Preliminary Study of CANDU-6 Moderator Temperature Prediction by using the CUPID Code

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1. Introduction

Accurate prediction of the flow in the Calandria vessel of a CANDU reactor is very important in terms of heat removal during a loss of coolant accident. In this study, we have validated the CUPID code using the single-phase flow experiments that were performed at Stern Laboratories Inc. The analysis has been further extended to two-phase flow conditions. This was carried out to confirm the applicability of CUPID to single- and two-phase flow analyses of the CANDU moderator system [1, 2].

2. Mathematical Model of the CUPID Code

2.1 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. In the tube bundle region, the frictional pressure drop for the cross flow is represented as follows [3];

$$PLC = \frac{\Delta P}{N_f \cdot \rho \cdot v_{fs}^2/2} = 4.54 \cdot Re^{-0.172} \qquad (1)$$

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

For axial flow, the hydraulic resistance could be expressed by the conventional correlations for the pressure drop in a cylindrical pipe;

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

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

3. Simulation of the STERN experiment

The test vessel of the STERN facility is a cylinder with a diameter of 2 m and width of 0.2 m. 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.

The three-dimensional grid was developed from that of the previous study using a two-dimensional grid [4]. It consists of 5 layers of the two-dimensional grid in the thickness direction, which is a combination of polyhedral mesh and bent structured mesh as shown in Fig 1. The porosity of the porous media region is 0.832.

In the calculation using the three-dimensional grid, it was found that the momentum flux distribution is relatively sensitive to the number of computational cells.

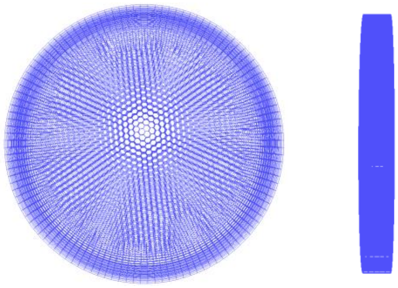

Fig. 1 Computational domain and grid system

4. Results and discusses

Two STERN experiments were used for the validation of the CUPID code; Isothermal and nominal condition tests.

4.1 Isothermal condition

In the isothermal condition, the inlet mass flow rate is 2.4 kg/s and all the heaters are off. The flow from the inlet nozzles goes up along the inner circular wall and stagnation point is formed at upper flow. Since there is no thermal load, the flow pattern showed exact y-axis symmetry as shown in the Fig. 2.

Fig. 3 shows the vertical velocity component from the vertical centerline. The calculation results tend to low estimate the downward velocity like two-dimensional calculation. Fig. 4 shows the tangential velocity along the radial coordinate at 60 degree. The results of CUPID are reasonably accurate. In general, The results of the 2D and 3D calculations were almost the same with each other [4].

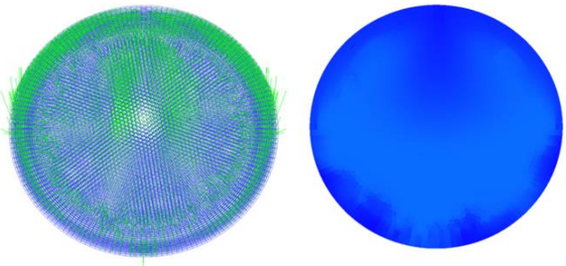

Fig. 2 Velocity vector and temperature for isothermal case

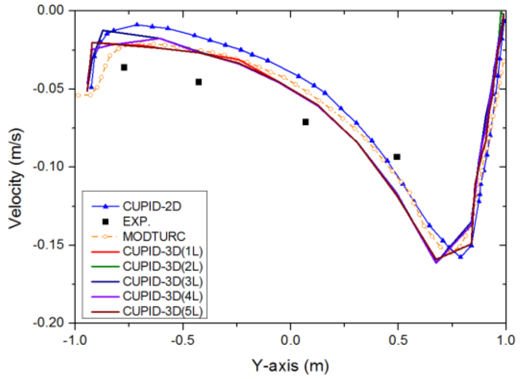

Fig. 3 Vertical velocity profile for isothermal case

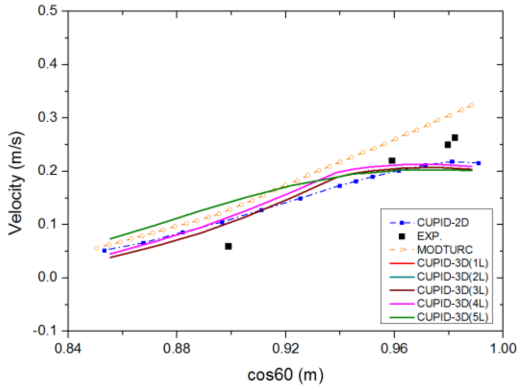

Fig. 4 Vertical velocity profile for the isothermal case

4.2 Nominal condition

For the nominal condition, the total flow rate from inlet nozzle is 2.4 kg/s, the corresponding inlet velocity is 1m/s, and the inlet temperatures of moderator are 55℃. Total thermal power of the heaters are 100 kW. In the results of the nominal condition calculation, a flow asymmetry is observed; Fig. 3 shows the contours of the velocity vector and liquid temperature distribution. The flow pattern of nominal condition is found to be mixed flow regime.

Fig. 6 and Fig. 7 show the temperature distribution along centerline of the y-axis and a horizontal line at y=0.57 m, respectively. In the lower center region, the CUPID code predicts a lower temperature than the experiment and that of the two-dimensional calculation. However, it can be said that the results of the three-dimensional calculation showed good agreement with the experiments and the two-dimensional results [4].

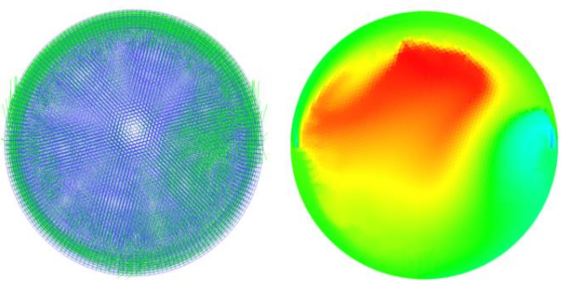

Fig. 5 Velocity vector and temperature for the nominal case

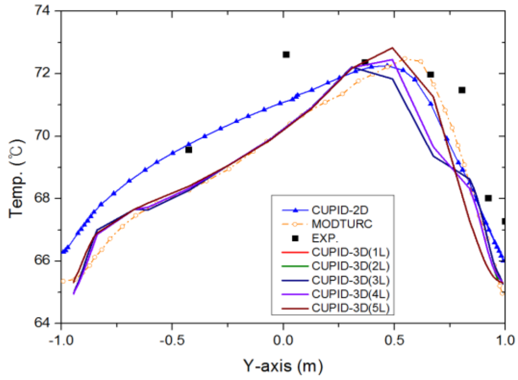

Fig. 6 Vertical profile of temperature at x=0

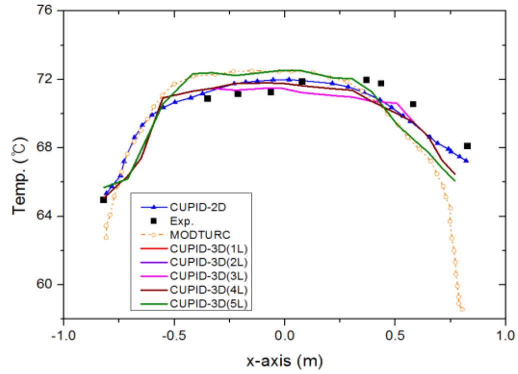

Fig. 7 Horizontal profile of temperature at y=0.57 m

5. Conclusions

In this study, the CUPID code was validated using the two experiments that had been performed at the STERN Lab. A three-dimensional grid was used for the calculations, meanwhile, a two-dimensional grid was used in the prevoius study. The calculation results showed good agreement with the experiments and those of the two-dimensional calculations. It can be said that the CUPID code can be applied to single-phase flow analyses of the CANDU moderator system.

ACKNOWLEDGMENTS

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