Development of a Test Facility to Simulate the Reactor Flow Distribution of APR+

D.J. Euh[a*], S.Cho, Y.J. Youn[a], J.T.Kim[a], H.S.Kang[a], T.S. Kwon[a]
[a]*Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejeon, 305-600, Rep. of KOREA*
[*]*Corresponding author: djeuh@kaeri.re.kr*

1. Introduction

Recently a design of new reactor, APR+, is being developed, as an advanced type of APR1400. In order to analyze the thermal margin and hydraulic characteristics of APR+, quantification tests for flow and pressure distribution with a conservation of flow geometry are necessary.

Hetsroni (1967) proposed four principal parameters for a hydraulic model representing a nuclear reactor prototype: geometry, relative roughness, Reynolds number, and Euler number. He concluded that the Euler number should be similar in the prototype and model under the preservation of the aspect ratio on the flow path. The effect of the Reynolds number at its higher values on the Euler number is rather small, since the dependency of the form and frictional loss coefficients on the Reynolds number is seen to be small.

ABB-CE has carried out several reactor flow model test programs, mostly for its prototype reactors. A series of tests were conducted using a 3/16 scale reactor model. (see Lee et al., 2001). Lee et al (1991) performed experimental studies using a 1/5.03 scale reactor flow model of Yong-gwang nuclear units 3 and 4. They showed that the measured data met the acceptance criteria and were suitable for their intended use in terms of performance and safety analyses.

The design of current test facility was based on the conservation of Euler number which is a ratio of pressure drop to dynamic pressure with a sufficiently turbulent region having a high Reynolds number. By referring to the previous study, the APR+ design is linearly reduced to 1/5 ratio with a 1/2 of the velocity scale, which yields a 1/39.7 of Reynolds number scaling ratio. In the present study, the design feature of the facilities, named "ACOP", in order to investigate flow and pressure distribution are described.

2. Design Features of ACOP

2.1 Scaling

In order to preserve the flow characteristics of the prototype reactor, APR+, a test facility, ACOP, is designed with a 1/5 of scaling ratio of prototype under the conserved geometry of major flow path. The scaling relations adapted in the ACOP facility with respect to the APR+ reactor are summarized in Table 1.

Table I: Summary of Scaling of ACOP

	APR+	Scaling Ratio	ACOP
Temperature, ^oC	310	-	60
Pressure, MPa	15.3	-	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
Mass Flow Ratio, -	1	$\boldsymbol{\rho_R V_R l_R^2}$	1/36
Density, kg/m^3	705.8	$\boldsymbol{\rho_R}$	983.2
Density Ratio	1	$\boldsymbol{\rho_R}$	1.39
Viscosity, Ns/m^2	8.88e-5	$\boldsymbol{\mu_R}$	4.67e-04
Viscosity Ratio, -	1	$\boldsymbol{\mu_R}$	5.26
Core Re Ratio, -	1	$\frac{\rho_R V_R D_R}{\mu_R}$	1/2.76
Ex-Core Re Ratio, -	1	$\frac{\rho_R V_R D_R}{\mu_R}$	1/37.8
DP Ratio, -	1	$\boldsymbol{\rho_R V_R^2}$	1/1.44

2.2 System Descripton

An overall configuration of the test facilities are shown in Fig. 1. ACOP has the same configuration near the reactor vessel having two hot legs and 4 cold legs. Since the facility is focused on the hydraulics, ACOP does not have steam generators, so that each hot leg is splitted into two cold legs and enters into pump, respectively. A centrifugal pump is installed in each cold leg, which has a nominal flow of 500 m^3/hr. The flow can be controlled by a VVVF type of inverter. Each cold leg has a heat exchanger of tube and shell type, which controlls the loop flow temperature by using flow control valve at secondary side. The secondary system consists of a cooling pump, flow control valves, a cooling tower and a flow meter and RTDs. The primary system pressure is controlled by a pressure control tank which is installed above the reactor simulator.

The major flow path inside the ACOP reactor vessel simulator has the same configuration and shape as that of APR+ except for the core region. The APR+ core consists of 257 fuel assemblies, each of which has 16X16 fuel rods. ACOP simplifies the fuel assembly into a hydraulic simulator having the same axial flow resistance and lateral crossflow characteristics. In order to supply boundary condition to estimate thermal margins of the reactor, the distribution of inlet core flow and core exit pressure should be measured in each of 257 fuel assembly simulators. A venturi type of design has been adapted for the measurement of core inlet flow. Three pressure delivery tubes per fuel assembly simulator should be drawn out of the reactor vessel for measurement; two lines for differential pressure in venturi and a line for outlet static pressure. All the 257 simulators for fuel assemblies are calibrated accurately in the separated facilities named "CALIP".

Each loop flow is measured by volumetric flow meter, which reduces into mass flow rate by referring a pressure and a temperature measured at downsteam of each flow meter. The loop flow, pressure, and temperature would be measured by using vortex flow meters and smart type pressure transmitters and RTDs. The major measured parameters inside the reactor simulators are pressures or differential pressures.

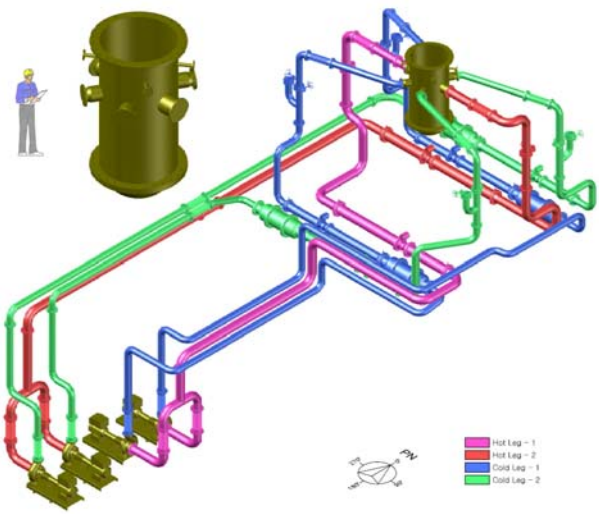

Fig. 1. Bird's eye View of ACOP Test Facilities.

Fig. 2 shows an instrumentation diagram inside the reactor vessel simulator. Sectional pressure drops are measured along the major flow path. Each level in the downcomer section has 12 measuring points in azimuthal angle. The pressure distribution at upper plenum as well as at core exit can be measured by using differential pressures and a reference pressure.

In total, 571 points of static pressure and differential pressures would be measured with a limited number of differential pressure transmitters. The application of same number of trasnmitters is impractical and impossible with respect to setup space, budget, and maintenance. In order to measure the huge number of points of pressures, this study developed a efficient way by using sequentially operated solenoid valves. By using the solenoid valve network, the number of instruments could be reduced to 41.

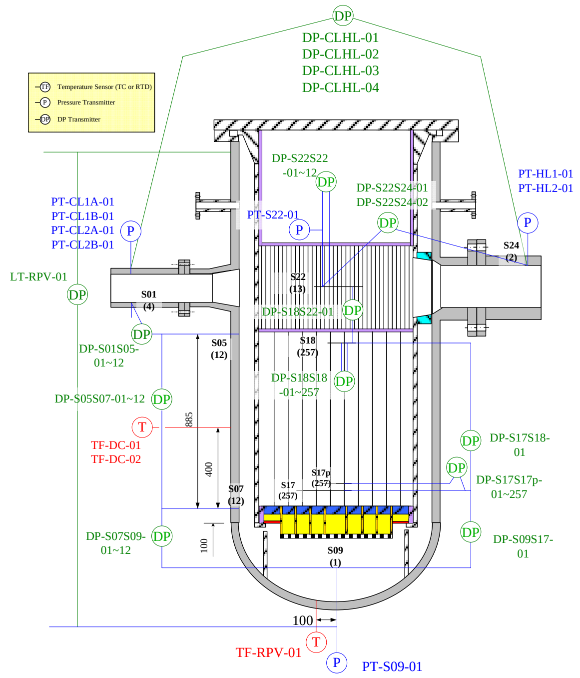

Fig. 2. Instrumentation inside a ACOP Vessel

3. Conclusions

In order to identify the flow and pressure distribution of the APR+ reactor, 1/5 linearly reduced scale of test facility, named "ACOP" is being designed with a conservation of flow geometry. This paper describes the overall design features including scaling, assembling, component design and instrumentation. The ACOP data will be utilized for an analysis of the safety and system hydraulic performance of the APR+ reactor.

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