Preliminary Design of Large Scale Sodium Thermal-Hydraulic Test Facility

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1. Introduction

A large scale sodium thermal-hydraulic test facility is being designed for verification of the advanced design concept of the passive decay heat removal circuit (PDRC) in a medium- or large-sized pool-type SFR. In the test, its cooling capability during the long- and short-term periods after the reactor trip will be evaluated, and also the produced experimental data will be utilized for the assessment and verification of the safety and performance analysis codes. Starting with the preliminary design of the test facility this year using KALIMER-600 [1] as a reference reactor, the basic and the detailed designs will be made through 2011-2012 based on the demonstration reactor which is intended to be constructed by 2028 according to a long-term national SFR development plan. The installation is scheduled to be completed by the end of 2013, and the main experiments will commence from 2015 after the startup test in 2014. This paper briefly introduces the preliminary design features which were produced as a first step to assess the appropriateness of the facility design methodology.

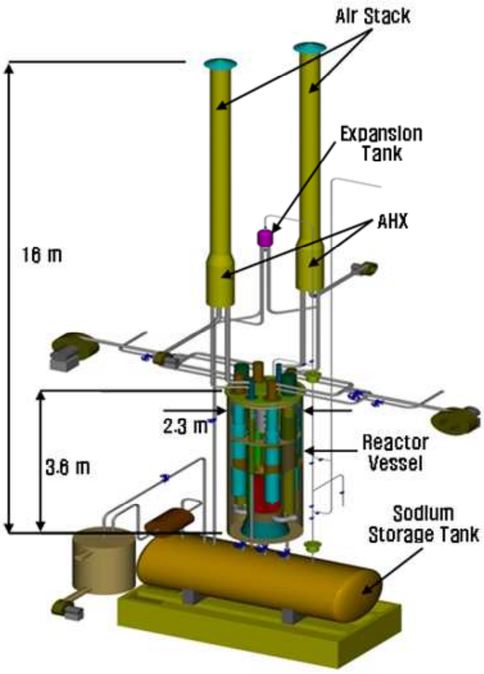

Fig. 1. Preliminary concept of the main test section

2. Preliminary Design Features

The main test section of the experimental facility is composed of a primary heat transport system and a PDRC. The main test section includes all major components reflecting the real configuration. The preliminary concept of it is shown in Fig. 1. Auxiliary fluid systems such as an intermediate heat exchanger gas cooling system, a sodium supply/purification system, a heat loss compensation system, a power supply system, and a gas supply system are included in the experimental facility. The overall scaling ratio of the facility is 1/125 for volume and 1/5 for length. The working fluid and operating temperatures are preserved in the test.

2.1 Major Design Parameters

In order to reproduce the major thermal-hydraulic phenomena in the test, the facility was designed based on proper scaling criteria for geometric, hydrodynamic and thermal similarities. Ishii et al.'s three-level scaling method [2] which consists of integral, boundary flow and local phenomena scalings was utilized in the design of the facility. The major design parameters which were drawn from the integral scaling are summarized in Table I where M and P means the model (test facility) and the prototype (KALIMER-600), respectively.

Table I: Major design parameters

Parameter	Scaling ratio (M/P)	
	Expression	Design Value
Length	l_{oR}	1/5
Diameter	d_{oR}	1/5
Area	$a_{oR}(=d_{oR}^2)$	1/25
Volume	$a_{oR}l_{oR}$	1/125
Temp. distribution	1	1
Velocity	$\sqrt{l_{oR}}$	1/2.24
Time	$\sqrt{l_{oR}}$	1/2.24
Aspect ratio	d_{oR}/l_{oR}	1
Core power density	$1/\sqrt{l_{oR}}$	2.24
Core power	$a_{oR}\sqrt{l_{oR}}$	1/55.9
Flow rate	$a_{oR}\sqrt{l_{oR}}$	1/55.9

2.2 Design Parameters of Major Components

The reactor vessel and internals were designed to preserve the distribution of the temperature, pressure, coolant volume, flow, and flow area. Most of the design parameters are based on the integral scaling parameters.

The configuration of the reactor vessel internals is the same as that of the prototype. Four intermediate heat exchangers (IHX), two decay heat exchangers (DHX) and two primary pumps are located inside the reactor vessel. An overall 3-dimensional schematic of the reactor vessel of the facility is shown in Fig. 2.

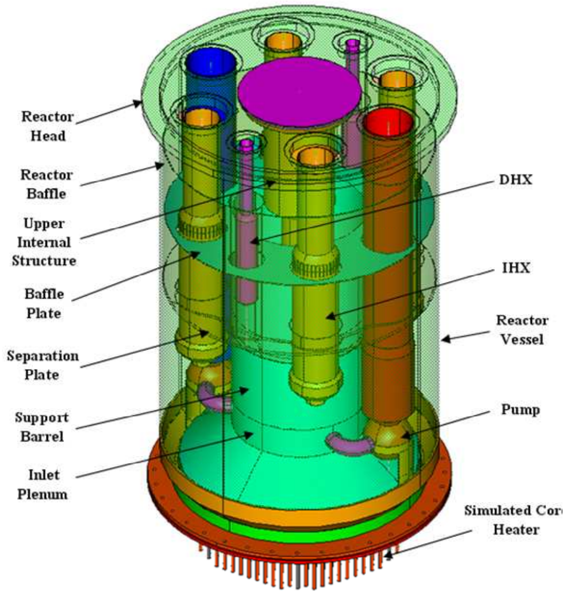

Fig. 2. 3-dimensional schematic of the reactor vessel

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 is 1, which implies the multidimensional flow and temperature distributions in the reactor pool could be simulated well. Currently, the distortion for the multidimensional phenomena is being assessed using CFD tools. The free surface movement during the decay heat removal operation is preserved if the heat transfer through the solid structure is preserved because the similarities of the coolant volume in each section inside the reactor vessel and the core power are maintained. 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. Also, it was assessed that the scaling distortion caused by the accumulated heat would not be large.

A total of 318 electrical heaters are used to simulate the core. The diameter of a heater was determined to be 29mm 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 1.9 MW which corresponds to 7 % of the scaled full power.

Heat exchangers such as IHX, DHX and AHX were designed as possible to have the same configuration, to preserve the overall heat transfer coefficients and the log-mean temperature differences, and to let the similarities for pressure loss, flow rate and heat capacity at design conditions to be satisfied. The design parameters of heat exchangers are presented in Table II.

Table II: Design parameters of heat exchangers

	IHX		DHX		AHX	
	M	M/P	M	M/P	M	M/P
Q (kWt)	6814	0.018	148	0.018	148	0.018
U ($W/m^2/K$)	8819	1.123	5200	0.918	17	0.582
ΔT_{LMTD} (^oC)	38.9	1.004	56.3	0.993	261.0	0.998
l_h (m)	1.38	0.230	0.75	0.198	11.38	0.342
D_i (mm)	10.0	0.746	9.0	0.450	19.0	0.380
D_o (mm)	13.6	0.857	13.4	0.558	24.0	0.444
ΔP_{tube} (Pa)	8813	0.217	1133	0.171	85	0.274
ΔP_{shell} (Pa)	4993	0.194	60	0.179	25	0.135

In Table II, Q, U, ΔT_{LMTD}, l_h, D_i, D_o, ΔP_{tube}, and ΔP_{shell} are the heat transfer capacity, the overall heat transfer coefficient, the log-mean temperature difference, the length of a heat transfer tube, the inner diameter of a tube, the outer diameter of a tube, the pressure loss of tube side and the pressure loss of shell side, respectively.

PDRC piping layout, which is important for a natural circulation in the PDRC loop, was designed in a way that the relative elevation, the pressure loss and the sodium inventory inside pipe satisfy the integral scaling criteria by adjusting the pipe diameters and pipe lengths.

3. Conclusions

Preliminary design features of large scale sodium thermal-hydraulic test facility were presented, which have been designed based on the KALIMER-600. Using a system code and a CFD method, the analyses to assess the appropriateness of the design methodology are now underway. The basic design of the facility will be resumed from 2012 using the demonstration reactor as a reference reactor.

ACKNOWLEDGEMENT

This work has been supported by the Ministry of Education, Science and Technology of Korea.

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