Experimental Identification of Flow Mixing in the Reactor Vessel under a High Convective and a Uniform Cold Leg Flow Condition

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1. Introduction

The mixing behavior of injected coolant having different properties from the cold leg or DVI (Direct Vessel Injection) nozzles inside the reactor is very important during a transient operation such as a reactivity insertion event owing to the rapid boron concentration or overcooling transient. Recently, the safety code capability has been enhanced that the multi-dimensional mixing behavior can be assessed. However, the experimental database is very limited for the validation of the code performance. This study aims at the generation of the benchmarking experimental database for a promising facilities representing the prototype plant behavior.

The mixing characteristics were identified by measuring the impedance transport for an asymmetric injection of fluid having different impedance. A new instrumentation to accurately measure the impedance of fluid flowing through the cold leg and hot leg pipes was developed. The current study includes the details of the test facilities, instrumentation and experimental results as well as the strategies of the test. [1,2]

2. Methods and Results

2.1 Test Facilities

The reactor vessel and inner structures of the REMIX facility are linearly scaled copies of the PWR prototype. By preserving the major flow path geometry and placing a flow condition having a sufficient high Reynolds number, the Euler number of the prototype reactor has been preserved in the test facility. The channel geometry, where the major reactor coolant should pass, should be preserved and appropriate scaling should be setup based on proper dimensionless parameters. Re and Eu numbers are usually considered important for flow mixing similar to the flow distribution test. For strict adherence to modeling criteria , the Reynolds number of the model and reactor should be equal , but Johnstown and Thring state that if the Reyno1ds number are greater than about 10 ,000 which is wel1 into the turbulent flow regime, the error induced by inequality of Reynolds numbers is not significant. [3]

The system includes the reactor vessel, reactor coolant system, shutdown cooling system (SCS), and chemical and volume control system (CVCS). The SCS and CVCS are important systems for the boron dilution event due to inadvertent operation of the CVCS during the shutdown cooling operation mode. For the current mixing test under high flow conditions, the SCS is isolated and the CVCS is utilized as a tracer injection system.

One cold leg, CL1B, among the four cold legs was utilized for the electrolyte injection. A pressurized tank containing electrolyte is connected to CL1B via flexible pipe. To simulate the impedance difference, the working fluid in the main system is demineralized water, and tap water mixing with $NaSO_4$ was utilized for the trace fluid.

The current study developed three core models for the scoping analysis of the mixing characteristics. The first is a free cavity model that simulates the core as a blank region while the outer shroud was preserved consistent with the prototype where a larger mixing effect can be expected than the prototype. The second one is simplified pipe model which simulates each fuel assembly as pipe having similar flow area. Since the pipe model does not have crossflow, most of the mixing occurs before the flow enters core region, which can yield conservative mixing results. The last is a realistic model having a mixing vane and spacer grid models, the design parameters of which were obtained after analyzing the pressure drop by using CFD. The vanes and spacers were simulated by holes having pressure drop similarity with prototype. The hydraulic diameter and the flow area of each fuel assembly were preserved by using nine rods which yields 2313 rods in total for the core. To minimize the flow distortion in the upstream of the core, a debris filtering bottom nozzle plate was fabricated by using 3D printer, which reflects the flow geometry realistically, consistent with the prototype.

2.2 Instrumentation

Fig. 1 shows the schematic of the overall instrumentations adopted in the REMIX facility. The instrumentation includes 18 pressure transmitters, 17 differential pressure transmitters, 11 flow meters, 36 thermocouples, 13 conductance sensors, as well as channel averaged impedance sensors and a wire mesh sensor. To control the thermal hydraulic parameters, the 21 flow control valves, 8 pumps, 3 heaters, and 4 water tanks were installed as displayed in Fig. 1. Table 1 summarizes the accuracy of used instrumentations

Table 1. Accuracy of Used Instrumentation

Instrumentation	Accuracy
PT/DPT (Rosemount 3051)	± 0.15 % of Span
Flowmeter (Siemens Sitrans FM MAG3100)	0.27% of Reading Value
Signal Converter (M8DY1)	±0.102 % of Span (Ω to V) ±0.141 % of Span (mA to V)
Conductivity (OMEGA Conductivity Sensor, CDCE-90-01)	2.0% of Reading Value
Wire Mesh Sensing System	2.0% of Reading Value
Channel Average Impedance Measuring System	2.06% of Reading Value
DAS (NI System)	±0.03 % of Span
TC (Watlow K)	±1.1 °C or 0.4 % (0 to 1,250 °C)

Six isolation valves indicated by red colored symbols are used for the boron dilution test, which will be carried out nearly stagnant flow conditions and for which the importantly considered volumes are the cold leg pump discharge lines, hot legs, SCS, CVCS, and reactor vessel. For the boron dilution test, the SG and pump components are isolated and not simulated.

The target flow is obtained by controlling the reactor coolant pump rpm referred by each cold leg flow rate. The temperature is controlled at each cold leg by controlling the heat exchanger's secondary flow rate by referring to the temperature measured by the thermocouples downstream of the heat exchanger.

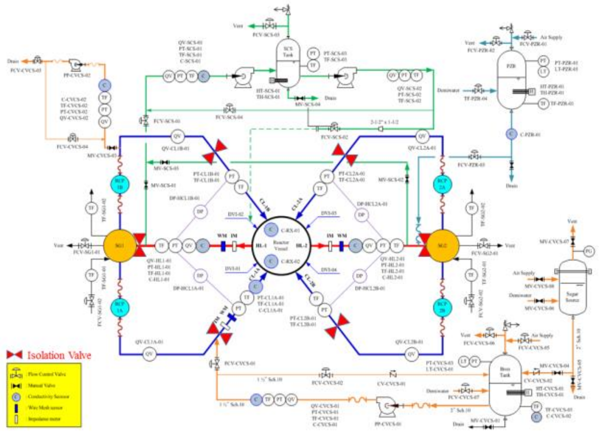

Fig. 1. Schematics of the overall piping and instrumentation

For the impedance measurement at the cold leg and hot legs, a channel average impedance measuring system has been developed based on the previous studies [4] The signal conditioner to measure the impedance is composed of a current generator, IO to/from impedance sensor, buffer amplifier and isolation amplifier. To verify the performance of the signal conditioner, two kinds of calibration process was conducted, which is separated check with the accurate resistors and in-situ calibration after installing. A set of impedance sensors was installed at the injected cold leg and two hot legs. To achieve a local conductance at the core inlet, the wire mesh measuring system was adopted with a corporation with HDZR of Germany. [5]

2.3 Results

Fig. 2 shows the typical results of the core inlet mixing factor distribution for the pipe core model, which shows a peak at the injected side as expected. The contour of the mixing factor has high non-equilibrium pattern because of the high convective flow condition.

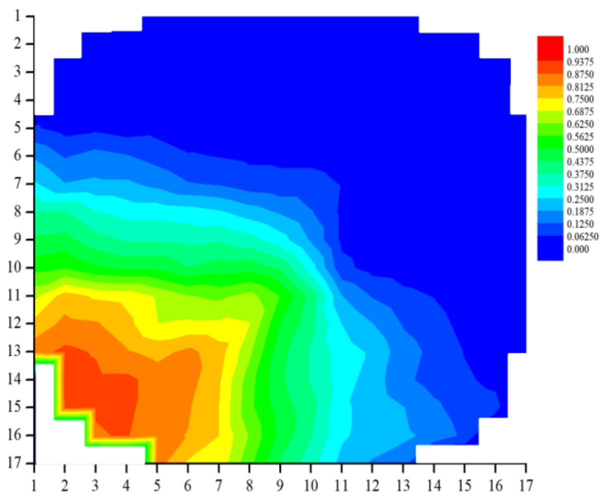

Fig. 2. Contour of the mixing factor at the core for a pipe core

model

3. Conclusions

The present study established a methodology for experimentally identifying the mixing characteristics of the injected cold leg flow through the downcomer and core to the hot legs. The facility was designed by the 1/5 linear scale law and all the geometric and thermal hydraulic parameters were set based on the scale. The mixing characteristics were identified by using the channel averaged impedance sensors and local wire mesh measuring system. The experimental data measured by using the REMIX facility can be used for validation of the safety analysis code and methodology. The database can also be used for a quantification of the performance of the various scales of the fluid dynamic analysis codes, including the systematic safety analysis, component scale, and CFD scale codes with respect to the multi-dimensional behavior prediction.

Acknowledgement

The authors would like to gratefully acknowledge the financial support of KHNP (Korea Hydro & Nuclear Power, Co., Ltd)

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