Component Designs of 9.5 MWT DHRS in SFR

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1. Introduction

SFR (Sodium-cooled Fast Reactor) is one of a next-generation nuclear power reactor. Since the SFR uses liquid sodium as a coolant, high operating pressure is not required and thermal efficiency is excellent. KAERI (Korea Atomic Energy Research Institute) has performed a conceptual design of the PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) [1]. KAERI has also performed a preliminary design of a pool-type SFR which consists of PHTS (Primary Heat Transport System), IHTS (Intermediate Heat Transport System) and DHRS (Decay Heat Removal System). This SFR has TRU core and the capacity of 3800 MWt. The DHRS is employed to remove the decay and sensible heat from the PHTS at any design basis accident.

In this study, detailed component designs of 9.5 MWt DHRS are presented. Methodologies of determining the geometric parameter and design conditions of heat exchangers and pipes are addressed, and main design parameters of the heat exchangers are presented.

2. System Descriptions

The DHRS removes the decay heat of the core and the sensible heat of the primary heat transport system transferred through the decay heat exchanger (DHX) when it is impossible to cool the primary heat transport system using the main steam and feedwater system. It performs the safety function by cooling the primary transport system to the safe shutdown temperature (351°C) after the reactor is stopped. The DHRS consists of a total of six loops which are grouped into three passive decay heat removal system (PDHRS) and three active decay heat removal system (ADHRS) loops to satisfy diversity and redundancy requirements, and each loop is arranged and operated independently. In the PDHRS, natural convection is formed by the density difference of air and heat transfer is performed through the natural-draft sodium-to-air heat exchanger (AHX), whereas in the ADHRS, air flow is formed by using a blower and the heat transfer is performed through the finned-tube sodium-to-air heat exchanger (FHX). The total heat removal capacity of the DHRS is 57 MWt which is 1.5% of nominal reactor thermal power.

3. Methods and Results

3.1 Design parameters of the DHX

DHX are designed utilizing SHXSA code [2]. This design code has capability of thermal sizing and performance analysis for the shell and tube type and counter-current flow heat exchanger unit. In this code, conservation equations for the mass, momentum, and energy balance for both shell and tube side flows are solved. Figure 1 shows a schematic diagram of heat transfer in each control volume. Heat transfer rates were transferred through the tube wall from the shell side flow to the tube side flow.

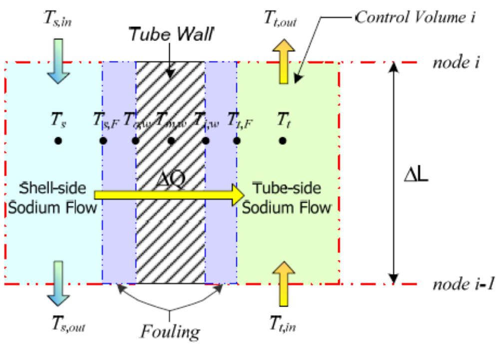

Fig. 1 Schematic diagram of heat transfer in each control volume

To calculate heat transfer and pressure loss in the SHXSA code, several correlations were implemented. The forced convection heat transfer coefficients on the tube side are calculated using the Lyon-Martinelli correlation [3] while Schad-modified correlation [4] is applied for the shell side flow. To calculate pressure loss, Darcy friction factor is used and appropriate form loss coefficients [5] are applied considering the flow geometries. The DHX of 9.5MWt DHRS was designed using the SHXSA code and main design parameters of the DHX are summarized in Table 1.

Table 1. Main design parameters of the DHX

Design parameter	Value
Number (ea)	3
DHX heat transfer rate (MWt)	9.5
Number of tubes (ea)	474
Pitch to diameter ratio	1.5
Active tube length (m)	2.7
Shell mass flow rate (kg/s)	54.8
Tube mass flow rate (kg/s)	59.9
Shell inlet/outlet temperature (°C)	360.0/227.5
Tube inlet/outlet temperature (°C)	215.1/335.8

3.2 Design parameters of the AHX

AHX are designed utilizing AHXSA code [2]. In this code, the forced convection heat transfer coefficients on the tube side are calculated using Lubarski-Kaufman correlation [6] while Zhukauskas correlations [7] have been implemented on the shell side. Pressure loss is calculated using Mori-Nakayama friction factor [8] on the tube side and shell side pressure loss is obtained from Zhukauskas correlation. The AHX of 9.5MWt DHRS was designed using the AHXSA code and main design parameters of the AHX are summarized in Table 2.

Table 2. Main design parameters of the AHX

Design parameter	Value
Number (ea)	3
AHX heat transfer rate (MWt)	9.5
Number of tube rows	12
Number of tubes	483
Pitch to diameter ratio (transverse/longitudinal)	2.5/1.71
Active tube length (m)	39.6
Shell mass flow rate (kg/s)	38.3
Tube mass flow rate (kg/s)	59.9
Shell inlet/outlet temperature (°C)	40.0/292.6
Tube inlet/outlet temperature (°C)	335.8/215.1

3.3 Design parameters of the FHX

FHX are designed utilizing FHXSA code [2]. In this code, the heat transfer coefficients on the tube side are obtained Lubarski-Kaufman correlation while Zhukauskas correlations have been implemented on the shell side. The FHX of 9.5MWt DHRS was designed using the FHXSA code and main design parameters of the FHX are summarized in Table 3.

Table 3. Main design parameters of the FHX

Design parameter	Value
Number (ea)	3
FHX heat transfer rate (MWt)	9.5
Number of tube rows	34
Number of tubes	102
Pitch to diameter ratio (transverse/longitudinal)	2.5/2.05
Active tube length (m)	24
Shell mass flow rate (kg/s)	47.6
Tube mass flow rate (kg/s)	56.5
Shell inlet/outlet temperature (°C)	40.0/270.4
Tube inlet/outlet temperature (°C)	340/212

3.4 Pipe arrangements of the DHRS

The closed loop of the DHRS is composed of the DHX tube, the hot/cold pipe, and the AHX/FHX tube, etc. For pipe arrangement of the DHRS, the flow resistance should be calculated considering the parts where the flow cross-sectional area and the flow direction are changed. The flow resistance is divided into friction loss and form loss due to change in the shape of the flow path, and is calculated by the following equation.

$$C = \sum_i \frac{1}{2\rho_i A_i^2}\left[K_i + f_i \frac{L_i}{D_i}\right] \quad (1)$$

Where K is the form loss, and f is the friction loss coefficient. The friction loss coefficient is calculated by the following equation.

$$f = \begin{cases} \frac{64}{Re} & for\ Re < 2{,}000 \\ \frac{1}{(1.8\log(Re) - 1.64)^2} & for\ Re > 4{,}000 \end{cases} \quad (2)$$

Figure 2 and 3 shows the geometry of the AHX and FHX, respectively. Figure 4 and 5 shows the pipe arrangement of the PDHRS and AHDRS, respectively.

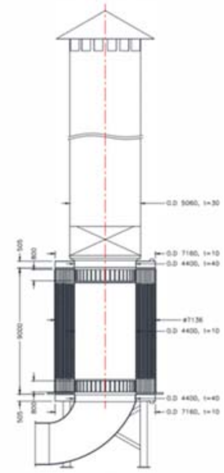

Fig. 2 Geometry of the AHX

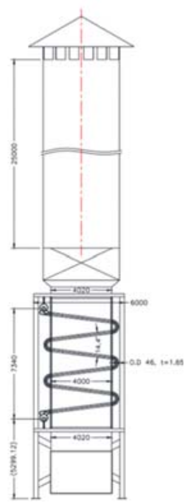

Fig. 3 Geometry of the FHX

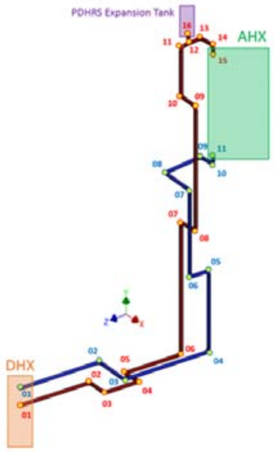

Fig. 4 Pipe arrangements of the PDHRS

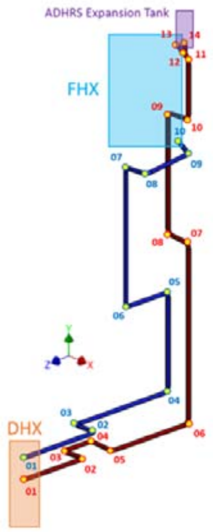

Fig. 5 Pipe arrangements of the ADHRS

4. Conclusions

Component designs of the DHRS in SFR with the capacity of 3800 MWt were performed. The DHRS was designed to consist of the PDHRS and ADHRS to satisfy diversity and redundancy requirements. Methods of determining the geometric parameter and design conditions of heat exchangers and pipes are addressed, and main design parameters of heat exchangers are presented.

The main components of the DHRS, DHX, AHX, and FHX were designed using the heat exchanger design codes, and the pipe arrangement of the DHRS was conducted by considering the flow resistance.

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