Preliminary Investigation on Turbulent Flow in Tight-lattice Rod Bundle with Twist-mixing Vane Spacer Grid

Chi Young Lee [a*], Young Kyun Kwack [a], Ju Yong Park [a], Chang Hwan Shin [a], Wang Kee In [a]
[a] *KAERI, 989-111 Daedeok-daero, Yuseong-gu, Daejeon 305-353, Republic of Korea*
[*] *Corresponding author: chiyounglee@kaeri.re.kr*

1. Introduction

Fuel assembly in PWR (Pressurized Water Reactor) is supported by the spacer grid, which has the mixing vane to improve the performance of CHF (Critical Heat Flux) and flow mixing between adjacent subchannels. Recently, our research group has developed and examined a dual-cooled annular fuel having the inner coolant channel to increase the reactor power and decrease fuel temperature [1]. In a same array size, a dual-cooled annular fuel bundle exhibits the tight-lattice configuration with a narrow rod-to-rod distance owing to inner channel, as compared with a conventional cylindrical solid fuel bundle: P/Ds (the ratios of pitch between fuel rods and fuel rod diameter) of dual-cooled annular and cylindrical solid fuel bundles are 1.08 and 1.35, respectively. Our research group has investigated the effect of P/D difference on the behavior of turbulent rod bundle flow without the mixing vane spacer grid, using PIV (Particle Image Velocimetry) and MIR (Matching Index of Refraction) techniques for tight-lattice fuel rod bundle application [2].

In this work, using the tight-lattice rod bundle with a twist-mixing vane spacer grid, the turbulent rod bundle flow is preliminarily examined to validate the PIV measurement and CFD (Computational Fluid Dynamics) simulation.

2. Experiment and Numerical Simulation

PIV measurement

As the test section, the simulated 3×3 rod bundle of P/D=1.08 was prepared using 1 inch (25.4 mm) tube. As the test loop and optical measurement technique, OFEL (Omni Flow Experimental Loop) and PIV system (Dantec Dynamics), described in Ref. [2], were used. To measure the turbulent flow in lateral direction between subchannels, the experimental set-up was modified, as shown in Fig. 1: Upper plenum was changed to transparent acrylic plate. Then, the high-speed camera was installed in the upper plenum, and the laser sheet was produced through the transparent FEP (Fluorinated Ethylene-Propylene) tubes of rod bundle to obtain the PIV images of subchannels.

As the spacer grid, the twist-mixing vane spacer grid, as shown in Fig. 2, was tested, and in Fig. 3, the cross-sectional view of test section was displayed with the measured region using PIV technique.

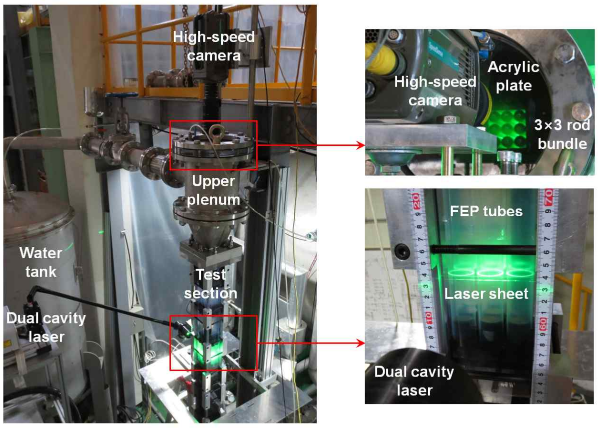


Fig. 1 PIV set-up.

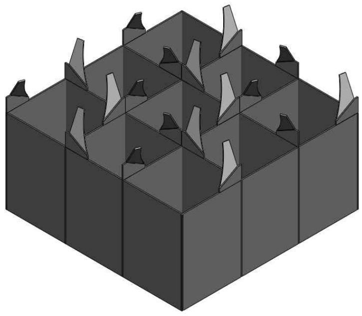


Fig. 2 Twist-mixing vane spacer grid.

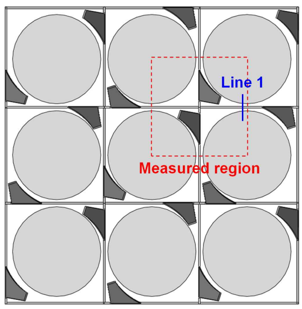


Fig. 3 Cross-sectional view of test section.

Numerical simulation

As the computational domain, the lengths of entrance and exit based on the twist-mixing vane spacer grid were 1 and 4 m, respectively. Using the trimmer of hexahedral mesh type with prism layer, 15 million grid points were generated as shown in Fig. 4. For simulation, a commercial computational code (STAR-CCM+ Ver. 8.02) was used with the SST (Shear Stress Transport) turbulence model. The inlet boundary condition was given with a uniform velocity of 2 m/s. The outlet boundary condition was set to be a relative pressure of 0

Pa at the top surface. For the rest of the walls, the no-slip wall condition was applied. As the working fluid, water at 23 °C was used. The convergence criterion was that a residual obtained at all cells is less than 10^{-4}.

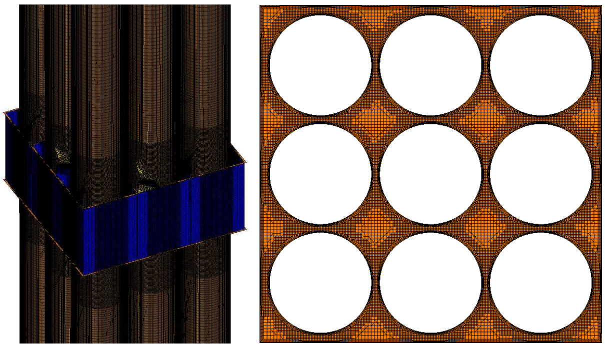
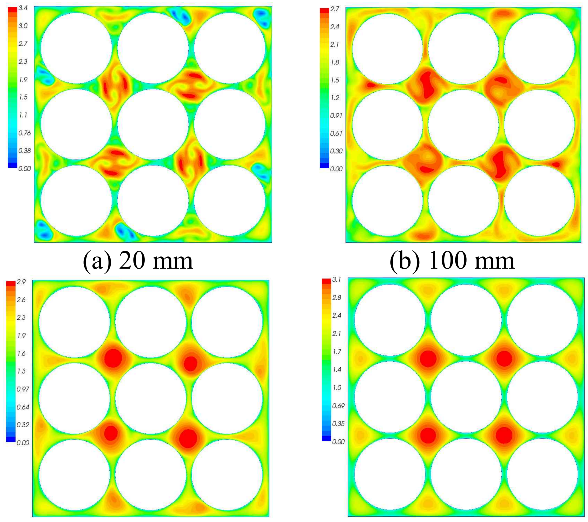


Fig. 4 Grids of the spacer grid and subchannels.

3. Results

In Fig. 5, the velocity contours of CFD simulation are shown at various axial positions. Near the twist-mixing vane, two vortices were observed in the subchannel. On the other hand, at far from the mixing vane, one vortex appeared. These were consistent with PIV measurement.



(a) 20 mm (b) 100 mm

(c) 322 mm (d) Outlet

Fig. 5 Velocity contours of CFD simulation at various axial positions.

In Fig. 6, for the cross-flow mixing rate per unit length (M) in Line 1 of Fig. 3, defined as Eq. (1), the measurement data of PIV measurement are compared with the CFD simulation along the axial position (L) behind twist-mixing vane spacer grid.

$$M = {v'}/{m'_{\mathrm{in}}} \qquad (1)$$

where v' and m'_{in} are the mass flow rate per unit length between subchannels and inlet mass flow rate, respectively. As shown in Fig. 6, the cross-flow induced by twist-mixing vane spacer grids dominantly occurred near the mixing vane. The cross-flow mixing rate per unit length was likely to be maximized near L=50 mm, and then, decrease along the axial position, as expected. The PIV measurements and CFD simulation were in a good agreement with each other within a reasonable degree of accuracy.

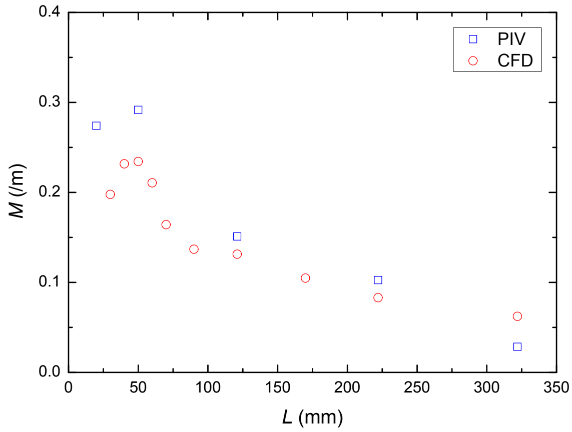


Fig. 6 Comparison of PIV measurement and CFD simulation for cross-flow mixing rate per unit length in Line 1.

4. Conclusions

The turbulent flow in the tight-lattice rod bundle with a twist-mixing vane spacer grid was preliminarily examined to validate the PIV measurement and CFD simulation. Both were in agreement with each other within a reasonable degree of accuracy. Using PIV measurement and CFD simulation tested in this work, the detailed investigations on the behavior of turbulent rod bundle flow with the twist-mixing vane spacer grid will be performed at various conditions, and reported in the near future.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) funded by the Korea government (MEST) (NRF-2012M2A8A5025824).

References

[1] T.H. Chun, C.H. Shin, W.K. In, K.H. Lee, S.Y. Park, H.T. Kim, K.H. Bae, K.W. Song, A Potential of Dual-cooled Annular Fuel for OPR-1000 Power Uprate, In: 2009 LWR Fuel Performance, Paris, France, Paper 2185, 2009.
[2] C.Y. Lee, C.H. Shin, J.Y. Park, W.K. In, An Experimental Investigation on Turbulent Flow Mixing in a Simulated 3×3 Dual-cooled Annular Fuel Bundle using Particle Image Velocimetry, Nuclear Engineering and Design (Accepted).