A Single Hydraulic Test for APR+ Reactor Flow Distribution under a Uniform Pump Flow Condition

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1. Introduction

To analyze the hydraulic design characteristics of an APR+ reactor, a test facility named “ACOP” was constructed. ACOP was designed with a linearly reduced scale of 1/5 as a prototype reactor to preserve the flow distribution characteristics. Among the test matrix, a single hydraulic test corresponding to a uniform 4-pump flow condition was performed for the reactor flow distribution. The test condition has around a 1/40 Re number scale ratio, when compared with the APR+ nominal flow conditions, which is a sufficient turbulent condition. The distributions of the core outlet pressures and core inlet flow rates were measured for an analysis of the reactor thermal margin. To verify the hydraulic design of the reactor, the segmental and overall pressure losses along the main coolant flow paths were measured in the test facility.

2. Design and Scaling

2.1 Scaling Ratio

To preserve the flow characteristics, the ACOP was linearly reduced at a scaling ratio of 1/5 and conserved the flow geometry of the APR+ reactor. The scaling relations adapted in the ACOP facilities with respect to the APR+ reactor are summarized in Table 1.

Table 1: Summary of Parameter Scaling

	APR+	Scaling Ratio	ACOP
Temperature, ^{o}C	310	-	60
Pressure, MPa	15	-	0.2
Length Ratio, -	1	l_R	1/5
Height Ratio, -	1	l_R	1/5
Diameter or Width Ratio, -	1	l_R	1/5
Area Ratio, -	1	$\boldsymbol{l_R^2}$	1/25
Volume Ratio, -	1	$\boldsymbol{l_R^3}$	1/125
Aspect Ratio, -	1	-	1.0
Velocity Ratio, -	1	$\boldsymbol{V_R}$	1/2.16
Mass Flow Ratio, -	1	$\boldsymbol{\rho_R V_R l_R^2}$	1/39.0
Density, kg/m^3	704	$\boldsymbol{\rho_R}$	983.2
Density Ratio	1	$\boldsymbol{\rho_R}$	1.40
Viscosity, Ns/m^2	8.43e-5	$\boldsymbol{\mu_R}$	4.66e-04
Viscosity Ratio, -	1	$\boldsymbol{\mu_R}$	5.53
Ex-Core Re Ratio, -	1	$\frac{\rho_R V_R D_R}{\mu_R}$	1/40.9
DP Ratio, -	1	$\boldsymbol{\rho_R V_R^2}$	1/2.58

2.2 System Configuration

The ACOP test facility preserves the flow geometry in the reactor’s major flow path and the connection goemetry of the cold and hot legs to the reactor vessel. Each of the legs has a flow meter along with pressure and temperature sensors. Each cold leg has an independent pump, and the flow and temperature are controlled with a heat exchanger installed at each cold leg. The system pressure is controlled by a pressure control tank installed above the reactor simulator.

The core inlet flow distribution and outlet pressure distribution, to supply data to estimate the thermal margins of the reactor, were simulated by using 257 simulators, which conserve the pressure drop of the fuel assemblies calibrated accurately in a separated facility named “CALIP”.

The loop flow, pressure, and temperature were measured using vortex flow meters and smart type pressure transmitters and RTDs. In total, 9 points of static pressure, 327 differential pressures for the pressure distributions, and 257 differential pressures for the core inlet flow rates were measured with a limited number of differential pressure transmitters using sequentially operated solenoid valves. The 9 RTDs were installed to control and measure the primary system temperature.

3. Results

The test matrix consists of a minimum of 29 steady state flow conditions, which include 15 symmetric and 5 asymmetric flow conditions of a 4-loop operation, and 9 asymmetric flow conditions with a 3-loop operation simulating a pump failure. As a first step, a single test case, ACOP-4P-A-026, was described in the current study, which is related to the symmetric flow condition. The major flow parameters are summarized in Table 2.

The results show that the core inlet flow distribution covers 86.0% to 126% of the average fuel assembly flow rate, of which the minimum value is considered to be a relatively large flow ratio when compared with other system results. The core outlet pressure distribution has a range of 96.3% to 107% of core pressure drop. The sectional pressure drops along the major flow path were measured, correponding to Fig. 1. The mass difference of the total flow rate between the hot legs and cold legs were 0.4%, and the total core flow rates were less than 2.3% lower than the cold leg flow rates, which is a very good mass balance. The summation of the segmental pressure drops is 2% larger than the differental pressure between CL to HL, which is also an excellent pressure drop balance.

Table 2 Test Condition

Parameter	Values	Comment
Pressure 1, kPa	375.3	CL1A
Total Loop Flow, kg/s	540.0	
Loop-01, kg/s	135.0	CL1A
Loop-02, kg/s	135.0	CL1B
Loop-03, kg/s	135.0	CL2A
Loop-04, kg/s	135.0	CL2B
Temperature, ^{o}C	59.9	CL1A

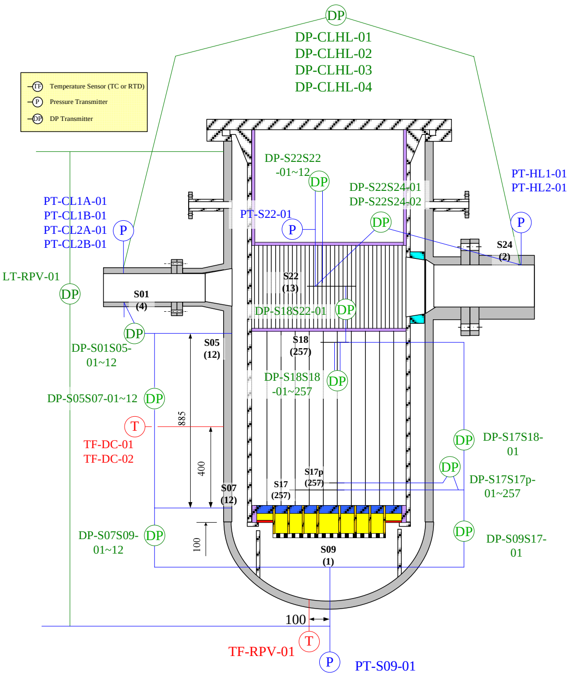

Fig. 1. Measuring Points inside Reactor Simulator

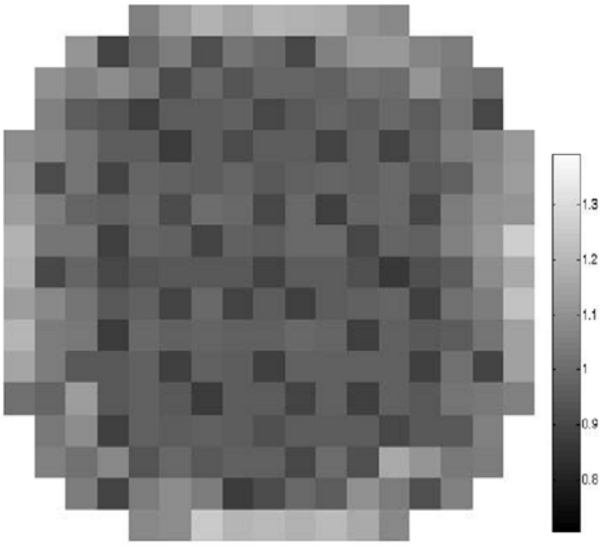

Fig. 2. Dimensionless Core Inlet Flow Distribution

3. Conclusions

To identify the flow and pressure distribution of the APR+ reactor, a single hydraulic test for a uniform pump flow condition was performed at a 1/5 linearly reduced scale of the test facility, ACOP. The results show that the data set has good consistency at the measurement of the mass flow rate and pressure drops. The inlet flow distribution shows that the minimum channel flow ratio of APR+ is higher than in OPR1000 or APR1400. The data set of the current study will contribute toward setting the final statistical results for the APR+ reactor flow and pressure distribution. The data will be utilized for an analysis of the safety and system hydraulic performance of the APR+ reactor.

Acknowledgement

The authors would like to gratefully acknowledge the financial support of Ministry of Knowlege and Economy.

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