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Experimental Validation of the LSS Design Change for Uniform Core Flow

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1. Introduction

The uniform core flow distribution of an Advanced Power Reactor Plus (APR+) is required to prevent the failure rate of the HIPER fuel assembly and to ensure the core thermal margin. Experimental program launched by KAERI has been performed to investigate the hydraulic characteristics of the APR+ reactor including core region since 2011. In the previous research [1-3], they found that the intact design of the Lower Support Structure Bottom Plate (LSSBP) of the APR+ can induce a negative effect considering the uniformity at the core region. It means that the core flow rates were intense especially near the edge region of the intact LSSBP. Therefore, KAERI proposed the design change of the Lower Support Structure Bottom Plate (LSSBP) to reduce the excessive large flow rate at the core edge region. In this study, an experimental study were carried out to evaluate the effect of the design change of the LSSBP on the core flow distribution, although some test results were already reported in the literature [1-4].

Same test facility with the previous works, named APR+ Core Flow & Pressure (ACOP) test facility which was constructed with a reduced linear scale of 1/5 referring to an APR+ reactor is used, but the comprehensive experimental test conditions were considered in this study. The tests were performed under three different flow conditions, such as a 4-pump balanced flow, 4-pump unbalanced flow, and 3-pump flow conditions. The same test procedure and conditions were applied to the current study for comparison with the previous test results.

2. Test Facility and Design change of the LSS

The ACOP test facility was exactly construed with a 1/5 linear scaling ratio to simulate the fluid flow phenomena of the APR+ reactor. The main test section including all of the internal structures were designed with conserving the geometric and dynamic similarity by using a scale analysis. The main design parameters of the ACOP test facility are summarized in Table 1. The test condition was also determined according to the similarity principle as shown in Table 2. The detailed explanation for the main test section, piping system and data acquisition system were described well in the literature [1, 2], and thus the current study will elaborate on the design change of the LSSBP.

Table I: Scaling Parameters of ACOP Test Facility [2]

Parameter	Scaling Ratio	ACOP
Temperature [ºC]	-	60
Pressure [MPa]	-	0.2
Length ratio	l_R	1/5
Height ratio	l_R	1/5
Diameter	l_R	1/5
Area ratio	l_R^2	1/25
Volume ratio	l_R^3	1/125
Aspect ratio	1	1.0
Velocity ratio	V_R	1/2.16
Mass Flow ratio	$\rho_R V_R l_R^2$	1/39.0
Density ratio	ρ_R	1.40
Viscosity ratio	μ_R	5.53
Ex-core Re ratio	$\rho_R V_R^2 D_R/\mu_R$	1/40.9
DP ratio	$\rho_R V_R^2$	1/2.58

Table II: Test Conditions

Parameter	4P-B (Balanced)	4P-U Unbalanced	3P
Cold Leg Pressure, kPa		370~380	
Total Core Flow, kg/s	540	540	347.8
Cold Leg 01, kg/s	135	136.1	160
Cold Leg 02, kg/s	135	136.1	62.6
Cold Leg 03, kg/s	135	130.7	125.2
Cold Leg 04, kg/s	135	137.1	125.2
Temperature, ºC		60	

The ACOP main test section is shown in Fig. 1. The LSSBP is located in the lower plenum. The LSSBP have many holes to stabilize the fluid flow from the lower plenum to the core inlet region. As shown in Fig. 1, the edge region of the LSSBP have low hydraulic resistance, and thus it can induce the high flow rate. There are 16 different types of zones, among them, the holes of the outer region of the 11 zones were blocked up to the 50%

of the intact flow area. Figure 2 shows an example of 50% blockage holes.

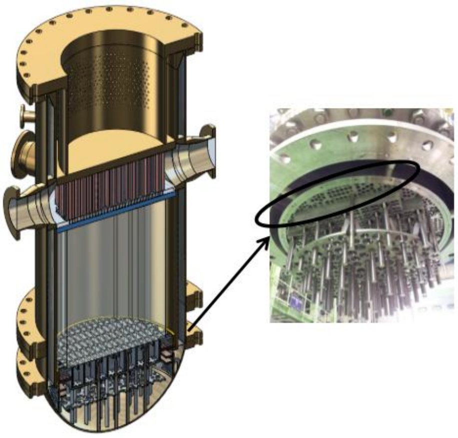


Fig. 1. High Flow Rate Region of the LSSBP in the ACOP

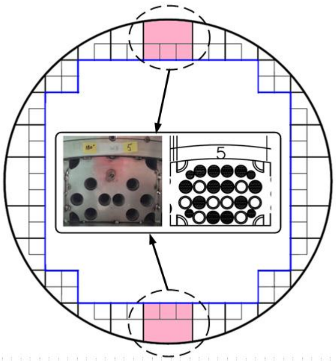


Fig. 2. Example of the 50% Blockage Holes

3. Test results

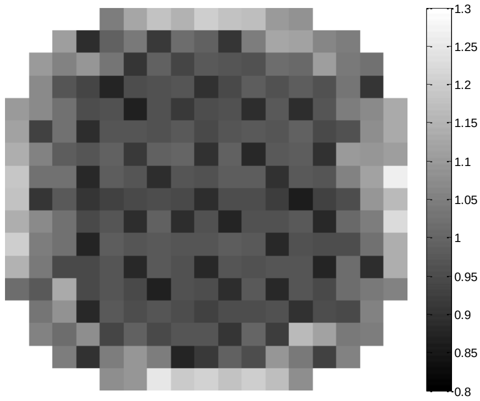
The core region of the ACOP test facility were simulated by using 257 core simulators to measure the core inlet flow rates and core outlet pressure simultaneously [1]. For the each test conditions as shown in Table 2, several independent tests were carried out, and the each test results were checked about the repeatability, and mass balance, and pressure drop balance with the ensemble averaged values. All results shows a good agreement within 2.0% relative errors, although not shown here.

Figures 3 and 4 show the contour maps of the normalized core inlet flow rates and core exit pressure distribution obtained from the current tests. The core inlet flow rates and outlet pressure were normalized by using the averaged values as follows;

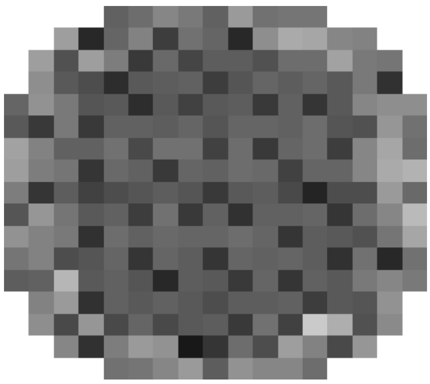
$$W_{core\ inlet,i} = \frac{W_{core\ inlet,i}}{\overline{W}_{core\ inlet,}},$$

$$E_{Exit,i} = \frac{P_{exit,i} - \overline{P}_{exit}}{\overline{P}_{inlet} - \overline{P}_{exit}}. \quad (1)$$

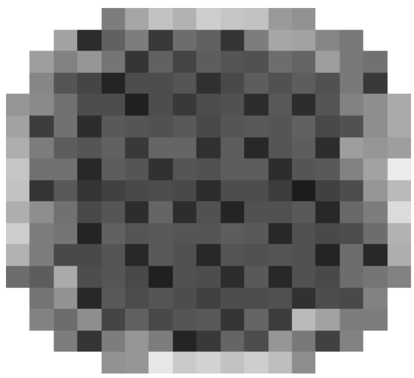
The current test results were compared with that of the previous tests [1]. As shown in Fig. 3, all flow rates at the outer region were greatly decreased from 8.1~19.7%. Figure 4 also shows the normalized core inlet flow rates along the x-direction at the centerline of Fig. 3. As shown in Fig. 4, the decreased high flow rates at the outer region cause the increase the overall inlet flow rates. This tendency is expected to improve the core thermal margin in the nuclear safety analysis.



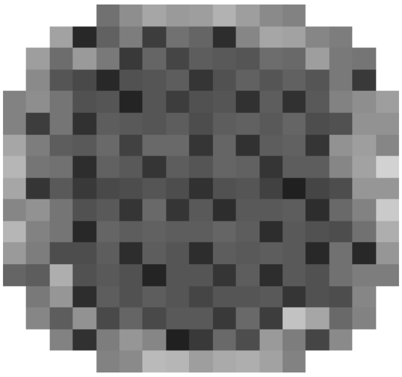
(a) 4P-B [1]



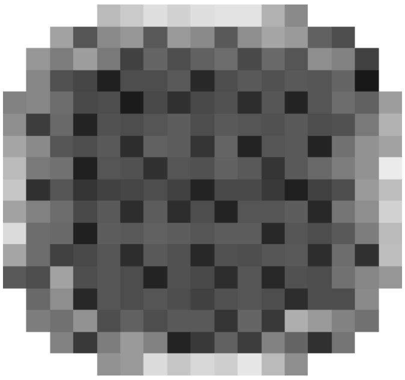
(b) 4P-B



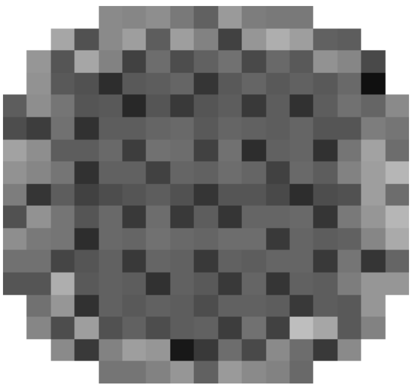
(c) 4P-U [1]



(d) 4P-U



(e) 3P [1]



(f) 3P

Fig. 3. Comparison of the Normalized Core Inlet Flow Rates

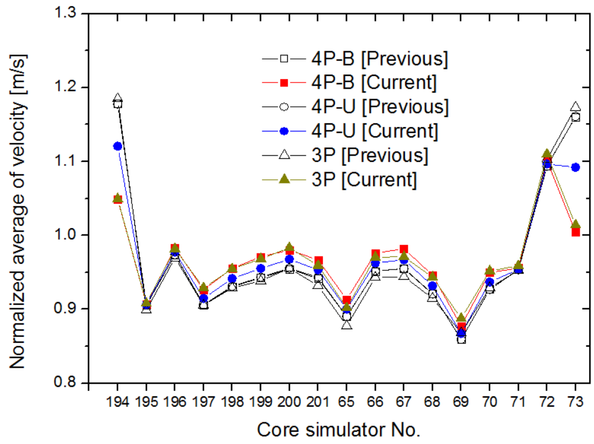
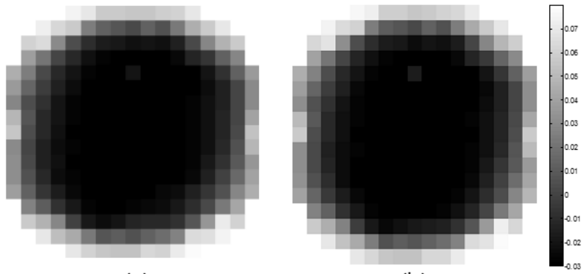


Fig. 4. Normalized Core Inlet Flow Rates along the x-direction



(a) (b)

Fig. 5. Contour map of the core outlet pressure distribution (a: 4P-balanced, b:4P-balanced for intact LSS [4])

Figure 8 shows the outlet pressure distributions for the 4-pump balanced flow condition. The core exit pressure distributions of the two tests were very similar to each other, as shown in Fig. 5. The core exit pressures were more uniformly distributed compared with those of the core inlet flow, since the coolant was mixed again passing through the core region due to the cross flow between the adjacent core simulators. It was also noted that the total pressure loss from the cold leg to hot leg increased about 1.2% comparing with the previous test result because of the increase of the hydraulic resistance at the LSS, but the fraction is negligible considering the total pressure loss.

4. Conclusion

For three different test conditions, comprehensive experimental study was carried out to validate the design change of the LSSBP. This study focuses on the core inlet flow rate and outlet pressure distributions for the test conditions, since the distributions can be used as an input data in the safety analysis. All test results were analyzed with an ensemble averaged values, and compared with that of the intact LSSBP. The results showed great improvement considering the uniformity at the core region. The changed design of the LSSBP is expected to improve the core thermal margin of an APR+ reactor.

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