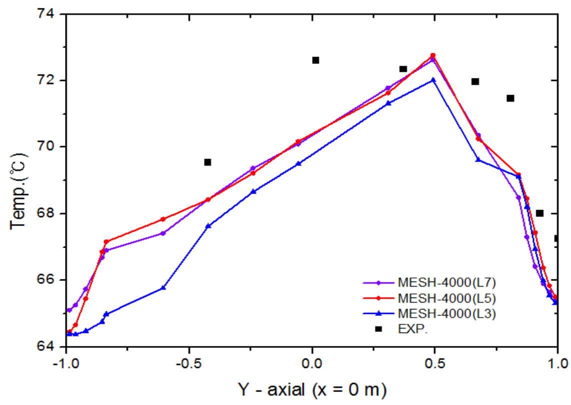

Fig. 3. Sensitivity analysis on the number of the layer for the nominal case

the temperature increases due to the effects of the resistance of cross and axial flow. Thus, grid sensitivity analysis shows that the two-dimensional plane(cross direction) 7000 grids and the axial direction 5 layers are sufficient for STERN simulation to avoid mesh effects.

5. Conclusions

The applicability of the CUPID code to the CANDU moderator system analysis has been evaluated. In this study, the empirical pressure drop model for a porous media was implemented into the CUPID code first for a three-dimensional analysis. Then, three-dimensional grid sensitivity tests were performed, which is based on the previous two-dimensional analysis. It was shown that the maximum temperature is getting lower as decreasing the number of total grids. As a result, the three-dimensional grid of 7000 meshes in the cross section and 5 layers in the axial direction is proper.

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