Design Features of the Separate Effect Test Facility for a Forced-Draft Sodium-to-Air Heat Exchanger (FHX) with Helical Finned Tubes

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1. Introduction

Fourth-generation (Gen-IV) nuclear power plants have been being developed for a minimal waste and effective utilization of uranium resources [1]. A sodium-cooled fast reactor (SFR) is one of the most promising options to pursue these purposes, and the Korea Atomic Energy Research Institute (KAERI) is currently developing a PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) with a pool-type reactor vessel [1]. Among the many components in an SFR, a decay heat removal system (DHRS) is very important for a safety of nuclear power plants. The PGSFR adopted two different kinds of DHRS: an active and passive DHRS, and the decay heat from the primary sodium pool is moved to the two kinds of sodium-to-air heat exchangers as ultimate heat sinks through sodium-to-sodium decay heat exchangers (DHX) [2]. A forced-draft sodium-to-air heat exchanger (FHX) is one of the ultimate heat sinks in the PGSFR, and it is charge of an active control of heat balances during a normal operation of plant systems as well as an active cooling at situation of accidents [2, 3].

The FHX has the four-pass serpentine (M-shape) tubes with many helical heat fins. To verify the cooling performances and thermal-hydraulic characteristics of this type of heat exchanger, a separate effect sodium test facility named as SELFA (Sodium thermal-hydraulic Experiment Loop for Finned-tube sodium-to-Air heat exchanger) is being developed [3, 4]. The purposes of SELFA are verification and validation of the design code for FHX. For this, scales and configurations of SELFA are carefully defined as similarity with the FHX in the PGSFR [3, 4]. In this paper, we propose the key design features of SELFA including the model FHX (M-FHX) unit.

2. Methods and Results

2.1 Overview of the SELFA facility

The SELFA consists of a main test loop, and a gas supply and related auxiliary systems. The sodium-side (tube-side) main components of this facility are the M-FHX, an electromagnetic pump, an electric loop heater, flow meters, an expansion tank, and a sodium storage tank. The air-side (shell-side) key components are a blower and dampers. The general arrangement of the SELFA facility is shown in Fig. 1.

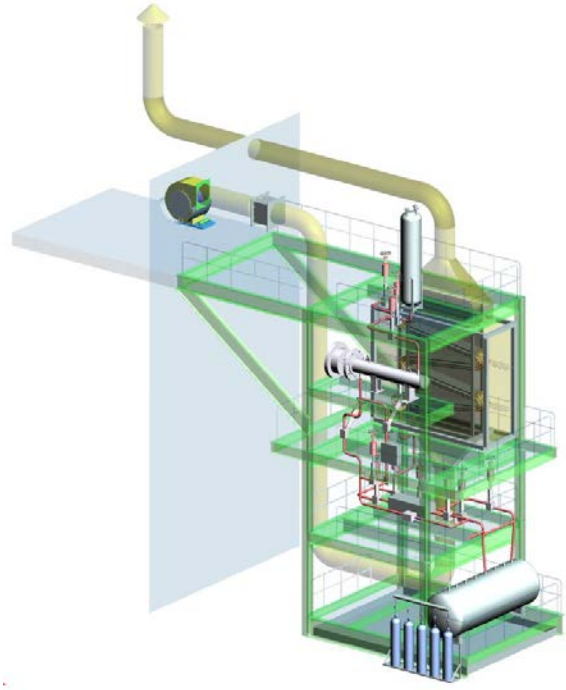

Fig. 1. General configuration of the SELFA.

The designed maximum temperature of the facility is 500 °C, and the designed power capacity of the main heater is 650 kW. The total electric power putting into the facility is 750 kW. The pipe diameter of the whole facility is 2 inch of Sch20, and the expected operation flow rates are from 0.99 kg/s to 4.38 kg/s in the tube-side and from 0.12 kg/s to 3.4 kg/s in the shell-side. The maximum available flow rates of the electromagnetic pump and the blower are around 6 kg/s and around 5 kg/s with margins, respectively.

2.2 General Instrumentation

The flow rates, temperatures, and pressures are crucial instrumentation targets in the tube-side of the SELFA. First, for the measurements of flow rates in the tube-side, we adopted both an electromagnetic flowmeter (EMF) and a Coriolis mass flowmeter. Each flowmeter will be operated properly. The EMF will be calibrated with the Coriolis flowmeter at the first, and they can be crossly checked mutually. If we need another calibration except this mutual method between the EMF and the Coriolis flowmeter, we can also calibrate the flowmeters with the level meter of the expansion tank. Second, for temperature measurements, we follow the same strategy with the STELLA-1 facility as application of thermocouples with thermowells. Finally, we choose NaK filled pressure transducers as instruments for pressures. This is available up to 538 °C, and no solidification of medium material (i.e. sodium-potassium alloy, NaK) at a room temperature. We conducted pre-calibrations with the NaK filled pressure transducers to confirm a linearity of the sensors in the relatively low pressure level under 2 bar.

The instruments for temperatures, flow rates, and moistures in the shell-side are also determined by experiences of the operation with the STELLA-1 facility. To reduce uncertainty of air properties in the shell-side, measuring locations of the inlet and outlet in the duct will be chosen as many as possible.

2.3 Design of the model FHX (M-FHX)

The M-FHX was carefully designed to maintain the similarity of the FHX in the PGSFR. The M-FHX has the same length scale, but the reduced power scale with 1/8 by reducing the number of tubes columns. Table I represents the key design parameters of the FHX and the M-FHX.

Table I: Key design parameters of the FHX and the M-FHX

Design parameters	FHX (PGSFR)	M-FHX (SELFA)
Thermal duty [MWt]	2.5	0.3125 (1/8)
No. of tubes	96	12 (1/8)
Tube arrangement [Pitch to Dia. (D=Tube OD)]	P_T/D=2.5, P_L/D=2.05	P_T/D=2.5, P_L/D=2.05
Tube material	9Cr1Mo	STS316L
Bare tube OD/ID [mm]	34.0/30.7	34.0/30.7
Thickness [mm]	1.65	1.65
Finned tube length per single tube [m]	8.0	8.0
Fin height [mm]	15.0	15.0
Fin thickness [width, mm]	1.5	1.5
Tube inclined angle [degree]	7.2	7.2
No. of fins per unit length [m]	152	152

A thermal expansion is one of the crucial issues in the M-FHX design. To prevent a damage of the M-FHX, details of the M-FHX is carefully designed in a consideration of thermal expansion effects. We accept four separated plates as a flow guide to define a flow area of the shell-side, and each plate can stretch by thermal expansion as shown in Fig. 2. In addition, the upper duct as an outlet of air flow is designed like a cap covering the flow guide to allow thermal expansion through z-direction (negative direction of gravity).

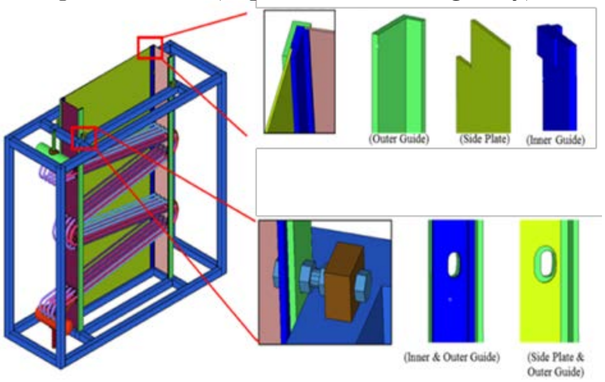

Fig. 2. The conceptual design of flow guide plates of M-FHX to allow the thermal expansions of each plate.

Every bending part of tubes has a thermocouple with a thermowell to measure temperature of inside sodium (Fig. 3). The upper chamber as an inlet plenum of sodium-side and the lower chamber as an outlet plenum have own thermocouples with thermowells and pressure transducers. The details of our M-FHX is represented in Fig. 4.

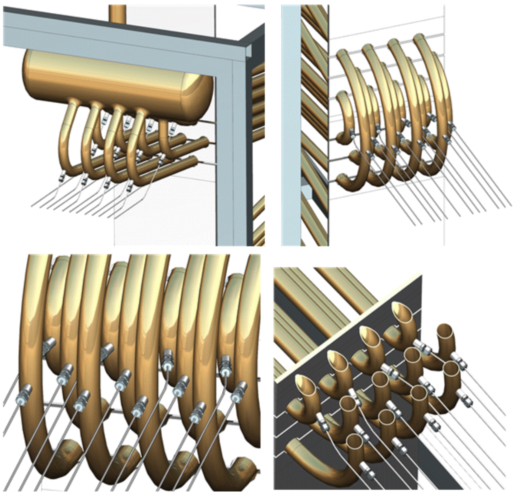

Fig. 3. The schematic drawings of the instrumentation to measure sodium temperature inside every tubes.

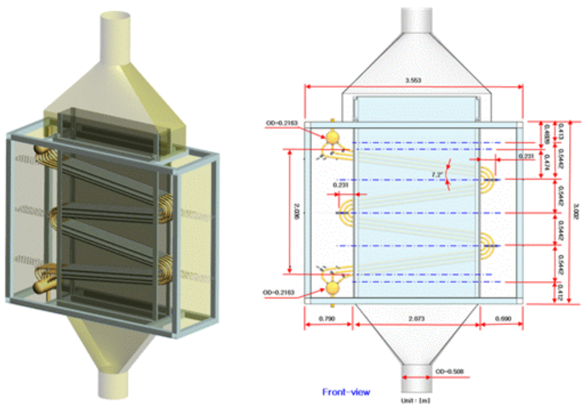

Fig. 4. The details of M-FHX including a front-view.

3. Conclusions

To verify and validate a design code of the FHX in PGSFR, a separate effect test facility called as SELFA has being developed in KAERI. The sodium-side of the SELFA facility consists of well-developed sodium components by our past experiences such as an electromagnetic pump, an electric loop heater, flow meters, an expansion tank, and a sodium storage tank. And shell-side of the SELFA includes a blower and dampers. The most important component of the SELFA is the M-FHX, and the M-FHX was designed not only to have the similarity with the FHX of the PGSFR, but also to prevent damages by thermal expansions. In the near future, we will conduct more specific designs of the SELFA including the M-FHX to fabricate the facility in this year.

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