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Measurement of the Flow Pattern of the Moderator Circulation and Axial Heat Flux Profile of an Electric Heater for MCT at KAERI

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) started the experimental research on moderator circulation as one of a national R&D research programs from 2012. This research program included the construction of the Moderator Circulation Test (MCT) facility, production of the validation data for self-reliant CFD tools, and development of optical measurement system using the Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) techniques. So far non-heating isothermal flow pattern tests and numerous heating flow pattern tests up to maximum power of 167 kW under various flow rate and inlet temperature conditions have been carried out. Also, to identify the thermal boundary condition to the moderator, an electric heater for the CANDU-6 Moderator Circulation Test Facility was modified and refabricated to measure the axial heat flux distribution of it. This is to confirm how close the actual axial heat flux distribution of the electric heaters installed in MCT facility is to the axial heat flux of the electric heater as designed and installed for the MCT test, and to provide the accurate thermal boundary condition to the CFD simulations of the CANDU-6 Moderator Circulation Tests. The procedure how the electric heater for this test was designed and fabricated is described, and the preliminary assessment of the temperature difference across the S.S. pipe which serves as the heater outer sheath is presented, and the procedures how the holes for installing the thermocouple(TC)s are designed and installed and TC installation are described.

2. Motivation and Current Status

One of the important test boundary conditions that have not been confirmed is the axial heat flux profile of the electric heaters used. Normally the quality assurance(QA) of the electric heater heat flux profile was left to the heater manufacturers, but as the heater for MCT was fabricated by the local manufacturer, it was decided to set up an experimental facility where the axial heat flux of the heater that was installed at MCT can be measured. In this paper the current status of this test for measuring the axial heat flux of the heater is presented.

2.1 Identifying the Flow Pattern of Moderator Circulation as a function of Ar no.

The objective of the MCT experiment was to explore the flow patterns within the moderator circulation in a 1/4 scaled-down model of the CANDU-6 reactor. The scaling analysis was performed using Archimedes' number (Ar), which is the ratio of the buoyancy to the inertia[1]. PIV flow measurements are widely used as a nonintrusive flow field measurement technique to obtain detailed flow pattern data. The overall flow patterns were measured by iteratively changing the camera position to overcome the perspective limitations of the camera. The iteratively measured velocity data were merged into a unified dataset for analysis. The impingement positions of the inlet jet were measured under different inlet and heating conditions. The momentum-dominated flow patterns without buoyancy were measured under isothermal conditions (Ar = 0) to reveal an almost symmetric pattern at the center of the jet impingement position. The maximum downward velocity was obtained at the center of the jet impingement position. We measured the flow interactions within the moderators and the downward velocity by varying the tank position. The main measurement under heating was obtained assuming the mixed flow regime ($0 < Ar < 0.157$). The jet impingement position was found to be biased toward the side. The biased positions of the jet *impingement as a function of Ar were examined.*

The impingement position of the inlet jet was located at the center during isothermal experiments (Ar = 0) and was slightly biased by the asymmetric flow rate. The biased position was mainly influenced by imbalances in the inertial momentum of the inlet jet. Under heating conditions ($Ar > 0$), the impingement position was no longer located at the center, and the position was significantly biased. The bias direction was controlled by applying an artificial imbalance to the inlet flow rate, and the direction did not change significantly once the direction was fixed. The flow patterns during heating were measured as a function of Ar. The biased magnitude of the impingement position increased as Ar increased. The biased magnitude depended more strongly on the buoyancy effects than on the inertial effects in the range Ar > 0. Although imbalances in the inlet flow rate reversed, the bias direction did not change. The effects of the inertial momentum were negligible at higher values of Ar.

2.2 Preliminary CFD analysis for MCT test

Two numerical CFD simulations for the prototype and scaled-down moderator tanks are carried out to check whether the moderator flow and temperature patterns of both the prototype reactor and scaled-down facility are identical.

CFD model

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

Mesh generation

ICEM CFD version 14.0 [9] is used to generate the mesh of moderator tank and boundary surfaces. 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 as shown in Fig. 1.

(a) Prototype (CANDU6)

(b) MCT (scaled-down model)

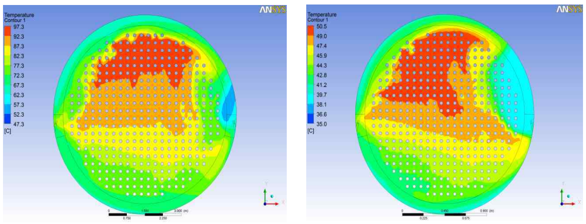
Fig. 1 Mesh configuration for the prototype and scaled-down model.

Boundary conditions

Flow boundary condition is applied to 8 inlet surfaces and outlet boundary condition to 2 outlet surfaces. Moderator enters the calandria with the velocity of 4.0 and 1.0 m/s through each inlet nozzle for prototype and scaled-down model, respectively. Volumetric heat source is set to fluid domain. An 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 cocentric power zones, with a heat power ratio of 1.4 between the inner and the outer zones.

Temperature distribution

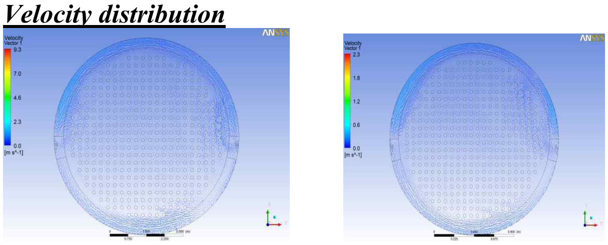
The results of temperature and velocity profiles are unsteady but show a unique pattern. Figure 2 shows the temperature distribution inside the moderator tank for CANDU-6 and MCT. The temperature contours for both cases show a typically asymmetric pattern,



(a) Prototype (CANDU6) (b) MCT (scaled-down model)

Fig. 2 Temperature distribution on the axial center plane.

Velocity distribution



(a) Prototype (CANDU6) (b) MCT (scaled-down model)

Fig. 3 Velocity vector on the axial center plane

2.3 Axial Heat Flux Profile Measurement

One of the important boundary condition that has not been confirmed was the axial heat flux profile of the electric heaters used. Normally the QA of the electric heater heat flux profile was left to the heater manufacturers, but as the heater for MCT was fabricated by the local manufacturer, it was decided to set up an experimental facility where the axial heat flux of the heater that was installed at MCT can be measured.

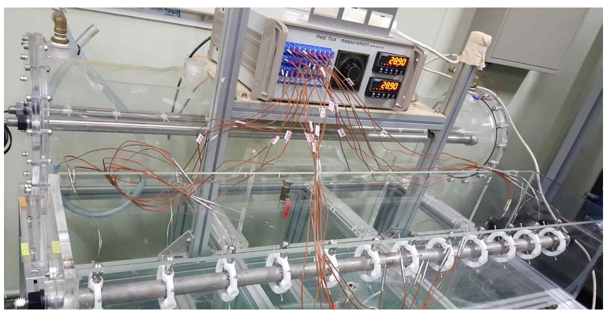


Fig. 1. Devices to measure the heat flux and the hole depth of 24 holes for TC installation.

3. Conclusions

The current research program included the construction of the MCT facility, production of the validation data for self-reliant CFD tools, and development of optical measurement system using PIV and LIF techniques. So far non-heating isothermal flow pattern tests and numerous heating flow pattern tests up to maximum power of 167 kW under various flow rate and inlet temperature conditions have been carried out. Also CFD models for analyzing the moderator temperature and flow fields are prepared. The future work will be use of these CFD models to simulate the test results obtained so far for various operating conditions, and evaluate and assess the modelling capability of these CFD models for the licensing application. However the axial heat flux profile of the electric heaters used has not been confirmed yet, and the current status is to have the heater with TC holes with different depth in the S.S. pipe are prepared, and the depth of these holes measured and TC are installed, ready for testing for various heater power conditions.

ACKNOWLEDGMENT

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