Comparison of CFD Simulations of Moderator Circulation Phenomena for a CANDU-6 Reactor and MCT Facility

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1. Introduction

Prediction of the local temperature distribution of a moderator in the CANDU-6 moderator tank (Calandria) is essential to assess the channel integrity during a loss of coolant accident without emergency core cooling in a CANDU-6 reactor. The Korea Atomic Energy Research Institute is constructing a Moderator Circulation Test (MCT) facility [1] to simulate thermal-hydraulic phenomena in a 1/4 scale-down moderator tank similar to that in a prototype power plant during steady state operation and accident conditions.

In the present study, two numerical CFD simulations for the prototype and scaled-down moderator tanks were carried out to check whether the moderator flow and temperature patterns of both the prototype reactor and scaled-down facility are identical.

2. Test Facility

2.1 Scaling of MCT

According to the previous scaling analysis [2], the moderator tank of the MCT is scaled-down to preserve the dimensionless number, ***Ar***, which is defined as

$$Ar = g\beta_{ref}\,\Delta T D\,/\,U_i^2, \tag{1}$$

where

β_{ref} = reference thermal expansion coefficient(1/K),
g = gravity constant (m/s^2),
ΔT = temperature rise (^{o}C),
D = vessel diameter (m),
U_i = area-average velocity at the inlet deflector (m/s).

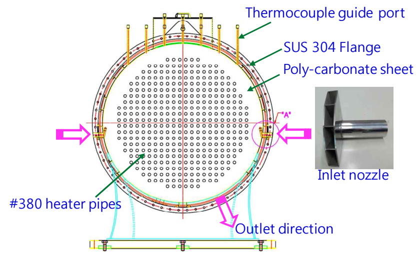
The MCT facility was reduced to a 1/4 scale. The present simulation was performed for a power supply capacity of 493 kW as compared to 100MW for the prototype. Table 1 shows the main design parameters for the prototype and scaled-down model.

2.2 Design features of MCT

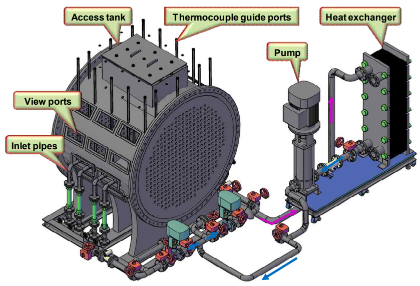
The MCT consists of the same primary and secondary water circuits as in the CANDU6 moderator system. The primary circuit, as shown in Fig. 1, includes a moderator tank, a circulating pump, a heat exchanger, and intermediate pipe lines. The circulating pump forces the cold water to enter the tank through eight nozzles, four nozzles on each side, and heated water exits from two outlet pipes at the bottom of the tank. When water flows through the heat exchanger tubes, primary hot water is cooled by the secondary side water circulating through the external cooling tower. Cold water then returns to the inlet nozzles through a circulating pump.

Table 1: Main design parameters for the prototype and MCT

Model	Prototype (CANDU-6)	1/4 scale (MCT)
Heating power	1×10^5 kW	493 kW
Tank diameter (D)	7.6 m	1.9 m
Temperature rise (ΔT)	23 ^{o}C	8 ^{o}C
Tube (heater) diameter	0.131 m	0.033 m
Tube pitch	0.286 m	0.072 m
Number of tubes	380	380
β_{ref}	5.0×10^{-4} K^{-1}	3.76×10^{-4} K^{-1}
Inlet velocity (U_i)	2.034 m/sec	0.517 m/sec
Archimedes number (Ar)	0.21	0.21



(a) Cross sectional view of the moderator tank



(b) Overview of test facility

Fig. 1. Geometric configuration of the MCT test faciltiy.

3. CFD Model

3.1 Computer code

A commercial CFD code, ANSYS CFX version 14.0, is used to simulate the prototype and MCT under normal operating conditions.

3.2 Mesh generation

ICEM CFD version 14.0 is used to generate the mesh of the moderator tank and boundary surfaces. A hexagonal mesh (around the tube region) and unstructured mesh (inlet nozzle region) are combined to produce a total of 638,000 and 658,000 mesh elements for the prototype and scaled-down model, respectively. The prototype and scaled-down model use the same mesh model except the step end region.

(a) Prototype (CANDU-6)

(b) Scaled-down model (MCT)

Fig. 2. Mesh configuration for the prototype and scaled-down model.

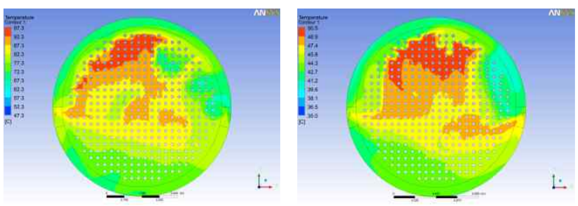
3.3 Boundary conditions

The flow boundary condition is applied to eight inlet surfaces, and the outlet boundary condition is applied to two outlet surfaces. The moderator enters the Calandria through each inlet nozzle at a velocity of 4.0 and 1.0 m/s for the prototype and scaled-down model, respectively. The volumetric heat source is set to the fluid domain. The axial power profile is a symmetric cosine profile with a peak-to-average ratio of 1.4. A radial power profile is simplified into two concentric power zones, with a heat power ratio of 1.4 between the inner and outer zones.

4. Calculation Results

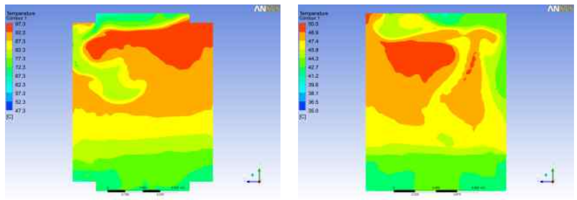
4.1 Temperature distribution

Each simulation was carried out with 3,000 iterations from the initial conditions. The results of the temperature and velocity profiles are unsteady but show a unique pattern. Figure 3 shows the temperature distribution inside the moderator tank for the CANDU-6 and MCT. The temperature contours for both cases show a typically asymmetric pattern, which is called a mixed-flow pattern owing to a balance of inertial momentum and buoyancy forces.



(a) CANDU-6 (b) MCT

Fig. 3. Temperature distribution on the axial center plane.

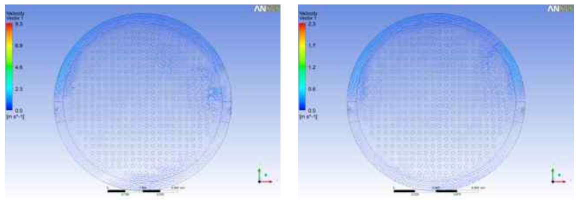


(a) CANDU-6 (b) MCT

Fig. 4. Temperature distribution along the axial direction.

4.2 Velocity distribution

The velocity vectors for the prototype and scaled-down model are compared in Fig. 5. The impingement point is located at the top right hand side of the tank for both cases.



(a) CANDU-6 (b) MCT

Fig. 5. Velocity vector on the axial center plane.

5. Conclusions

Two different sets of simulations of the moderator circulation phenomena were performed for a CANDU-6 reactor and MCT facility. The results of both simulations were compared to study the effects of scaling on the moderator flow and temperature patterns.

There is no significant difference in the results between the prototype and scaled-down model. It was concluded that the present scaling method is properly employed to model the real reactor in the MCT facility.

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[2] B.W. Rhee, H.T. Kim, S.K. Park, J.E. Cha, and H.L. Choi, A Scaling Analysis of a CANDU-6 Moderator Tank Scaled-down Test Facility, Proceedings of the 21th International Conference on Nuclear Engineering (ICONE21), July 29-August 2, 2013, Chengdu, China.