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Effect of the design change of the LSSBP on core flow distribution of APR+ Reactor

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1. Introduction

The uniform core inlet flow distribution of an Advanced Power Reactor Plus (APR+) is required to prevent the failure rate of the HIPER fuel assembly and improve the core thermal margin. KEPCO-E&C and KAERI proposed a design change of the Lower Support Structure Bottom Plate (LSSBP), since the core flow rates were intense near the outer region of the intact LSSBP in a previous study. In this study, an experiment was carried out to evaluate the effect of the design change of the LSSBP on the core flow distribution using the APR+ Core Flow & Pressure (ACOP) test facility. The results showed great improvement on the core flow distribution under a 4-pump balanced flow condition.

2. Introduction

An experimental program launched by KAERI has been conducted to investigate the hydraulic characteristics of an APR+ reactor including the core region since 2011. The ACOP test facility was constructed with a reduced linear scale of 1/5 referring to an APR+ reactor. KAERI has been successfully conducted various hydraulic experiments, which were a 4-pump balanced flow, 4-pump unbalanced flow, and 3-pump flow conditions. The test results were carefully analyzed, and have been reported in the literature [1 to 3]. In their experiments, regardless of the test conditions, the core inlet flow rates near the outer region showed very large deviations compared with the average core inlet flow rates. They concluded that the large deviations around the outer core region could be a drawback, since the high inlet flow rates may increase the failure rate of the fuel assemblies located on the outer region the core, and could not ensure or improve the core thermal margin of an APR+ reactor.

The pressure drop caused by the LSSBP is the main reason for the large flow deviation at the core inlet. Therefore, KAERI proposed the design change of an LSSBP to mitigate the high flow rate, and conducted a preliminary CFD analysis using CFX version 14 to obtain the optimal design of the LSSBP [4], although it is not shown here. From the results of the CFD analysis, KEPCO-E&C and KAERI proposed a 50% blockage of the flow holes on the outer region of the LSSBP. In this study, several experiments under a 4-pump balanced flow conditions were conducted to validate the effect of the flow holes on the LSSBP, and the test results were carefully examined comparing with the previous results of the intact LSSBP.

3. Design change of the ACOP test facility

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, was designed by conserving the geometric and dynamic similarity 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 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: Design Parameters of ACOP Test Facility [2]

Parameter	Scaling Ratio	ACOP
Temperature [°C]	-	60
Pressure [MPa]	-	0.2
Length ratio [-]	l_R	1/5
Height ratio [-]	l_R	1/5
Diameter or width ratio [-]	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 of 4-Pump Balanced Flow

System Pressure (Cold Leg) [kPa]	370~380
System Temperature, ℃	60.0
Each Cold Leg Mass Flow [kg/s]	135.0
Each Holt Leg Mass Flow [kg/s]	270.0

Total Core Mass Flow [kg/s]	540.0

The ACOP main test section is shown in Fig. 1. The LSSBP is located in the lower plenum, and there are many holes to stabilize the fluid flow from the lower plenum to the core region. As shown in Fig. 1, there is a high flow rate region owing to the relatively low hydraulic resistance, in which there are 16 different types of zones. In this study, the holes of the outer region of the LSSBP were blocked at up to 50% of the flow area. Figure 2 shows an example of 50% blockage holes in zone 8.

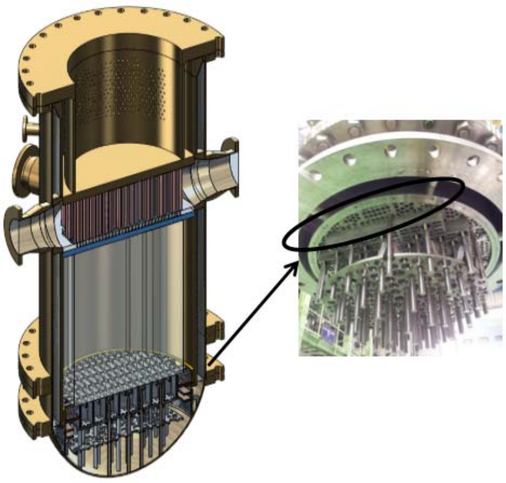


Fig. 1. High Flow Rate Region of the LSSBP in the ACOP

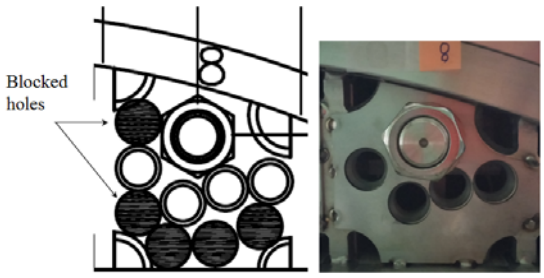
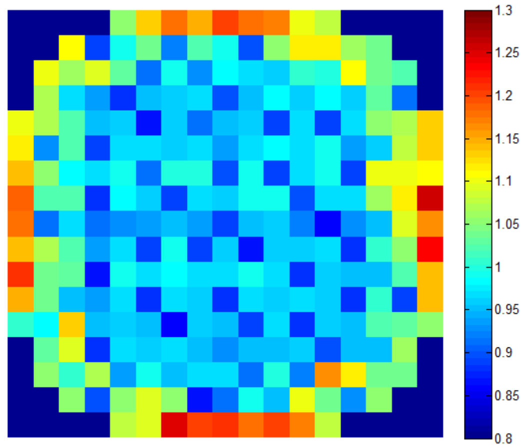


Fig. 2. Example of the 50% Blockage Holes on Zone 8

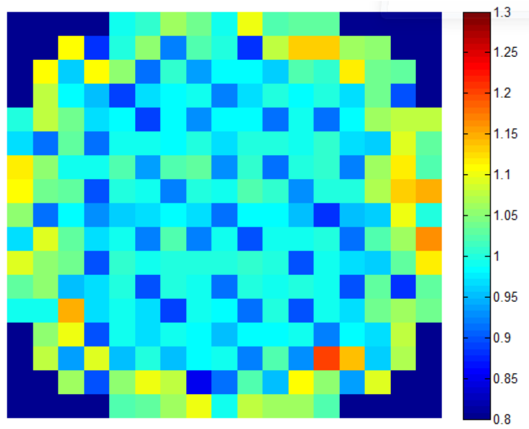
4. Test results

The core region of the ACOP test facility was simulated using 257 core simulators to measure the core inlet flow rates [1]. Under the 4-pump balanced flow condition, fifteen tests were carried out independently, and the test results were checked regarding the repeatability, and mass balance, pressure drop balance using the ensemble averaged values. All results show good agreement within 2.0% relative errors.

Figure 3 shows the contour maps of the normalized core inlet flow rates, which were ensemble averaged values of all fifteen tests. The current test results were compared with that of the previous tests [1]. As shown in Fig. 3, the flow rates at the outer region were greatly decreased, ranging from -4.6% to -18.3%. 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 an increase the overall inlet flow rates. This tendency is expected to improve the thermal margin and reduce the failure rates of the fuel assemblies at the outer region simultaneously.



(a) Previous Result [1]



(b) Current Result

Fig. 3. Normalized Core Inlet Flow Rates Contour Map

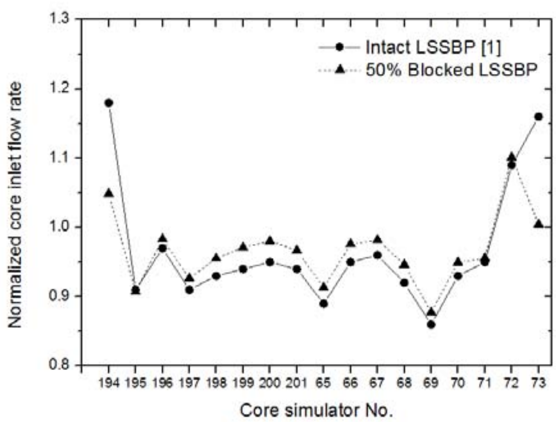


Fig. 4. Normalized Core Inlet Flow Rates along the x-direction

5. Conclusion

Under the 4-pump balanced flow condition, fifteen tests were repeated using the ACOP test facility to verify the effect of the 50% blocked flow area at the outer region of the LSSBP on the core inlet flow distribution. The profiles of the core inlet mass flow rates were analyzed using ensemble averaged values, and compared with that of the intact LSSBP. The results showed great improvement for the overall core region. The change in design of the LSSBP is expected to improve the hydraulic performance of an APR+ reactor.

REFERENCES

[1] Euh, D.J., Kim, K., Youn, Y.J., Bae, J.H., Chu, I.C., Kim, J.T., Kang, H.S., Choi, H.S., Lee, S.T., Kwon, T.S., A flow and pressure distribution of APR+ reactor under the 4-pump running conditions with a balanced flow rate, Nuclear and Technology, Vol. 44, pp. 735-744, 2012.

[2] Kim, K., Euh, D.J., Chu, I.C., Youn, Y.J., Choi, H.S., Kwon, T.S., Experimental study of the APR+ reactor core flow and pressure distributions under 4-pump running conditions, Nuclear Engineering and Design, Vol. 265, pp. 957-966, 2013.

[3] Euh, D.J., Kim K., Youn, Y.J., Chu, I.C., Choi, H.S., Lee, S.T., Kwon, T.S., Identification of Asymmetry Reactor Flow Characteristics for a Single Pump Failure Condition with 1/5 Scale linearly Reduced Facilities Referring to APR+, Proceedings of ICAPP 2014, Charlotte, USA, April 6-9, 2014.

[4] Kim, K., T.S. Kwon, Euh, D.J., A preliminary CFD analysis of the lower hole change effect on a flow distribution of reactor, Proceedings of Korea Society for Fluid Machinery, Jeju, November 27-29, 2013.