Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

CFD Benchmark Tests on a 5x5 Rod Bundle Array

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1. Introduction

The coolant flow in the subchannels of a PWR core is very complicated owing to the mixing spacer grids, which are equipped for enhancing the lateral turbulent mixing in the subchannels. Recent experimental studies for unveiling the flow structure at the down-stream of the mixing spacer grid in a rod bundle have been conducted. Langford et al. [1] conducted the measurements of the swirling flow in a subchannel of a square arrayed 5 x 5 rod bundle using a PIV. Holloway et al. [2] performed the experiments of the convective heat transfer for a turbulent flow through a rod bundle having a mixing spacer grid. Recently, Conner et al. [3] presented the CFD methodology developed by Westinghouse to model a single-phase, normal operation in a PWR core using the STAR-CD code.

Under these circumstances, an international benchmark exercise test has been conducted to provide the data of detailed turbulent flow mixing in a 5 x 5 rod bundle for validating the CFD codes. A 5 x 5 rod bundle having mixing spacer grids was adopted as a test rig, and the 25 rods in a bundle have dimensions of 25.4 mm O.D. and a 3,863 mm length. The axial bulk velocity in a rod bundle was maintained at about 1.50 *m/s* (equivalent to *Re*~50,000) with the loop conditions of 35°C and 1.57 bar. Detailed measurements of a turbulent flow in the sub-channels have been accomplished using 2-D LDV at four different distances (0.5, 1, 4, and 10 D_H) from the downstream of the mixing spacer grid.

2. Experimental Method

The experimental study was conducted at the cold test loop in KAERI, which can perform a hydraulic test at normal pressure and temperature conditions for a rod bundle array in water. The loop consists of a water storage tank, circulation pump, and test section (Fig. 1). The heater and cooler are contained in the water storage tank for maintaining the experimental temperature conditions during the test. The loop conditions are monitored and controlled by electric signals from instruments such as thermocouples, pressure transmitters, and flow-meters. During the experiments, the loop temperature was maintained at 35 ºC and the system pressure was 1.57 bar. Experiments were performed at the condition of the *Re* = 50,000 (equivalent to W_{avg} = 1.5 m/s) at the test rig. A 2-D LDV system was used to measure the turbulent velocities in a rod bundle. It comprises an Argon-ion laser source, optics, and a 2-D probe.

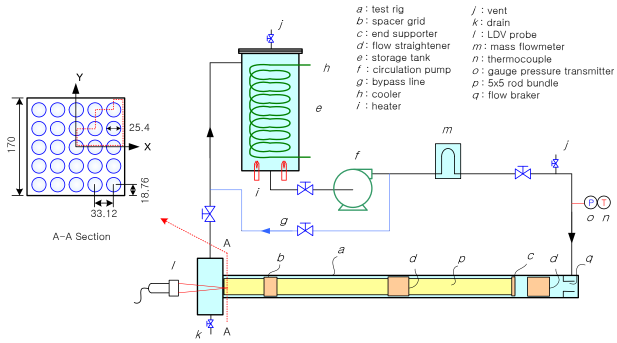
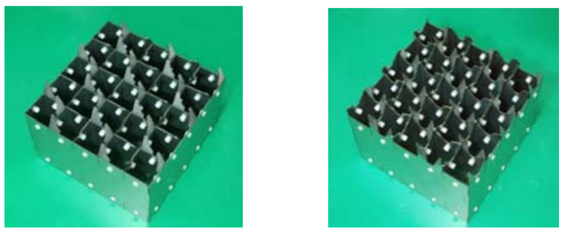


Fig. 1. Schematic diagram of the test loop

One of the spacer grids installed in a rod bundle is of a 'split-type', which features two vanes at each crossing of the grid straps, as shown in Fig. 2 (a). The vanes are bent through 30° with respect to the horizontal. The other spacer grid is a 'swirl-type', which has four vanes at every cross of the grid strap, as shown in Fig. 2 (b). In this case, the vanes are bent through 35°, based on the diagonal line. More details are included in the benchmark test specifications [4].



(a) Split-type Spacer Grid (b) Swirl-type Spacer Grid

Fig. 2. Two types of spacer grids used in this work

3. Measurement Results

For the lateral velocity (*U*,*V*) measurements, the LDV probe is placed at the front of the test rig, as shown in Fig. 1. The measurement points are distributed in a dotted region with a spatial resolution of 0.75 mm, and consequently, the total is 4,173 measurement points. The axial velocities *W* are also measured at the selected gap lines, which are the centrelines (0.5 *and* 1.5 *P*) at the first and second lanes of the rod gaps, and another one is the line of 2.455 *P* placed at the wall gap at each downstream distance *Z.*

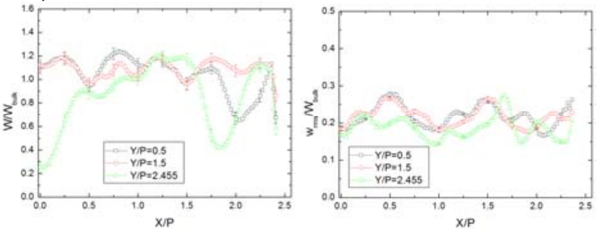
3.1 Axial Velocity Measurements

The mean and RMS of the axial velocities from the LDV measurements are expressed as follows:

$$W = \bar{w} = \frac{1}{n}\sum_{i=1}^{n} w_i$$

$$w_{rms} = \{\overline{(w-\bar{w})^2}\}^{1/2}$$

Three measurement trajectories, those representing the centrelines in each gap for a typical 'split-type' S/G, have been selected to highlight the turbulent properties of the flow in a 5 x 5 rod bundle, as illustrated in Fig. 3. All of the velocities and their *RMS* values are normalized with respect to the bulk velocity, W_{bulk} (1.50 m/s), and the X-Y coordinate with a rod pitch, *P* (33.12 mm).

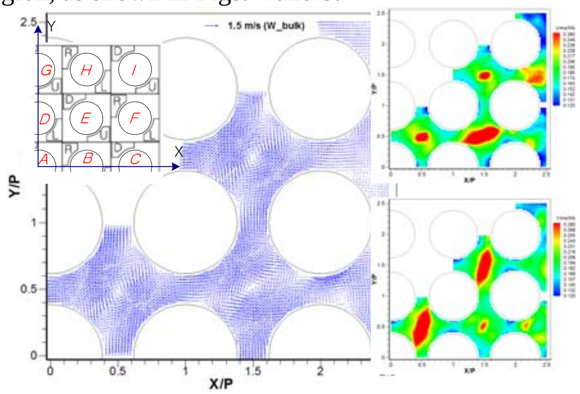


(a) Velocity profiles (b) Turbulence intensity profiles

Fig. 3. Axial velocity properties at Z=1 D_H (split-type)

3.2 Lateral Velocity Measurements

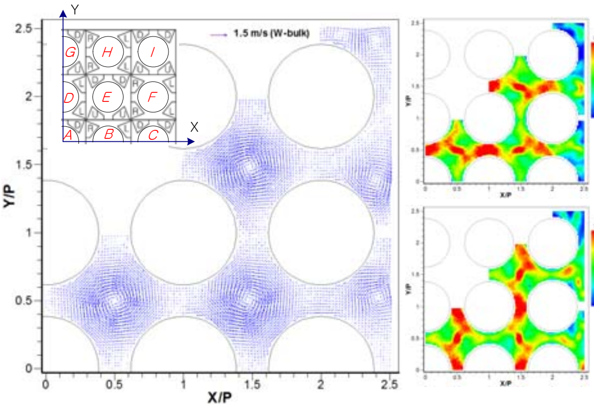
The mean and RMS of the lateral velocities (*U*,*V*) from the LDA measurements are also expressed through the above equations. Among the measurement data, the typical lateral velocity vectors and their turbulence intensities are mapped in a full measurement region, as shown in Figs. 4 and 5.



(a) Velocity vectors (b) Turbulence intensity profiles

Fig. 4. Lateral velocity properties at Z=1 D_H (split-type)

Fig. 4 (a) shows the feature of the lateral flow at 1 D_H downstream of the 'split-type' spacer grid. Elliptic swirls at subchannel centre and strong cross-flow in the gaps are observed, and these are apparently due to the arrangement patterns of the mixing vanes. Fig. 4 (b) shows the turbulence intensities of the *U*- and *V*-components. In subchannels #1 and #5, where the vanes are bent in the *x*-direction, the turbulence intensity of the *V*-component (v_{rms}) is much higher than the turbulence intensity of the *U*-component (u_{rms}). On the other hand, in subchannel #2, where the vanes are bended in the *y*-direction, the turbulence intensity of the *U*-component (u_{rms}) is much higher than the turbulence intensity of the *V*-component (v_{rms}). This trend shows that there is a strong anisotropy of the turbulence intensity in subchannels near the downstream of the 'split-type' spacer grid, and strongly depends on the patterns of the vane arrangement.



(a) Velocity vectors (b) Turbulence intensity profiles

Fig. 5. Lateral velocity properties at Z=1 D_H (swirl-type)

Figs. 5 (a) and 5 (b) show the lateral velocity vectors and the turbulence intensities of the *U*- and *V*-components at 1 D_H downstream of the 'swirl-type' spacer grid, respectively. It shows that the turbulence intensities are relatively high at gaps and centres in the subchannels, but the anisotropy is much less than in the case of a 'split-type' spacer grid.

4. Conclusions

Detailed velocity measurements using 2-D LDV have been conducted on the turbulent mixing in a rod bundle with two different types of mixing spacer grid. Lateral velocity measurements have been carried out intensively in a 1/8 quadrant region of the flow channel with a fine measurement resolution at four downstream distances from the mixing spacer grid of two types of spacer grids. Detailed velocity measurement data in the subchannels are expected to be utilized to verify the turbulence models and/or numerical schemes in the CFD codes.

REFERENCES

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