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# Status of the Moderator Circulation Tests at Korea Atomic Energy Research Institute

Hyoung Tae Kim*, Bo Wook Rhee, Jae Eun Cha, Hwa-Lim Choi
*Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea, 305-353*
**Corresponding author: kht@kaeri.re.kr*

## 1. Introduction

The Korea Atomic Energy Research Institute (KAERI) started experimental research on moderator circulation as one of its national R&D research programs in 2012. In the present paper, we introduce a scaling analysis performed to extend the scaling criteria suitable for reproducing thermal-hydraulic phenomena in a scaled-down CANDU-6 moderator tank, 1/40 and 1/8 small-scale model tests to identify the potential problems of the flow visualization and measurement in the main 1/4 scale MCT (Moderator Circulation Test) facility, a manufacturing status of the 1/4 scale moderator tank, and preliminary CFD analysis results to determine the flow, thermal, and heating boundary conditions with which the various flow patterns expected in the prototype CANDU-6 moderator tank can be reproduced in the experiment.

## 2. Scaling Analysis

The purpose of the present scaling analysis is to derive a set of scaling criteria suitable for reproducing thermal-hydraulic phenomena in a scale-down CANDU moderator tank similar to that in a prototype power plant during steady state operation and accident conditions [1,2].

### *2.1 Scaling Criteria*

According to a previous study by Khartabil et. al [1], the following dimensionless parameters from governing equations can be derived as follows:

$$\mathrm{Pr} = \mu\, C_p / k, \quad (1)$$

$$\mathrm{Re} = \rho_{ref}\, U_i D / \mu, \quad (2)$$

$$\mathrm{Ar} = g\beta_{ref}\, \Delta T D \, / \, U_i^2, \quad (3)$$

$$q^* = \frac{qD}{\rho_{ref}\, C_p U_i \Delta T}, \quad (4)$$

### *2.2 Scaling Procedure*

The scaling of the moderator is used to determine the tank size, nozzle size, heater power, inlet mass-flow rate, inlet, and outlet temperature of the calandria. Given the geometry scaling at the beginning of scaling, the scaling can be done to determine the heater power, mass-flow rate, and inlet and outlet temperatures.

1) For example, all linear dimensions are scaled simply by the same factor of 1/4.
2) Choose an appropriate $\Delta T = T_{out} - T_{in}$ as high as possible for the best measurement resolution while keeping within the pumping and heating constraints.
3) Using the similarity of Ar number of the prototype, calculate the velocity in the nozzle of the model with the scaled nozzle diameter by the following scaling ratio of the inlet velocity ($U_i$),
$$U_R = \left(\frac{\beta_R \Delta T_R D_R}{Ar_R}\right)^{0.5}$$
4) Calculate the power of the scaled-down model using the energy balance equation and ΔT. Check whether the power of the model is available in the power supply system for the test facility.

### *2.3 Scaling Results*

According to the present scaling procedures, the main design parameters for the small-scale 1/40 and 1/8 test facilities and main 1/4 scale MCT test facility can be determined as shown in Table 1. All scaled-down models are preserving the dimensionless parameters of Ar and q* [2]. For the 1/40 scaled-down model, the porosity value is maintained, while the tube diameter and tube pitch are not linearly scaled owing to the geometric limitation of the manufacturing and flow visualization.

Table 1: Main design parameters for the prototype and scaled-down models

| Model | CANDU-6 (prototype) | 1/40 scale | 1/8 scale | 1/4 scale |
|---|---|---|---|---|
| Heating power (kW) | $1\times10^5$ | 1.839 | $2.146\times10^2$ | $1.560\times10^3$ |
| Tank diameter (m) | 7.6 | 0.181 | 0.98 | 1.9 |
| Area of an inlet nozzle (m$^2$) | $5.7456\times10^{-2}$ | $3.258\times10^{-5}$ | $9.506\times10^{-4}$ | $3.591\times10^{-3}$ |
| ΔT (°C) | 23 | 10 | 15 | 17 |
| Calandria tube diameter (m) | 0.131 | 0.017 | 0.017 | 0.033 |
| Tube pitch (m) | 0.286 | 0.037 | 0.037 | 0.072 |
| Number of tubes | 380 | 12 | 380 | 380 |
| Ar | 0.21 | 0.21 | 0.21 | 0.21 |
| q* | 0.013 | 0.013 | 0.013 | 0.013 |
| Porosity | 0.83 | 0.83 | 0.83 | 0.83 |
| Inlet velocity (m/sec) | 2.034 | 0.163 | 0.454 | 0.780 |

## 3. Scaled-down Test Facilities

### *3.1 Small- Scale Tests for Optical Measurements*

Small-scale test facilities with scaled-down ratio of 1/40 (Fig. 1) and 1/8 (Fig. 2) are installed for the feasibility study of optical measurements [3] such as PIV (Particle Image Velocimetry) and LIF (Laser Induced Fluorescence).

The 1/40 scale moderator tank with an inner diameter of 0.2 m consists of 12 electric heaters with a 17.3 mm outer diameter and 3 kW design power.

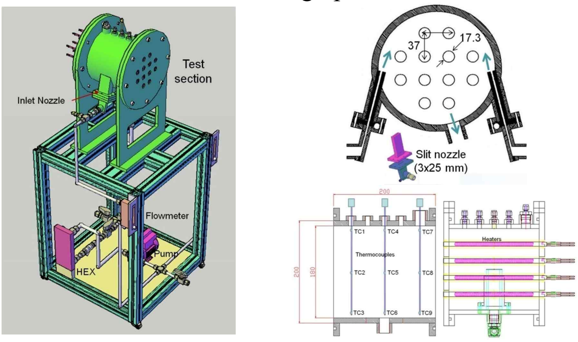


Fig. 1. Configuration of the 1/40 scaled-down model.

The 1/8 scale moderator tank has a cylindrical shape with an inner diameter of 0.98 m and a slice-type calandria modeling only a quarter of the axial configuration of the prototype.

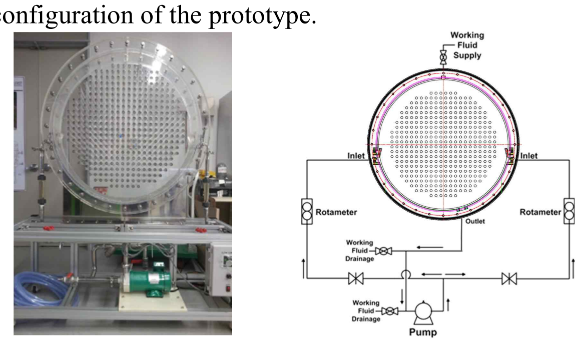


Fig. 2. Configuration of the 1/8 scaled-down test facility.

### *3.2 1/4 Scale Moderator Circulation Test (MCT)*

Following the geometric scaling results in Table 1, the 1/4 scale moderator tank was designed and manufactured. The primary circulation loop will be installed and optical measurements will be performed.

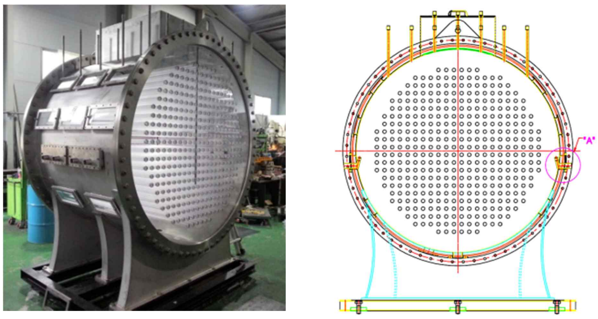

Fig. 3. Configuration of the 1/4 scale moderator tank of MCT facility.

## 4. CFD Analysis

Optical measurement results in the ¼ scale test facility will be compared with the CFD predictions. Figure 4 shows the grid modeling and preliminary calculation results for the moderator circulation in the calandria of CANDU6 using the ANSYS CFX code.

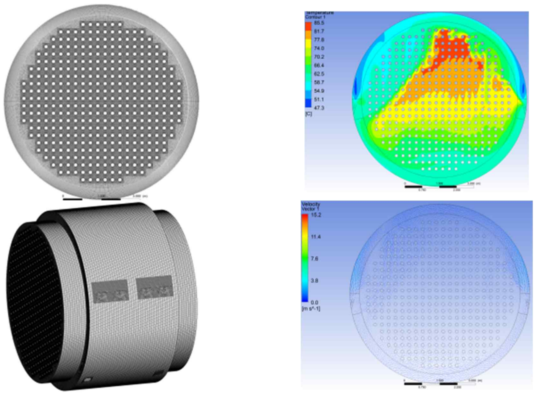

Fig. 4. Preliminary CFD analysis for moderator circulation in a calandria of CANDU6.

## 5. Conclusions

KAERI has launched an experimental program for moderator circulation in a CANDU6 reactor. The scaling analysis produced the design parameters of the MCT facility, and the manufacturing process is ongoing. The application of the optical fluid measurements to the MCT was preliminary tested by small scale test models.

The various flow patterns arising from a complex interaction between the buoyancy and inertia forces can be simulated in the MCT facility. In addition, the experimental results will be compared with the CFD results.

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