APR+ reactor core flow with 15% unbalanced flow conditions

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1. Introduction

The mixing characteristics of a core flow are regarded to be of major importance in improving the core thermal margin, which involves CHF limits. The objective of this experiment is to evaluate the mixing performance at the core inlet of the APR+ reactor with unbalanced 4-cold leg flow rates. The experiments were performed in the ACOP (APR+ COre Flow & Pressure) test facility, which was constructed with a 1/5 scale ratio of the APR+ reactor [1]. Three different tests, one case of balanced 4-cold leg flows and two cases of unbalanced 4-cold leg flows, were carried out under 4-pump running conditions. The coolant mixing characteristics were identified quantitatively by measuring the mass flow rates at the inlet of 257 core simulators representing an individual fuel assembly. The results were carefully examined through the core inlet flow distributions of each steady-state test.

2. Test facility

2.1 Scaling and test conditions

The ACOP test facility was designed with a principle of similarity to preserve the main flow path inside the reactor vessel. More specifically, the internal structures in the low plenum, such as the lower support structure, flow skirt and ICI nozzles, were manufactured with a linear reduced scale to preserve the internal volume and flow area at the core inlet, as shown in Fig.1. The detailed description of the ACOP test facility is shown in Ref [2].

The scaling ratio and test conditions applied to this study are shown in Tables 1 and 2, respectively. The ACOP test facility was designed to operate at 0.2MPa and 60^{o}C with about a 1/45 Reynolds number ratio for a sufficient turbulent flow condition. Two unbalanced flow tests, symmetric and asymmetric flow conditions, were independently carried out, and the balanced flow test was set as a reference for comparison with the others.

2.2 Instrumentation at the core inlet

The 257 core simulators were assembled in the ACOP test facility to simulate the core region of the APR+ reactor. The configuration of the 257 core simulators is shown in Fig. 2. The core simulator was designed to have the same hydraulic characteristic as a real HIPER fuel assembly, and evaluated experimentally to verify the axial pressure drop and cross flow characteristics in previous works [3, 4]. The inlet flow rates can be calculated using the calibrated discharge coefficients and the measured differential pressures at the inlet of 257 core simulators.

Table 1. Scaling ratio for test conditions

Parameter	APR+	Scaling Ratio	ACOP(1)	ACOP(2)
Temperature [°C]	310	-	60	60
Pressure [MPa]	15	-	0.2	0.2
Length ratio [-]	1	l_R	1/5	1/5
Height ratio [-]	1	l_R	1/5	1/5
Diameter or width ratio [-]	1	l_R	1/5	1/5
Area ratio [-]	1	l_R^2	1/25	1/25
Volume ratio [-]	1	l_R^3	1/125	1/125
Aspect ratio [-]	1	1	1.0	1.0
Velocity ratio, [-]	1	V_R	1/2.30	1/2.48
Mass Flow ratio, [-]	1	$\rho_R V_R l_R^2$	1/41.0	1/44.4
Density ratio [-]	1	ρ_R	1.40	1.40
Viscosity ratio [-]	1	μ_R	5.53	5.53
Ex-core Re ratio [-]	1	$\rho_R V_R^2 D_R/\mu_R$	1/43.3	1/46.8
DP ratio [-]	1	$\rho_R V_R^2$	1/3.79	1/4.42

(1) Balanced flow condition
(2) Unbalanced flow condition

Table 2. Test conditions

4-Pump test conditions		CL1-A	CL-1B	CL-2A	CL-2B	Total
Balanced flow	Flow ratio	0.250	0.250	0.250	0.250	1.00
	Inlet mass flow rates [kg/s]	128.0	128.0	128.0	128.0	512.0
Unbalanced flow (1)	Flow ratio	0.270	0.270	0.230	0.230	1.00
	Inlet mass flow rates [kg/s]	128.0	128.0	108.8	108.8	473.6
Unbalanced flow (2)	Flow ratio	0.230	0.270	0.230	0.270	1.00
	Inlet mass flow rates [kg/s]	108.8	128.0	108.8	128.0	473.6

Fig. 1 Internal structures in the low plenum

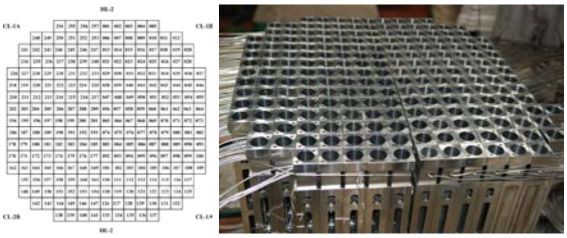

Fig. 2 Configuration of core simulator

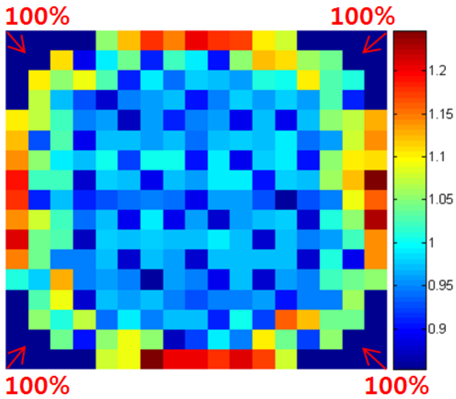

Fig. 3 Core inlet flow distribution of balanced test

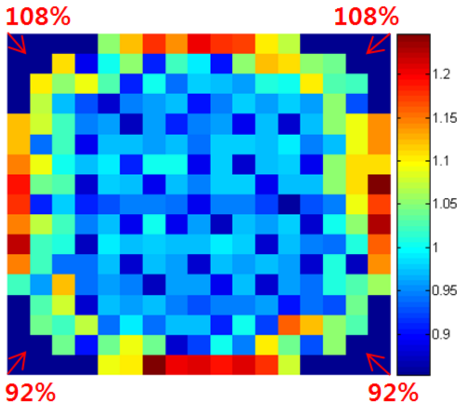

Fig. 4 Core inlet flow distribution of unbalanced test

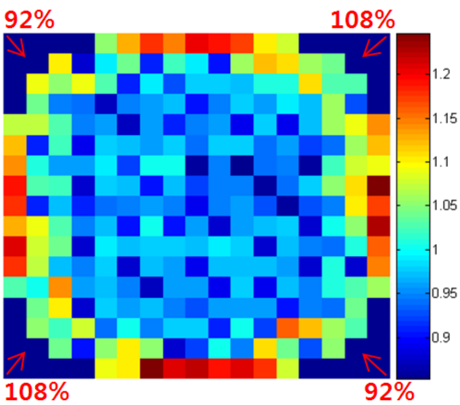

Fig. 5 Core inlet flow distribution of unbalanced test

3. Test results

The measured core inlet flow rates per core simulator were converted into a normalized form by dividing the average core inlet flow rate, since the total flow rates of the unbalanced tests were different with those of the balanced test. The normalized core inlet flow rates for the three tests are shown in Fig. 3 to 5. There were 257 discrete points on the contour map along the locations of the core simulators.

The three contour maps showed very similar distributions within a 5% difference when comparing the results of unbalanced tests with those of a balanced test. The distributions of the balanced and unbalanced tests showed a similar range of 85% to 126%. This means that the altered coolant flows by the cold legs were sufficiently mixed by passing through the flow skirt structure in the lower plenum.

4. Conclusion

In this study, the coolant mixing characteristics at the core inlet were evaluated experimentally under 15% unbalanced flow conditions of the cold legs. The inlet flow rates at 257 core simulators were measured, and the results were discussed through the distributions of the normalized core inlet flow rates. In an overall sense, the results of the unbalanced tests were reasonable considering the performance of the coolant mixing even with the severe unbalanced flow conditions.

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