Flow Structure Visualization inside Subchannels of 6x12 Rod Bundle: a Preliminary Report

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1. Introduction

LOCA (loss of coolant accident) is one of major concerns related to safety issue of nuclear fuel. It has been investigated by numerous researchers. From previous researches, various characteristics related to nuclear fuel and surrounding heat transfer phenomena could be revealed. In addition, flow characteristics inside nuclear core (rod bundle) has been investigated by several researchers. Chang et al. introduced 2D laser Doppler anemometry to study flow in rod bundle with different spacer grids [1]. McClusky et al. investigated swirling of flow in subchannel using particle image velocimetry (PIV) [2]. However, detail flow characteristics inside rod bundle is still unrevealed. Moreover, crossflows are generated in subchannel which is related to mixing phenomena [3-4]. This phenomena are directly related to the safety of nuclear core. Therefore, precise investigation on flow characteristics inside rod bundle is required and crucial for safety analysis.

In order to understand multi-dimensional flow phenomena in LOCA, an experiment facility named PRUS-II (in-PWR Rod-bundle Investigation of Undeveloped mixing flow across Sub-channel) is established at the innovative system safety research division, KAERI. This facility is designed to simulate the single phase steam flow above the swell level. Moreover, to evaluate turbulent diffusion and dissipation term in subchannel code analysis, high level of precision is designed in the acquisition of velocity information.

In this study, PIV-MIR technique was adopted to obtain velocity field and detail profiles related to flow characteristics [5]. As a preliminary study confirming PIV-MIR technique and the test facility, velocity profiles of inlet with various conditions were obtained. In addition to typical uniform inlet flow, non-uniform inlet conditions were provided to investigate mixing phenomena in various aspects.

2. Experimental setup

2.1 PRIUS-II

Figure 1 shows a schematic diagram of the test facility named PRIUS-II. Test section had a rectangular geometry with a dimension of 160.21 mm × 80.1 mm × 1.5 m. To investigate the non-uniform inlet condition, test section was designed to have two square arrays of rod bundles. Rod bundle was 6 x 12 array of rods with a diameter of 10 mm and a pitch of 13.35 mm. This configuration provided a hydraulic diameter of 12.69 mm which is similar to the typical hydraulic diameter of PLUS-7. Eight pressure taps were evenly distributed on left and right side of the test section. From these, pressure drops at 6 different locations could be measured. Estimated uncertainty of pressure drop measurement was 0.28%. All parts of test section were made of acryl.

In the inlet section, several multi-hole parts and additional channel were installed to provide stable straight flow. In addition, in order to investigate the effect of inlet condition, inlet section was divided into two regions. Two inlets were connected to branch lines which were installed to divide flow. Fluid flow was supplied by a centrifugal pump with controllable impeller speed. Measurement instruments for flow rate, temperature and pressure were installed in each branch of fluid lines. Estimated uncertainty of instruments were 0.29 %, 0.29 % and 0.35 %, respectively. In addition, air cooling device was mounted to maintain the fluid temperature at 30 °C.

In order to minimize the distortion from the difference in refractive index, the matching index of refraction (MIR) technique was used. To match the refractive index of acryl (1.49), a water solution of 62.5 % sodium iodine (NaI) was chosen as a working fluid.

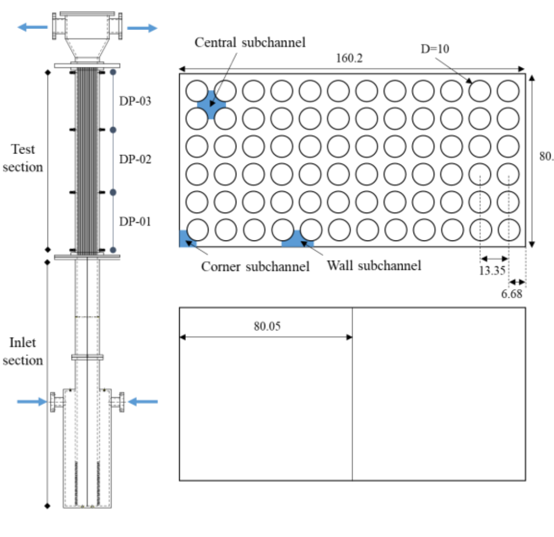

Fig. 1 Schematic diagram of PRIUS-II and cross sectional views of test section (Rod bundle) and inlet section.

2.2 PIV

PIV was utilized to study the flow characteristics in subchannels. PIV measurement system was consist of a 65 mJ Nd:YAG laser (532 nm) with optic lenses, a 2K $\times$ 2K CCD camera and delay generator as illustrated in Fig. 2. Fluorescent (Rhodamine B) polymer particles with an average diameter of 20 μm were used as a tracer particles. The acquisition rate is 5 frames per second. The interrogation window size of 32 $\times$ 32 pixel^2 was used with 50 % overlap. The corresponding effective spatial resolution was calculated as 0.53 $\times$ 0.53 mm^2. Using the ensemble average of 500 instantaneous velocity vector fields, statistical results were obtained including mean velocity and turbulence intensity. As a preliminary test, the inlet velocity profile was obtained. The inlet velocity field was measured 380 mm (30 D_h) upstream from the test section. Uncertainty of PIV result was evaluated as 4.40 % for maximum Reynolds number case [6].

Various inlet conditions were investigated. Conditions were divided into two major group, uniform and non-uniform inlet. For the case of non-uniform inlet, two ratios were chosen. Table 1 shows test conditions briefly. Due to limitation of control devices, some conditions, especially non-uniform inlet condition, could not be conducted.

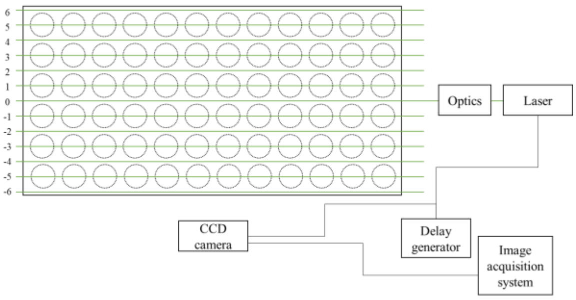

Fig. 2 Schematic of PIV measurement system.

Table I: Experimental conditions

Parameter	Range
Max Reynolds number	3000, 6000, 9000, 12000
Inlet Ratio (left : right)	5 : 5 (uniform) 6.5: 3.5 (non-uniform) 8 : 2 (non-uniform)

3. Results and discussions

Velocity profile of inlet in various conditions are described in Fig. 3. It shows that uniform inlet and non-uniform inlet condition were well-generated. For the case of uniform inlet flow, flow velocities have similar value in two regions. On the contrary, flow velocities show differences in the case of non-uniform inlet condition.

Pressure drops of different location with different Reynolds number and uniformity of inlet conditions are shown in Fig. 4. As Reynolds number increased, pressure drops were increased. In contrast to uniform inlet condition where pressure drops on left and right side of test section were same, pressure drops in non-uniform inlet condition provide uneven values at first (DP-01). Because pressure drop is linearly related to the square of velocity, higher velocity in the left side caused larger pressure drop. However, at the downstream, pressure drops show even values. This implies that the effect of asymmetric inlet velocity disappeared at about 40 D_h due to the lateral turbulent mixing. The experimental results are expected to be used in the verification of the subchannel analysis codes because it provides velocity information as well as pressure drop.

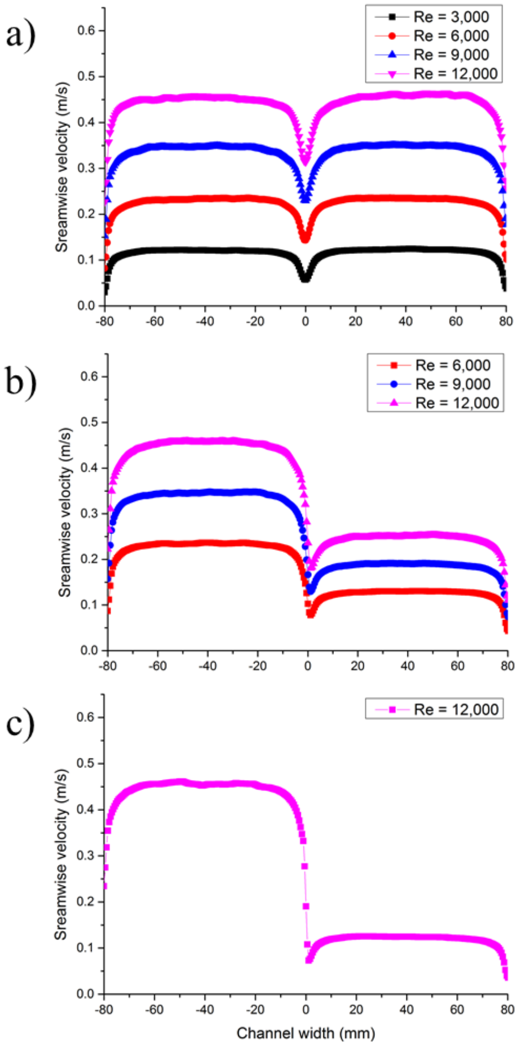

Fig. 3. Streamwise mean velocity profiles at the plane 0 of inlet with different inlet conditions: a) Uniform (5:5) b) Non-uniform (6.5:3.5) c) Non-uniform (8:2)

4. Conclusion

PRIUS-II experiments provide useful information about flow characteristics in subchannel of rod bundle. Various inlet conditions were successfully generated and tested. By employing PIV-MIR technique, velocity field and detail profiles were obtained. With measured pressure drops in the rod bundle, the experimental results will be used for development and validation of subchannel model in simulation analysis. In the near future, flow structure of subchannel flow with respect to distance from inlet will be investigated with the test facility and visualization technique.

ACKNOWLEDGEMENTS

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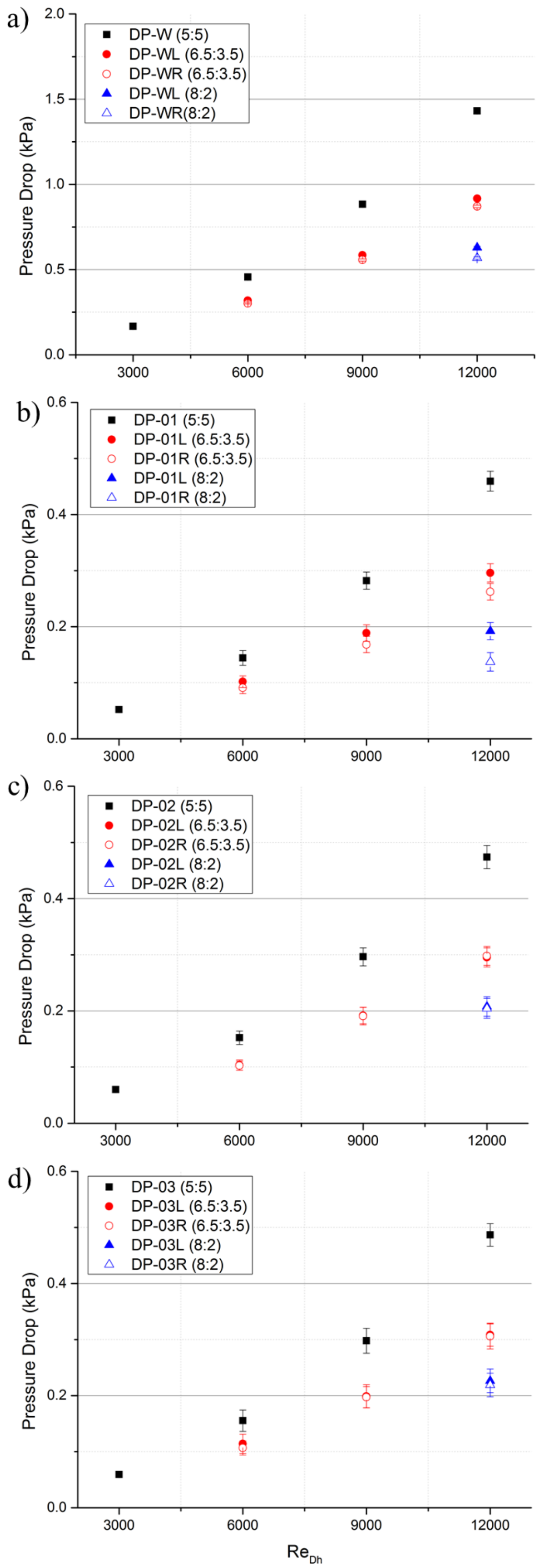

Fig. 4. Pressure drop measured at test section: a) Whole range of test section b) DP-01 c) DP-02 d) DP-03