Comparison of Velocity Profile between Particle Image Velocimetry and CFD Analysis in a Scaled-down Facility for CANDU6 Moderator Tank

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1. Introduction

The CANDU6 moderator tank is the actual reactor core including fuel channels and moderator. It is also called as Calandria vessel. The ability of cooling in the reactor is related to the circulation characteristics of the moderator. Therefore, velocity and temperature distributions in the Calandria vessel are important considerations for the safety of the CANDU reactor. Various experimental and numerical efforts to predict and analyze the thermal-hydraulic characteristic of Calandria vessel have been made [1-2].

Heget et al. [3] carried out 2-dimensional moderator circulation tests at a 1/4 scaled-down facility in the Stern Laboratories in Canada. Laser Doppler Anememetry (LDA) was used to detect the velocity profile. Yoon et al. [4] developed a CFD model for the CANDU6 moderator analyzing the velocity profile and the temperature distribution.

There are many methods to analyze the velocity profile and the temperature distribution in Calandria veseel. In the present work, a Particle Image Velocimetry (PIV) technique is used in a scaled-down Calandria vessel to obtain velocity profiles. The experimental data for the velocity profile are compared with the result of CFD analysis.

2. Experimental Setup

2.1 Particle Image Velocimetry

A PIV technique was used for measuring velocity profile in a scaled-down Calandria vessel. Fig. 1 shows the PIV system installed for measuring velocity profile in the scaled-down Calandria vessel. A Nd-YAG double-cavity laser beam comes from the vertical side of CCD camera. The light sheet is created in the vessel and CCD camera traces the particles that react with laser. After tracing particles with CCD camera, the velocity profile is analyzed by computer system.

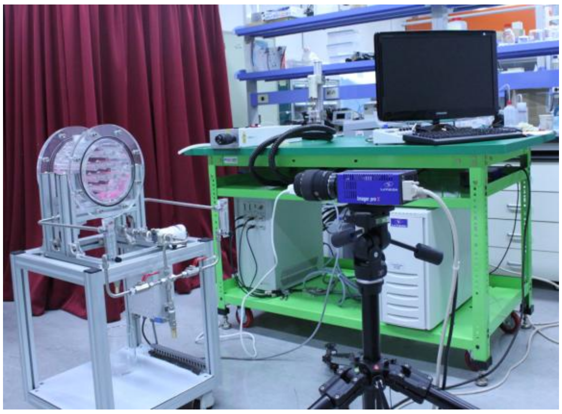


Fig. 1. PIV system with a scaled-down Calandria vessel

2.2 Preparation of a scaled-down CANDU6 moderator

The scaled-down Calandria vessel was designed with acrylic. Because the PIV system uses Nd-YAG pulsed laser, the transparent material was needed to pass the light sheet.

Fig. 2 shows the cross section of the scaled-down Calandria vessel. The scaled-down Calandria vessel was based on the CANDU6 moderator tank. The scaled-down ratio is 1/40 comparing with CANDU6 moderator tank. 12 acrylic pipes were installed in the tank to consider a matrix of Calandria tube/pressure tube including fuel elements in CANDU6 Calandria vessel. Two inlet nozzles are located in both side of the mock-up tank and operated with the same velocity.

Inlet nozzles have rectangular shape with 25 mm X 3 mm and outlet nozzle is connected with 1/2 inch SS pipe. In the present work, unlike CANDU6 moderator tank, two inlet nozzles and one outlet nozzle are positioned on the same cross section.

The experimental procedure is as follows. The water which contains the particle flows into the tank from two inlet nozzles with the same volumetric flow rate and comes out of the outlet pipe. One rotameter and one ball valve are equipped in each inlet pipe to fit into the same volumetric flow rate.

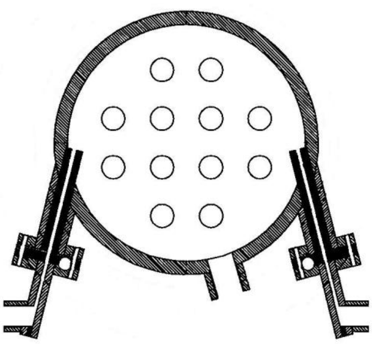
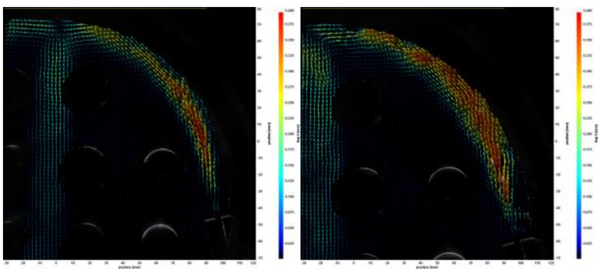


Fig. 2. Cross section of scaled-down Calandria vessel

3. Results and Discussion

The PIV experiments were carried out in different positions; left and right position of inlet nozzles. Full cross section of velocity profile was not obtained because of acrylic pipe. The velocity vectors were obtained with average value of each position. 20 frames were calculated for making one result. For CCD camera, double frame timing was 2000μs. Fig. 3 (a) shows the velocity profile distributed from right inlet nozzle. Fig. 3 (b) shows the velocity profile distributed from left inlet nozzle. As shown in the distribution, it is found that the water flow ejected and formed from both nozzles is not balanced in the distribution. Initially, the design of the Calandria vessel has been expected to be in a balance at the center in the vessel. This is due to the outlet location tilted from the center.

To evaluate of the PIV result, CFD analysis is performed under the same condition of PIV experiment. About turbulence modeling in CFD analysis, we used k-epsilon model which has been implemented in most general industry standard model. The same trend of results can be obtained from CFD analysis result. Fig. 4 (a) and Fig. 4 (b) are the result of CFD analysis at each inlet positions. It shows a good agreement with PIV result and CFD analysis. Table I shows the result maximum velocity value between PIV and CFD analysis at each position.



(a) (b)

Fig. 3. The average velocity profile with (a) right inlet nozzle (b) left inlet nozzle (PIV)

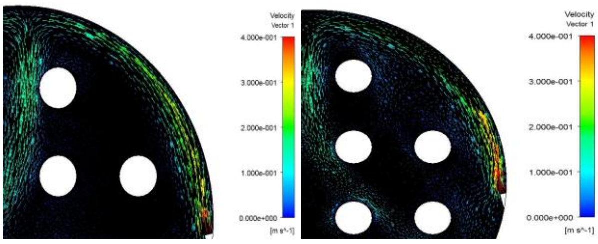


Fig. 4. The average velocity profile with (a) right inlet nozzle (b) left inlet nozzle (CFD)

Table I: Problem Description

Position	PIV analysis (m/s)	CFD analysis (m/s)
Fig. 3 (a) & 4 (a)	0.3985	0.3949
Fig. 3 (b) & 4 (b)	0.4822	0.4756

4. Conclusion

In the present work, a Particle Image Velocimetry (PIV) technique is used in a scaled-down Calandria vessel to obtain velocity profiles.

First, the present work shows a new technical approach for analyzing velocity profiles in moderator tank with a PIV system.

Second, the scaled-down of CANDU6 moderator tank is utilized to analyze velocity profile with PIV. In comparison with results using commercially-available CFD code, the PIV results are well matched.

Lastly, the distortion of flow distribution from both nozzles should be more considered for the thermal-hydraulic considerations related to reactor safety

The various experimental conditions such as flow velocity, temperature, and geometry (scale) will be more considered to get velocity profiles in the CANDU6 moderator circulation in terms of developing more accurate thermal-hydraulic models related to safety analysis.

REFERENCES

[1] M. Kim, S. Yu, H. Kim, Analysis on Fluid Flow and Heat Transfer Inside Calandria Vessel of CANDU-6 using CFD, Nuclear Engineering and Design, Vol.236, pp. 1155-1166, 2006.

[2] B.W. Rhee, C. Yoon, B. Min, CFD Simulation of the CANDU-6 Moderator Circulation, Under Normal Operating Conditions, ICONE10-22527, Apr.14-18, 2002.

[3] T.G. Huget, J. K. Szymanski, W. I. Midvidy, Experimental and Numerical Modeling of CANDU moderator circulation, Annual Conference of Canadian Nuclear Society, 1990.

[4] C. Yoon, J. H. Park, Development of a CFD Model for the CANDU-6 Moderator Analysis using a Coupled Solver, Annals of Nuclear Energy, Vol.35, pp. 1041-1049, 2008.