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Powerful Swirl Generation of Flow-driven Rotating Mixing Vane for Enhancing CHF

Han Seo, Seok Bin Seo, Hyo Heo, In Cheol Bang*
School of Mechanical and Nuclear Engineering
Ulsan National Institute of Science and Technology (UNIST)
UNIST-gil 50, Eonyang-eup, Ulju-gun, Ulsan Metropolitan City 689-798, Republic of Korea
**Corresponding author: icbang@unist.ac.kr*

1. Introduction

Mixing vanes are swirl generators that are placed on the top edge of the structural grids in the fuel assembly. Mixing vanes are utilized to improve CHF and heat transfer performance in the rod bundle during normal operation. Also, the structures provide secondary flow such as swirl and crossflow that increase the mixing and turbulence in the rod bundle. This means that mixing vanes have an effect on lateral velocity, turbulence intensity, and Reynolds stress. Therefore, researches on the optimum design specifications of mixing vanes have been widely conducted based on experimental and numerical methods.

Experimental measurement of the swirling flow from a split vane pair was conducted using particle image velocimetry (PIV) and boroscope [1]. The lateral velocity fields show that the swirling flow was initially centered in the subchannel and the computational fluid dynamics (CFD) analysis was performed based on the experiment [2]. To visualize flow patterns in the 5×5 subchannel using PIV, matching the refraction between the working fluid and the structure was considered and the experiment aimed to develop the experimental data for providing fundamental information of the CFD analysis [3]. The fixed split vane is the main mixing inducer in the fuel assembly. In a heat exchanger research, propeller type swirl generates at several pitch ratios and different blades angles were used to enhance heat transfer rate [4]. Significant improvements of the heat transfer rate using the propellers were confirmed due to creation of tangential flow.

In the present study, the mixing effect of rotation vane which has a shape of propeller was studied using PIV. A split vane was considered in the experiment to show the effect of rotation vane. Vertical and horizontal flow analyses were conducted to show the possible use of rotation vane in a subchannel.

2. Experimental Setup

2.1 Experimental Facility

Fig. 1 shows a schematic diagram of the test facility for vertical flow. Water was used as the working fluid. Major components of the facility include liquid reservoir tank, pump, flowmeter, gate valves, and test section. Air compressor is installed to simulate two-phase flow in the test section. Major loops are designed with acrylic for flow visualization in all experimental facility. Differential pressure transmitter is located in the test section to measure the pressure drop of the vanes. The area of the test section is 70 mm × 70 mm and the total length of vertical test section is 1200 mm.

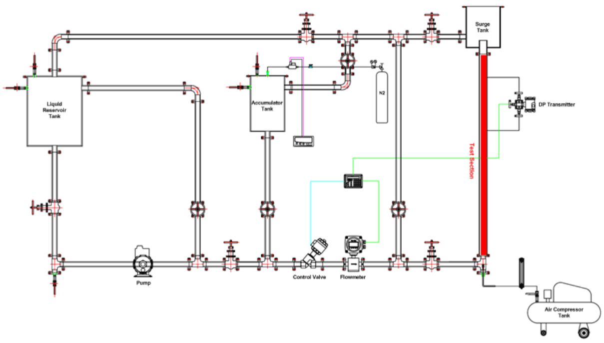

Fig. 1. Schematic diagram of vertical flow experimental facility.

Fig. 2 indicates a schematic diagram of the test facility for horizontal flow. Water storage tank, pump, flowmeter, and test-section are the major components of the closed-loop facility. The area of the test section is the same as the vertical test section and the total length of the horizontal test section is 1500 mm. Differential pressure transmitter is also installed in the test section to show the effects of vanes.

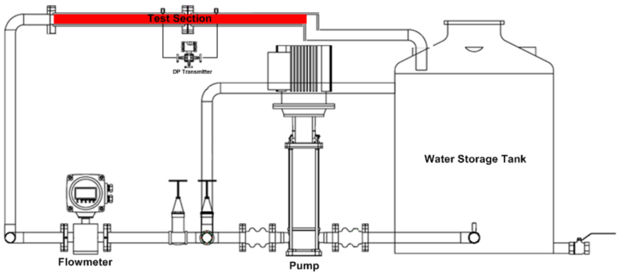

Fig. 2. Schematic diagram of horizontal flow experimental facility.

2.2 Design of vanes

To show the effect of rotation vane, three types of vanes are designed. Fig. 3 shows the vanes that are installed in the test section: bare vane, mixing vane, and rotation vane. The mixing vane and the rotation vane are made on the bare grid structure. The mixing vane, used in the present work, has the similar shape of mixing vane that is commonly used in nuclear power plants.

The design of rotation vane was based on the patent [5]. The flow pattern and turbulence intensity of vanes are analyzed to see the effect of the rotation vane.

Fig. 3. The test structure of bare vane, mixing vane, and rotation vane.

2.3 Experimental Procedure

The effects of rotation vane in the vertical and the horizontal facility were evaluated using PIV for flow visualization. Nd-YAG double-cavity laser beam comes from the vertical side of CCD camera. The light sheet is created in the test section and the CCD camera traces the particles that are reacting with laser. After tracing particles with CCD camera, the velocity profile is analyzed by computer system. The changes of vertical and horizontal flow are considered in the present study.

3. Results and Discussions

For the vertical flow, the velocity fields at centerline of the test section were analyzed. Fig. 4 shows the vertical flow experimental results at 240 LPM. The average speed of flow channel was about 0.8 m/s. As shown in Fig. 4(a), the flow pattern after the bare grid structure was equally spaced in the flow channel. However, the flow pattern for the mixing and the rotation vane was converged to the wall surface due to the mixing effect. Based on the velocity profiles at 975 mm, 1000 mm, and 1100 mm, the mixing effect of the rotation vane higher compared to the mixing vane. This means that mixing effect of the rotation vane can prolong because the turbulence kinetic energy was higher than the bare vane and the mixing vane. The turbulence kinetic energy is characterized by measured root mean square velocity fluctuations. Turbulence kinetic energy and Reynolds stress are the term describing the mixing effect in the experiment. Two terms could be described as:

$$E_{tke} = |V_{rms}|^2 \quad (1)$$

$$V_{RSxy} = \frac{1}{n\sum_{i=1}^{n}\left(\left(V_i - V_{avg}\right)_x \left(V_i - V_{avg}\right)_y\right)} \quad (2)$$

Fig. 4(c) indicates the turbulence kinetic energy for each vane type. However, vertical flow patterns could not show lateral movement. Therefore, the horizontal flow analysis using the same vanes was conducted in the horizontal experimental facility.

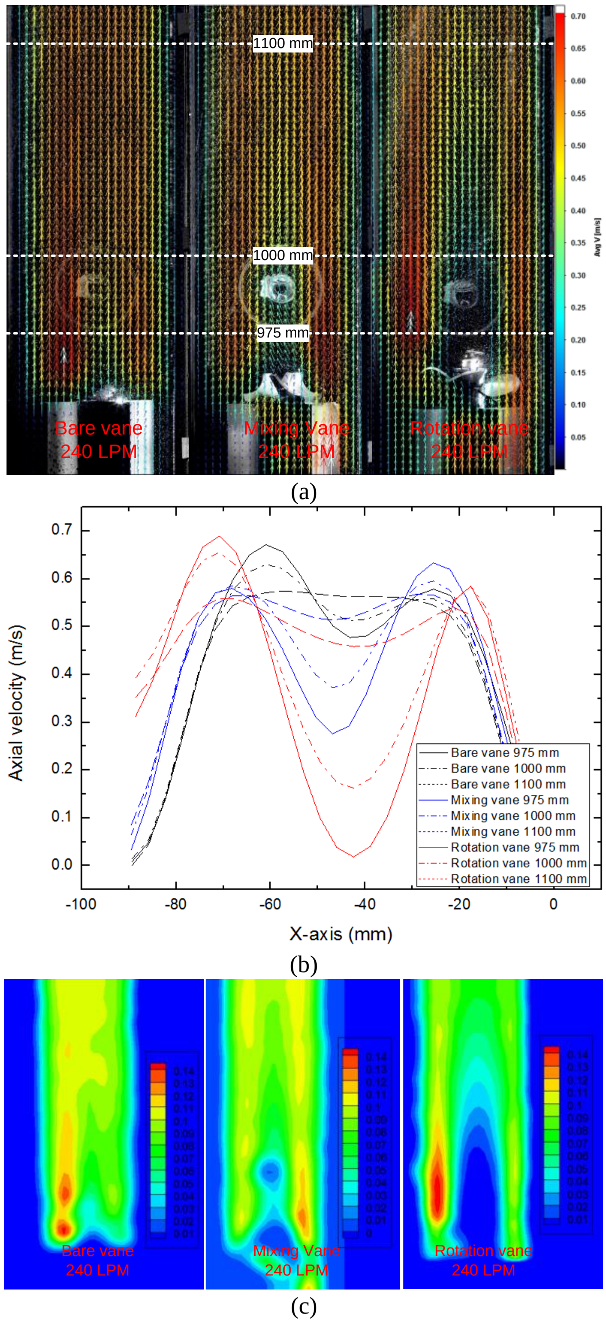

Fig. 4. Experimental results in the vertical flow at the centerline of the channel: (a) velocity distribution, (b) velocity profile at 975 mm, 1000 mm, and 1100 mm, (c) turbulence kinetic energy

Fig. 5 shows the analysis of horizontal flow at 240 LPM and 300 LPM. The average flow speed in the test section at 240 LPM and 300 LPM was same as the vertical flow speed. Two measurement sections of the horizontal test section were considered: 0 mm and 100 mm. The position of 0 mm was the point where the flow comes out from the vanes. The pressure drop of the mixing vane and the rotation vane was measured as 2000 Pa and 3000 Pa, respectively. Fig. 5(a) shows the measurement position using PIV. The velocity fields of the horizontal flow using three types of structures were analyzed as shown in Fig. 5(b). The same legend was used for comparison. The lateral flow was not developed in the bare vane structure because there was no obstacle. For the mixing vane, the lateral flow was formed but the lateral flow disappeared at the 100 mm. However, the rotation vane showed that the lateral flow persisted at the 100 mm. This means that flow mixing was maximized to the lateral position using the rotation vane. The results of the turbulence kinetic energy showed the same trend of the average velocity fields.

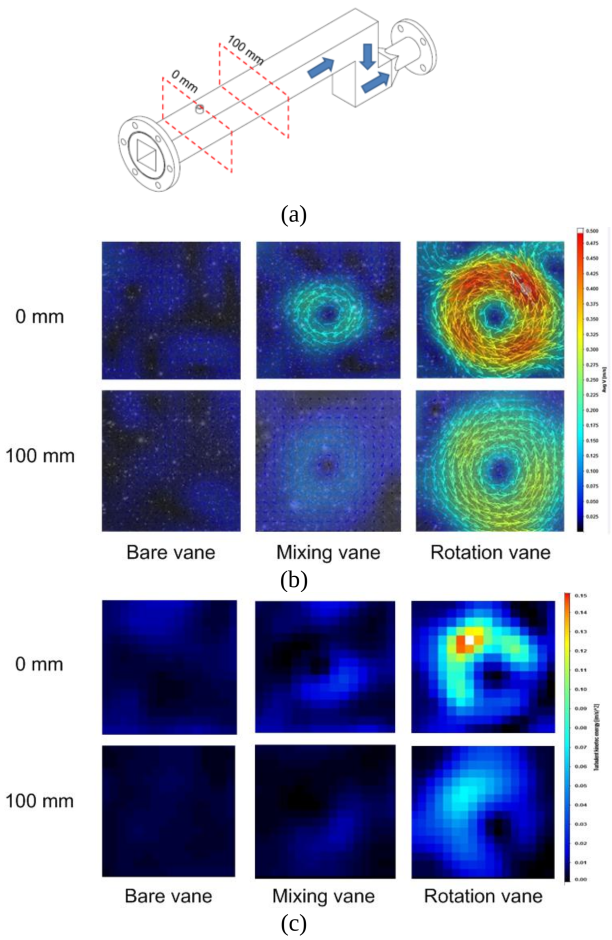

Fig. 4. Experimental results in the horizontal flow: (a) measurement sections, (b) velocity distribution, (c) turbulence kinetic energy

4. Conclusions

In the present work, the study of flow visualization using three types of vanes is conducted to show the mixing effect. The vertical flow and the horizontal flow distributions were analyzed in the two experimental facilities.

For the vertical flow facility, flow distributions, flow profiles, and the turbulence kinetic energy are analyzed at the centerline of the channel. The results show that the rotation vane has the highest flow and turbulence kinetic intensity at the centerline of the channel.

For the horizontal flow facility, the results indicate that lateral flow of the rotation vane is generated and maintained along with the flow direction. This means that rotation vane could provide secondary flow structures such as swirl and crossflow that increase the mixing and turbulence.

The various experimental conditions such as high flow rate, different structures of mixing vanes should be considered to enhance swirl and crossflow in the flow channel.

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