Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Cross Flow and Pressure Drop Evaluation for Rotational and Fixed Mixing Vane

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1. Introduction

In Pressurized Water Reactor (PWR), fuel rod bundles are supported by spacer grid, located between the rod bundles. The mixing vane is installed on top of the spacer grid to provides cross flow that enhances mixing and turbulence in the subchannel. The cross flow increases heat transfer from the fuel rod to coolant, enhance thermal margin and CHF, while the pressure drop from the mixing vane impedes the circulation of coolant. The cross flow and the pressure drop are the most important parameter in pressurized water reactor. The rotational and fixed mixing vanes has merits and demerits for cross flow and pressure drop. To propose optimized mixing vane on compromise the cross flow and pressure drop, this paper introduces various mixing vane types with fixed and rotational types. The fixed vanes can maximize the cross flow, meanwhile the pressure losses might be increase. The rotational mixing vane minimized the pressure drop and showed cross flow with swirl effect. Experimental approach with Particle Image Velocimetry (PIV) and pressure drop measurement was conducted. Also, Computational Fluid Dynamics (CFD) analysis was performed to validate flow field to show the cross flow and the pressure drop, using FLOW-3D. Then, measured cross flow and the pressure drop of fixed and rotational mixing vanes were compared with those of CFD simulations, to derive the optimized design on the purpose of the application to fuel assembly.

2. Experiment and CFD modeling

2.1 Mixing vane design

Fig. 1 shows the geometry of the spacer grid and mixing vane on top of the spacer grid. Bare Grid (BG), fixed Split Vane (SV) were prepared to represent general mixing vanes. Mixing effect and pressure drop for each vane design were compared by both experimental and numerical approaches. Among them, rotational fan vane (RV) design [3] was adopted to compare fixed and rotational effect of mixing vane

The candidate of rotational vane types with different vane blade design. All rotational vanes were designed with same length and height of blade. The rotational motion could be driven by fluid flow. The fixed mixing vane (FRV) was intentionally fixed to evaluate the effect of mixing vane geometry in the subchannel.

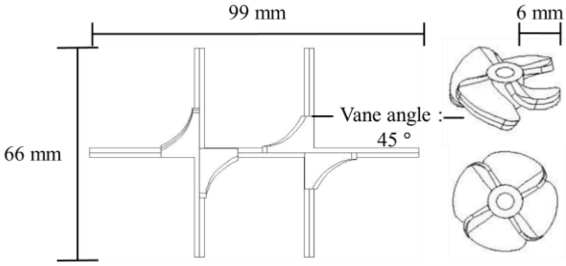


Figure. 1 Geometry of mixing vane

2.2 2×3 rod assembly test section

Figure. 2 shows the 2×3 rod assembly test section. The mixing vane was placed in the test section, simulating the subchannel with fuel rod assembly and mixing vane equipped spacer grid. Test section is designed with rectangular subchannel, with 2×3 fuel rod. Test section was 2.5 times scaled-up comparing to the typical Plus-7 fuel assembly channel. To visualize and evaluate the swirling effect of mixing vane in fuel assembly subchannel. Test section was made of acrylic with thickness of 10 mm was used with 99 mm of length, 66 mm of width, and height of 300 mm, respectively. Pin pitch was 33 mm. The acrylic fuel rod with the diameter of 25.4 mm was installed from the top-to-bottom, fixed by grid flange. For the CFD analysis, same geometry with 300 mm height rectangular test section was modeled. The mainstream velocity was 0.7 m/s. Corresponding Reynolds number was 12750.

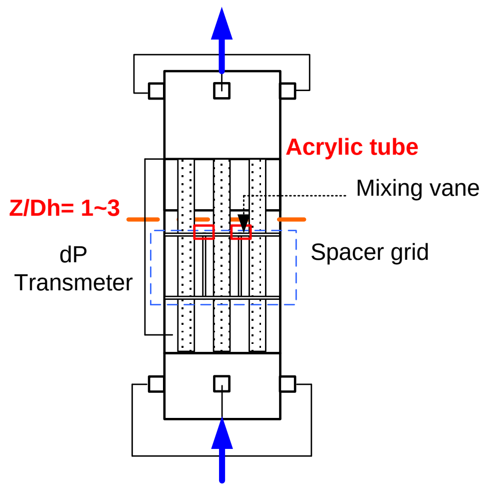


Figure. 2. 2×3 rod assembly test section

2.3 Experimental procedure

The mixing performances of the BG, FV, and RV were evaluated by 2D-PIV experiment. Single frame-PIV were used. An Nd-YAG double-cavity laser beam is used for the light source. The illuminating laser makes the horizontal sheet at the downstream of the flow. The laser has wave length of 532 nm. The pulse separation time (dt) was 150 μs. The CCD camera was set in front of the test section, toward the mirror. The flow field is observed through the mirror on top of the test section. The lateral velocity and flow field is measured to the horizontal plane for the test section. Measurement sections are $Z/D_h = 1$, from the top of the spacer grid. The pressure difference is measured by differential pressure gauge. The pressure difference at upper and lower pressure tap was measured. It was calibrated with 0.005 kPa accuracy. The head of fluid was calibrated as 0 Pa when test section is filled with working fluid without flow.

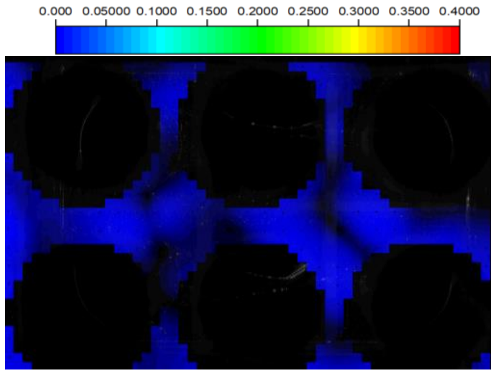
2.4 CFD Analysis set up

The numerical analysis was conducted to validate flow field obtained from PIV experiment and pressure drop. Further rotational and fixed vane option were tested through the CFD code. The commercial computational fluid dynamics (CFD) code, FLOW-3D was considered for the CFD analysis. FLOW-3D serves General Moving Object (GMO) model, which can describe coupled motion of RV with fluid flow. The fixed and rotational vane was tested by changing the GMO option. Also, an artificial power was given to the rotational mixing vane, with the rpm input. k-w turbulence model was adopted for the turbulence flow. Implicit, GMRES solver was used for pressure. The flow speed was the same as the experimental condition, 0.7 m/s. Relative outlet pressure was set as 0 Pa.

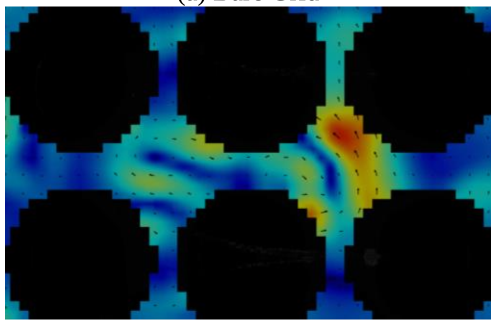
3. Results and Discussion

3.1 Cross flow and lateral velocity

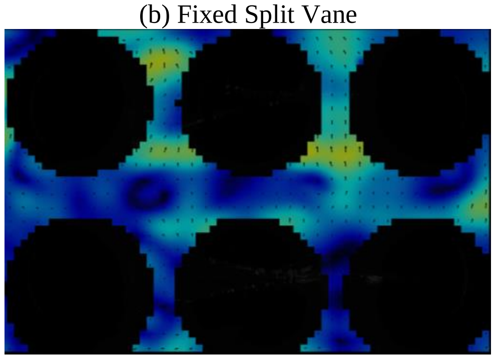
Figure. 3 shows the flow fields and lateral velocity of BG, SV, and RV from PIV experiment. The SV showed cross flow along with the vane. The cross flow formed x-axis and y-axis direction for the subchannel. The maximum lateral velocity was 0.4 m/s respectively. RV showed the equalized swirl flow. RV implied equalized cross flow toward the center of the subchannel. The magnitude of cross flow was small, the maximum lateral velocity was 0.25 m/s above the mixing vane and the magnitude of average velocity in the subchannel were lower comparing to the SV.



(a) Bare Grid



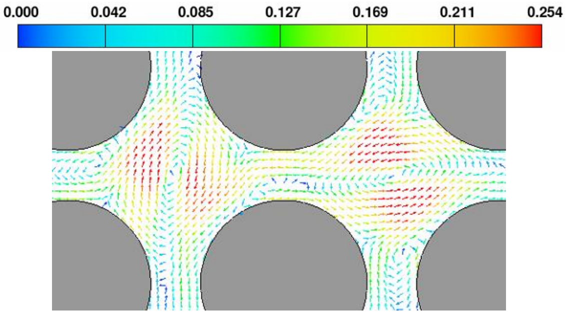
(b) Fixed Split Vane



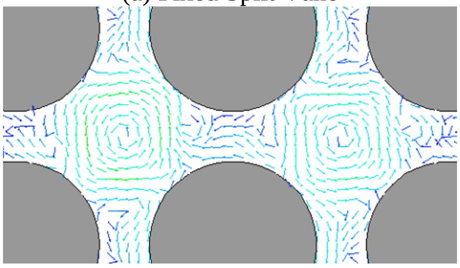
(c) Rotational Mixing Vane

Fig. 3 Measured flow field at $Z/D_h = 1$, Re=12,750

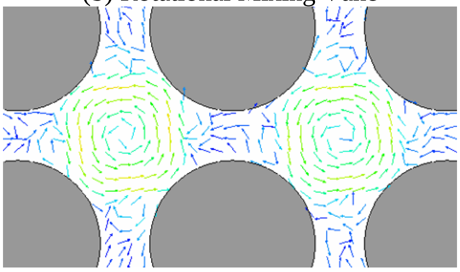
Figure. 4 shows the 2D lateral velocity field at the Z/Dh = 1 by CFD analysis. The CFD analysis results emphasized view of the center of the subchannel. The mixing performance of SV and RV were evaluated with the velocity magnitudes and directions. The fixed split vane shows cross flow through the subchannel. In contrast, RV shows swirl flow in subchannel due to the fan shape of the vane. The flow driven rotational motion, (b) shows, the least cross flow generation. The rotational motion with RPM input showed similar pattern but showed bigger lateral velocity since the momentum of the mixing vane. In comparison, (d), fixed mixing vane showed the maximum cross flow. The swirl direction reversed for the fixed mixing vane. By the results, it is known that the cross flow of the rotational mixing vane was driven by the rotational motion, not only the vane blade itself. The centrifugal force of the rotational mixing vane was developed to the downstream of the mixing vane so the cross flow and bubble detachment can be driven by the time variable rotational motion.



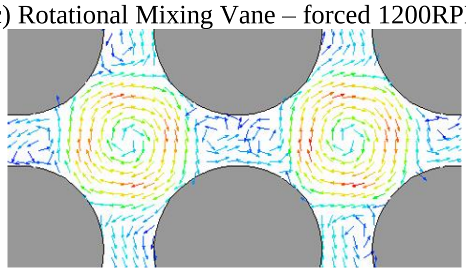
(a) Fixed Split Vane



(b) Rotational Mixing Vane



(c) Rotational Mixing Vane – forced 1200RPM



(d) Fixed Mixing Vane

Fig. 4 Predicted velocity field at Z/D_h = 1, Re=12,750

3.2 Pressure drop

Figure. 5 shows pressure drop of mixing vane types. Measured pressure drop data at velocity 0.7 m/s condition were 0.41 kPa for BG, 0.425 kPa for SV, and 0.41 kPa for FV, and it was the biggest for the fixed mixing vane, 0.6 kPa. The pressure drop results by CFD was smaller than the experimental results. The predicted pressure drop data by CFD simulation were 0.205 kPa, 0.211 kPa, 0.21 kPa, and the 0.213 kPa, respectively.

For both experiment and CFD analysis, the pressure drop was : BG was the smallest, RV showed the smallest between the mixing vanes, and the SV and FV showed increased pressure drop. However, the increase of pressure drop by the mixing vane was not dominant to the subchannel in this test section. The friction effect of fixed split vane and mixing vane was small in 2×3 test section.

Table I: Comparison of pressure drop for mixing vane

dP	Experiment	CFD
BG	0.41 kPa	0.205 kPa
SV	0.425 kPa	0.211 kPa
RV	0.41 kPa	0.21 kPa
FRV	0.625	0.213 kPa

4. Conclusion

This study evaluated cross flow and pressure drop of the BG, SV, RV and FRV. For the 2×3 subchannel, the pressure drop was measured and the cross flow was measured by the PIV experiment and CFD. The cross flow of SV and the swirl of RV and FV were visualized. By the results, swirl generation of RV and RV with RPM input had flow filed reversed direction of swirl, generated by the rotational motion of the mixing vane. The fixed split vane and fixed mixing vane showed bigger cross flow magnitude. The magnitude of cross flow was smaller than FRV, the centrifugal force of mixing vane could enhance heat transfer and had bubble detachment effect from the fuel rod. The pressure drop was decreased with rotational mixing vane, but the pressure drop difference were small in BG, SV, and RV in the 2×3 subchannel test section. Only FRV showed increased pressure.

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This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Korea government (MSIT) (No 2017R1A2B2008031).

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