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Measurements of Flow Mixing at Subchannels in a Wire-Wrapped 61-Rod Bundle for a Sodium Cooled Fast Reactor

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1. Introduction

Securing the structural integrity of a fuel assembly during reactor operation is of utmost importance in order to prevent reactor severe accident like the Fukushima nuclear power plant through a flow characteristics tests with test assembly scaled down from a prototype reactor of a sodium-cooled fast reactor (SFR) [1]. For a safety analysis in a core thermal design of a sodium-cooled fast reactor (SFR), flow mixing characteristics at subchannels in a wire-wrapped rod bundle are crucial factor for the design code verification and validation. Wrapped wires make a cross flow in a circumference of the fuel rod, and this effect lets flow be mixed [2, 3]. Therefore the sub-channel analysis method is commonly used for thermal hydraulic analysis of a SFR, a wire wrapped sub-channel type. To measure flow mixing characteristics, a wire mesh sensing technique can be useful method. A wire mesh sensor has been traditionally used to measure the void fraction of a two-phase flow field, i.e. gas and liquid [4]. However, the recent reports that the wire mesh sensor can be used successfully to recognize the flow field in liquid phase by injecting a tracing liquid with a different level of electric conductivity [5]. In this study, flow mixing experiments of 61-pin fuel assembly for sodium cooled fast reactor using a custom designed wire mesh sensor were conducted.

2. 61-pin fuel assembly test loop for flow mixing experiments

2.1 FIFFA test loop

The test loop for reactor core sub-channel flow test is shown in Fig.1, and the 61-pin test fuel assembly is to be installed at the central test section part. The test loop is named as 'FIFFA' (Flow Identification test loop for Fast reactor Fuel Assembly). The test loop consists of a tracing water tank, fuel rod with inside tube for water injection, and wire mesh sensor at the end of test assembly.

2.2 A wire mesh sensor design of 61-pin fuel assembly

A wire mesh system consists of a sensor and an electronic part. The sensor has both a transmitting electrode layer and receiving electrode layer with a short distance and an angle of 90°.

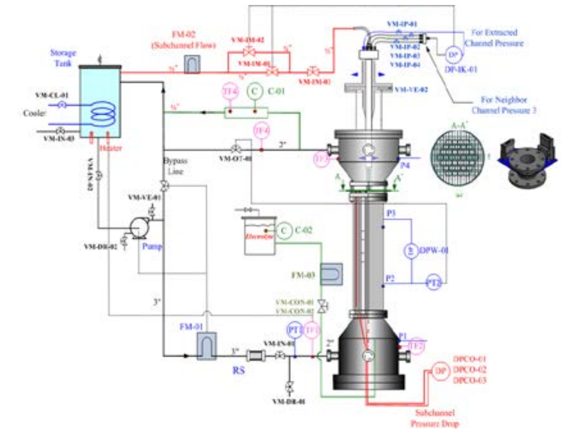


Fig. 1. Schematic drawing of the FIFFA test loop

As a driving voltage is supplied to the transmitting electrode layer, a current is derived in the receiving electrode layer. According to the electric conductivity level of the liquid between two layers, the derived currents are varied. Using this principle, a difference in the electric conductivity of the liquid across the cross points can be measured.

Wire mesh sensor was set up in the end of wire-wrapped 61-pin fuel assembly for a SFR with 5-mm distance. A cross point of the wires is fabricated to be located at the center or beside each subchannel. Active transmitting and receiving electrode wires consist of 19 × 19 using 32 × 32 channel, The schematic drawing and assembled pictures of the wire mesh sensor are shown in Fig. 2.

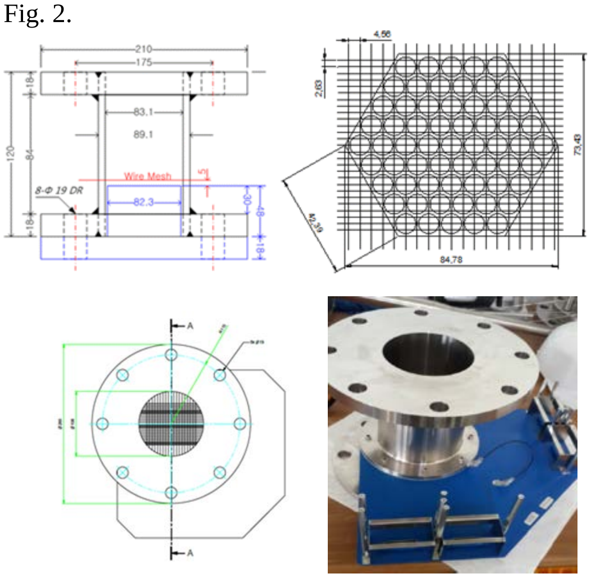


Fig. 2. Design of wire mesh sensor of 61pin wire mesh sensor

2.3 Experimental conditions

Geometry parameters are designed with a pitch to diameter ration (*P/D)* of 1.14 and wire lead length to diameter ratio (*H/D)* of 29.9. Hydrodynamic similarity with a SFR core is considered by matching these two geometric conditions (i.e., P/D and H/D).

A wire mesh sensor can receive electric conductivity level as integer values from 0 to 4079 (12 bits). We used deionized (DI) water as a background liquid, and tap water was injected as a tracing liquid. Because the conductivity of tap water is much higher than DI water, so it is available for a tracing liquid. The sensor gain was fixed as 100, and sampling frequency was also selected as 100 Hz. Every measurement was continued for 30 s including both homogeneous (~10 s) and injecting stage (~10 s) as shown in Fig. 3.

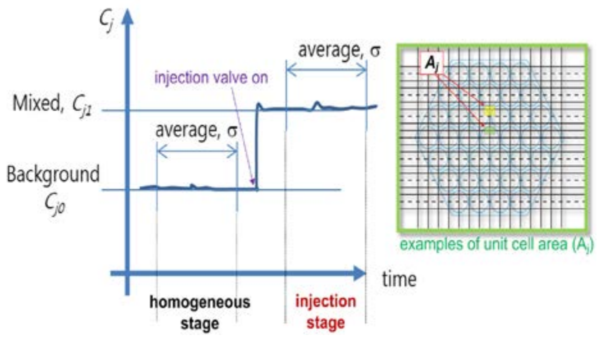


Fig. 3. Data acquisition procedure of each test.

3. Experiments results

3.1 Post-processing method

Eq. (1) shows our post-processing method considered both the unit cell area and the local value differences in homogeneous liquid. Especially, because wire mesh sensor was designed as an irregular type, weighting value was essential represented in Eq. (1).

$$C_{j,n} = \frac{C_{j1} - C_{j0}}{\sum_j A_j (C_{j1} - C_{j0}) / (\sum_j A_j)} \tag{1}$$

where $C_{j,n}$, C_{j1}, C_{j0}, A_j are $C_{j,n}$: normalized value on injection stage at each point. $C_{j1:}$: measured value on injection stage at each point. C_{j0} : measured value on injection stage at each point. A_j : unit cell area in mm^2 . From this process, uniformity in a homogeneous state is extremely increased and we can normalize the data in spite of conductivity increase of a background liquid as repeating experiments.

3.2 61-pin fuel assembly flow mixing results

There are two instruments rods deployed among 61 rods for measurements of mixing injection, as illustrated in Fig. 5.

Fig. 6 represents the flow fields from the flow mixing experiments using the wire mesh sensor and the post-processing method. In the case of an inner subchannel injection, injected liquid gradually diffused as shown in upper results (1H and 1L) of Fig. 5, because the cross flow by wrapped wires is almost eliminated for the opposite direction cross flow collision. However, in the case of an edge subchannel, all cross flow by wrapped wires should have the same direction: a clockwise direction without collisions. So, the peak point of the flow field should move around as edge walls of the fuel assembly as shown in lower results (60H and 60L) of Fig. 6.

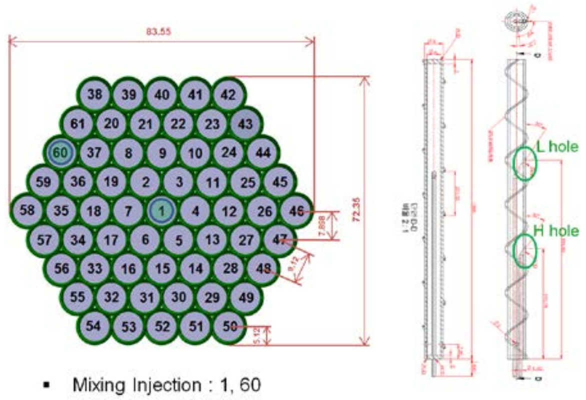


Fig. 5. Configuration of 61-pin mixing injection rods

Fig. 7 is shown in CFD analysis result at same mixing injection points. When comparing the experiments results and CFD analysis results, it showed very similar results.

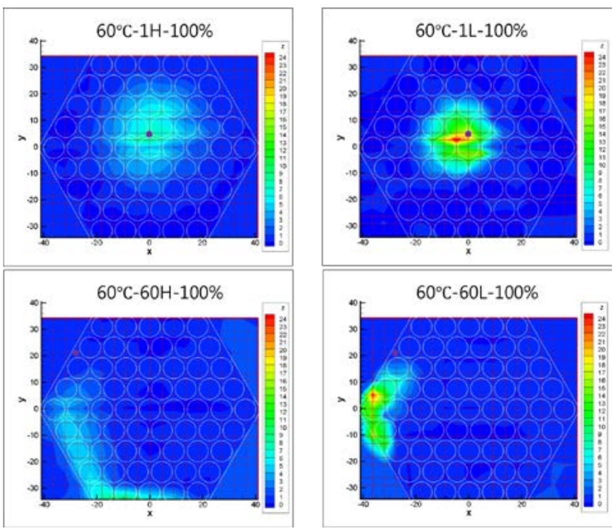
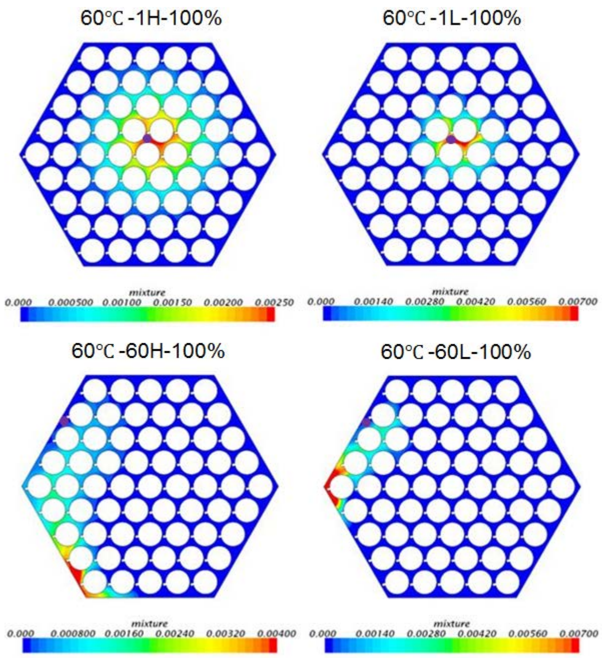


Fig. 6. 61-pin fuel assembly flow mixing results



4. Conclusions

The subchannel flow characteristics analysis method is commonly used for the thermal hydraulic analysis of a SFR, a wire wrapped subchannel type. In this study, mixing experiments were conducted successfully at a hexagonally arrayed 61-pin wire-wrapped fuel rod bundle test section. Wire mesh sensor was used to measure flow mixing characteristics. The developed post-processing method has its own merits, and flow mixing results were reasonable. Therefore, the data of mixing experiments can be used for design code verification and validation. Uncertainty analysis of 61-pin test assembly will conduct from now on.

ACKNOWLEDGMENTS

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