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Effect of Asymmetric Inlet Mass Flow Conditions on Flow Behavior inside Subchannel of a 6×12 Rod Bundle

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1. Introduction

Understanding the variations in coolant flow velocity among the subchannels of a nuclear reactor core is crucial for ensuring its safe and efficient operation under both normal and accident conditions. During normal operation, changes in coolant flow velocity may occur due to non-uniform reactor power distribution, fluctuations in coolant temperature, and manipulation of control rods. These variations can affect heat transfer rate, fuel rod temperature (particularly PCT), and overall reactor performance. In accident condition such as emergency shutdowns or control rod malfunction, coolant flow velocity may experience rapid and unpredictable changes, potentially leading to thermal-hydraulic instabilities and endanger reactor safety.

Therefore, fundamental research aimed at comprehensively characterizing the effect of non-uniform coolant velocity in reactor sub-channels on the reactor safety is essential. This kind of research can provide valuable insights to understand the dynamic behavior of coolant flow, aiding in the development of advanced reactor designs and safety protocols.

This study conducted fundamental experiments to explore how asymmetric inlet flow condition influences flow behavior inside the subchannel using PRIUS-II (in-PWR Rod-bundle Investigation of Undeveloped mixing flow across subchannel) test facility. Through meticulous control of inlet condition, the research focused on getting insights into the flow behavior inside the subchannel.

2. Experimental Facility and Method

In this section, the PRIUS-II test facility, test section and experimental method are described.

2.1 PRIUS-II test facility and test section

The PRIUS-II is a closed type loop facility which consists of a circulation pump, a surge tank, a test section, flow meters and a 2 inch piping system for the water supply to the test section. Figure 1 and 2 shows a schematic diagram of the PRIUS-II facility and a cross section of test section with its dimension. As shown in Figure 1, the working fluid discharged from the pump is divided into two pipes, each pipes is equipped with a flow meter and a valve with adjustable its opening rate to control the flow rate in each pipe. Two working fluid, divided into two pipes, travels through each fully separated channel before reaching the test section, and during this travel, it passes through multi-hole plates and honeycombs having the tranquillization chamber to create straight flow conditions. As a result, it can be used to make a qualified asymmetric inlet flow rate condition for the test section. Since there is no flow separator wall in the test section, it is expected that the working fluid streams supplied from the two flow channels at different velocity will freely mix after reaching the test section, resulting in cross-flow. DI water was used as the working fluid.

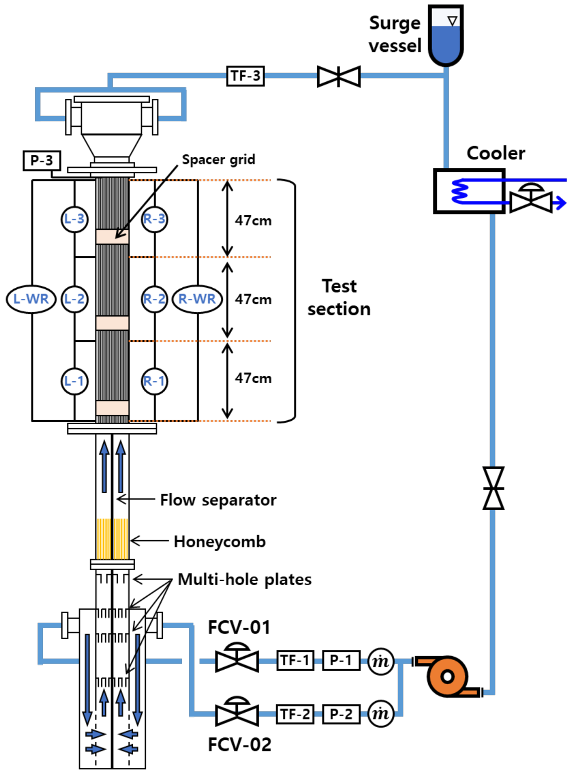

Figure 1. Schematic diagram of the PRIUS-II facility

The system pressure is measured at the top of the test section labeled P-3. Pressure taps were installed at 47 cm height interval on the both left and right side of the test section to measure the pressure difference. The pressure taps are located in the center of the side wall, as shown in Figure 2. At the same time, the pressure difference from the bottom to top of the test section was measured, and it is called wide range pressure difference. The pressure difference formed on the left and right sides of the test section under the asymmetric inlet conditions was measured, and was used as the fundamental to understand the flow behavior. Working fluid temperature was also measured at three different locations (inlet (TF-1, TF-2) and outlet TF-3). During the experiments, the maximum temperature difference among them was controlled to be less than 1°C.

Figure 2 shows a cross section of test section. Within a rectangular test section flow channel, a 6×12 array of acrylic rods was latticed at 13.35 mm intervals. Spacer grids was installed to minimize the vibration caused by fluid flow, ensuring the rods remain fixed in the same position. The all test section walls are made of acrylic panels which have transparency. This characteristic of the test section means that experiments with optical equipment such as lasers can be performed in the further research.

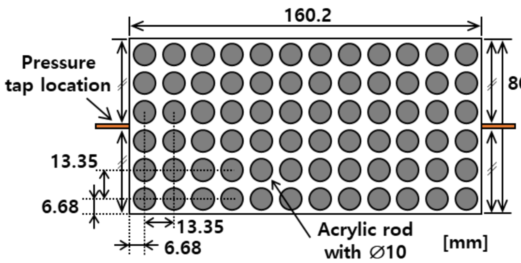

Figure 2. Cross section of test section

2.2 Experimental method and condition

In this study, all experiments were conducted under atmospheric pressure and 30 °C of working fluid. The experiments were conducted at total mass flow rate of 4.25, 5 and 10 kg/s, and the inlet flow rate symmetric ratios for each total mass flow rate conditions are listed at Table 1. To prevent breakage of the flow separator, the inlet asymmetric ratio was limited at high mass flow rate condition.

Table 1. Experimental conditions

$\dot{m}_{left}:\dot{m}_{right}$	Total mass flow rate (kg/s) [Average Re number]		
	4.25 [18,122]	5 [22,091]	10 [43,319]
5 : 5	○	○	○
6 : 4	○	○	○
7 : 3	○	○	
8 : 2	○		

3. Experimental Results

This section describes the representative wide range pressure difference results that are appropriate to explain the phenomenon. Table 2 ~ 4 show the wide range pressure different at total mass flow rate of 4.25, 5 and 10 kg/s. In particular, this paper focuses solely on comparing pressure loss induced by the working fluid flow. Thus, only the pressure difference excluding that caused by differences in pressure measurement axial locations is presented.

Table 2. Result at total mass flow rate of 4.25 kg/s

$\dot{m}_{left}:\dot{m}_{righ}$	Wide range pressure difference (kPa)	
	Left	Right
5 : 5	1.74	1.74
6 : 4	1.84	1.73
7 : 3	1.89	1.72
8 : 2	1.89	1.61

Table 3. Results at total mass flow rate of 5 kg/s

$\dot{m}_{left}:\dot{m}_{righ}$	Wide range pressure difference (kPa)	
	Left	Right
5 : 5	2.38	2.38
6 : 4	2.41	2.26
7 : 3	2.46	2.22

Table 4. Results at total mass flow rate of 10 kg/s

$\dot{m}_{left}:\dot{m}_{righ}$	Wide range pressure difference (kPa)	
	Left	Right
5 : 5	7.97	7.97
6 : 4	8.18	7.74

For all results, when the mass flow rate was in balance, the wide range pressure difference also showed same value to both left and right sides. As the difference in mass flow rate ratio between left and right sides increased, the pressure difference also increased. However, it did not occur proportionally to the difference of the mass flow rate. This is believed to be due to the dispersion of pressure loosed as the flow progresses, mixing with each other.

4. Conclusions

In this study, fundamental experimental results using a non-heated experimental facility that simulates asymmetric coolant inlet flow in the reactor core are presented in the form of a wide range pressure difference excluding a gravitational static pressure. The pressure difference results can be utilized as a basis for quantitative and qualitative evaluation of cross flow in the test section (reactor core) due to the asymmetric inlet condition. At the same time, it can contribute to assessment of the friction loss and form loss due to spacer grids.

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