Preliminary Design of KALIMER-600 PDRC Performance Test Facility

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1. Introduction

The PDRC (Passive Decay Heat Removal Circuit) is the only safety-grade decay heat removal system in KALIMER-600 [1]. The core decay heat after a reactor trip is removed by natural circulation of the PDRC loop and the reactor vessel inside. The PDRC comprises of two independent loops, and each loop is equipped with a DHX (sodium-sodium Decay Heat eXchanger), an AHX (sodium-Air Heat eXchanger), and the pipes connecting the DHX and the AHX. For a verification of the passive decay heat removal concept and an assessment of the system performance, the PDRC performance test was planned for. In the test, the natural circulation cool-down capability after a reactor trip will be investigated for the conservative accident condition such as a station blackout. This paper briefly introduces the preliminary design parameters of the major components which were produced as a first step to assess the appropriateness of the test facility.

2. Preliminary Design Parameters

The test facility is mainly composed of a PHTS (Primary Heat Transport System), a PDRC, a sodium supply/purification system and an air cooling system for IHX (Intermediate Heat eXchanger). A PHTS and a PDRC are scaled-down from KALIMER-600.

In order to reproduce the major thermal-hydraulic phenomena in the experiment, the test facility was designed based on proper scaling criteria [2] for geometric, hydrodynamic and thermal similarities. Overall scaling ratio of the facility is 1/400 for volume and 1/4 for length. The working fluid and operating temperatures are preserved in the test. A schematic diagram of test facility is presented in Fig. 1.

2.1 Similarity Criteria

Based on the scaling method proposed by Ishii and Kataoka [2], the overall similarity criteria were produced by using the dimensionless groups which were derived from the dimensionless conservation equations. These dimensionless groups include a Richardson number, a friction number, a modified Stanton number, a time ratio number, a Biot number, a heat source number, an axial length scale, and a flow area scale. The similarity criteria is shown in Table 1, which came from the condition of the same dimensionless groups between the model (test facility) and the prototype (KALIMER-600) for the given volume and length scales.

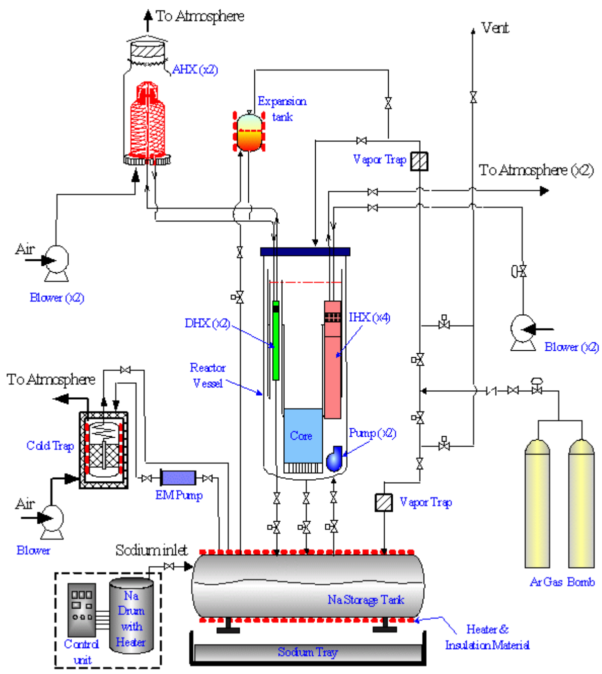

Fig. 1. Schematic diagram of test facility

Table 1. Overall similarity criteria

Parameter	Scaling ratio (M/P)	
	Expression	Design Value
Length	l_{oR}	1/4
Diameter	d_{oR}	1/10
Area	$a_{oR}(=d_{oR}^2)$	1/100
Volume	$a_{oR}l_{oR}$	1/400
Temperature rise	1	1
Velocity	$\sqrt{l_{oR}}$	1/2
Time	$\sqrt{l_{oR}}$	1/2
Gravity acceleration	1	1
Core power density	$1/\sqrt{l_{oR}}$	2
Core power	$a_{oR}\sqrt{l_{oR}}$	1/200
Flow rate	$a_{oR}\sqrt{l_{oR}}$	1/200

In Table 1, M and P means the model and the prototype, respectively.

2.2 Design Parameters of Major Component

The reactor vessel and internals were designed to preserve the distribution of the temperature, coolant volume, flow, and flow area. Most of the design parameters are based on the overall similarity criteria presented in Table 1. The configuration of the reactor vessel internals is the same as that of the prototype, and the height and diameter of the reactor vessel are 4.5 m and 1.2 m, respectively.

The important local phenomena considered in the design of the reactor vessel are the multidimensional phenomena in the reactor pool, the free surface behavior, and the heat transfer through the solid structure. The preservation of the multidimensional phenomena is closely related to the aspect ratio. The aspect scaling ratio factor is 1/2.5 which is close to the prototype compared with the case for the length scale ratio of 1 where the aspect scaling ratio factor is 1/20. However, a further assessment for a scaling distortion on the multidimensional phenomena should be performed in the future. The free surface movement during the decay heat removal operation is preserved if the heat transfer through the solid structure is preserved due to the similarities of the coolant volume in each section inside the reactor vessel and the core power. The heat transfer through the solid structure was assessed in terms of a heat loss and an accumulated heat. The heat loss will be compensated for by using the heat loss compensation system later. Also, it was assessed that the scaling distortion caused by the accumulated heat would not be large.

A total of 156 electrical heaters are used to simulate the core. The diameter of a heater was determined to be 2.54 cm by considering an assembly arrangement, an instrument space, a commercial availability, a flow area, and a cost. The simulated core is divided into 4 groups as the core of the prototype. Since the experiment will be performed at the decay power level, the total heater power was set to be 762 kWt which corresponds to 10 % of the scaled power.

Heat exchangers such as IHX, DHX and AHX were designed to preserve the overall heat transfer coefficients, the log-mean temperature differences. Also, the scaling ratios of the pressure loss and heat capacity are 1/4 and 1/200, respectively, according to the similarity criteria. The design parameters of those heat exchangers are presented in Table 2.

Table 2. Design parameters of heat exchangers

	IHX		DHX		AHX	
	M	M/P	M	Ratio*	M	M/P
Q (kWt)	1.90	0.005	41.25	0.005	41.25	0.005
U ($W/m^2/K$)	7841	0.998	5578	1.000	101	1.000
A_h (m^2)	6.21	0.005	0.13	0.005	1.53	0.005
l_h (m)	1.62	0.270	0.45	0.120	1.72	0.081
D_i (mm)	8.4	0.627	7.2	0.358	8.5	0.170
D_o (mm)	11.3	0.712	11.3	0.469	11.8	0.219
ΔP (kPa)	10.1	0.248	1.1	0.25	0.123	0.251

In Table 2, Q, U, A_h, l_h, D_i, D_o and Δ P are the heat transfer capacity, the overall heat transfer coefficient, the length of the heat transfer tube, the inner diameter of a tube, the outer diameter of a tube and the pressure loss through a tube, respectively.

PDRC piping layout which is important for a natural circulation in the PDRC loop was designed in a way that the pressure loss through the piping approaches 1/4 of that of the prototype while maintaining the scaling ratio of the height difference between the DHX and the AHX. The pressure loss was scaled by adjusting the diameters of the pipes. Overall 3-dimensional schematic of the preliminarily designed test facility is shown in Fig. 2.

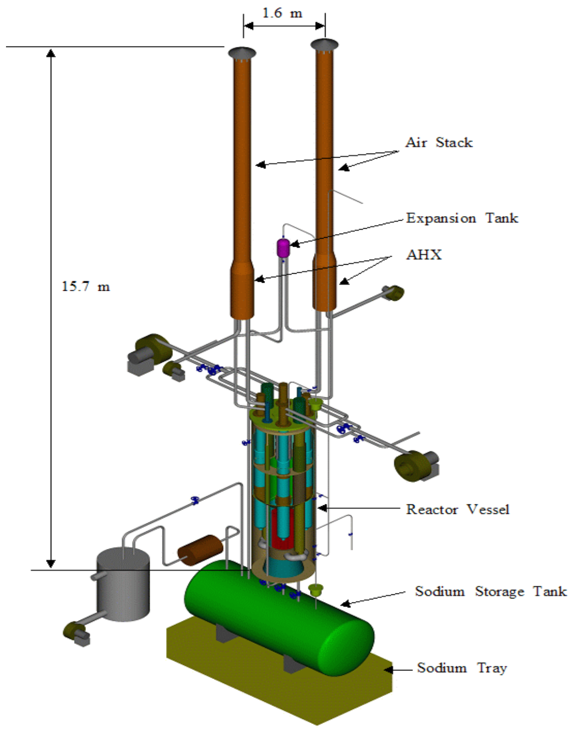

Fig. 2. Overall 3-dimensional schematic of test facility

3. Conclusions

Preliminary design parameters of KALIMER-600 PDRC performance test facility were presented. The design parameters were produced based on a proper scaling method, and will be used to assess the appropriateness of the facility design through the evaluation of the scaling distortion using a system code and a CFD method.

REFERENCES

[1] D.H Hahn et. al., KALIMER-600 Conceptual Design Report, KAERI/TR-3381/2007, 2007.

[2] M. Ishii, I. Kataoka, Similarity Analysis and Scaling Criteria for LWRs under Single-Phase and Two-Phase Natural Circulation, NUREG/CR-3276, ANL-83-32, 1983.