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Preliminary Design of Refueling Decay Heat Removal System for the PGSFR

Yohan Jung*, Hyun-Woo Lee, Huee-Youl Ye, Sun Rock Choi
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 Beon-Gil, Yuseong-gu, Daejeon, Korea
**Corresponding author: yhjung81@kaeri.re.kr*

1. Introduction

In the Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR), the Decay Heat Removal System (DHRS) is employed to remove the decay and sensible heat from the primary heat transport system (PHTS) at any design basis accident.

Researches have shown that an alternate decay heat removal system is necessary for maintaining the hot and cold shutdown conditions [1-5]. In the PGSFR, the Refueling Decay Heat Removal System (RDHRS) was designed to provide decay heat removal capability during the refueling operation because the safety grade DHRS is not used for decay heat removal during the refueling operation. The RDHRS offers an alternate decay heat removal path.

2. System Descriptions

A system is needed to remove decay heat at the normal operation, not accident because the DHRS is used at any design basis accident. Therefore the RDHRS was designed to remove decay heat generated in the core during the refueling operation after the reactor is shut down, thereby maintaining the temperature of the PHTS at 200 °C, which is the refueling operation temperature. The heat removal capacity of the RDHRS has 3.36 MWt which is 0.9 % of nominal reactor thermal power. This heat removal capacity was determined as the decay heat after 24 hours of the reactor shutdown. The PGSFR has two loops and the RDHRS has 100 % design capacity per loop taking into account maintenance for one loop during the refueling operation. The Main Steam and Feedwater System (MSFS) removes heat of core from 100 % power to the refueling operation. When the temperature of the PHTS reaches the refueling operation temperature, the MSFS is stopped, and then the RDHRS starts to operate.

The schematic of the RDHRS is shown in Fig. 1 and the RDHRS circuit forms a smaller circuit within the MSFS circuit of the balance of plant (BOP), which is independent from the piping of NSSS. The RDHRS consists of two loops, each of which is located and operated independently. Each loop of the RDHRS consists of one separator, two air-cooled condensers, two refueling recirculation pumps and one steam generator.

The flow path of the RDHRS is as follows. The feedwater flows from the pump to the tube inlet nozzle of the steam generator. As it passes through the steam generator tube, it absorbs heat and becomes the steam/water mixture. The two-phase mixture flows from the steam generator to the separator, where it is separated into steam and water. The saturated steam flows to the air-cooled condenser while the water is drained and collected in the separator storage tank. The saturated steam exiting the air-cooled condenser becomes the condensed water and flows into the separator storage tank. The water in the separator storage tank flows to the tube inlet nozzle of the steam generator by the refueling recirculation pump, and then circulates the flow path of the RDHRS.

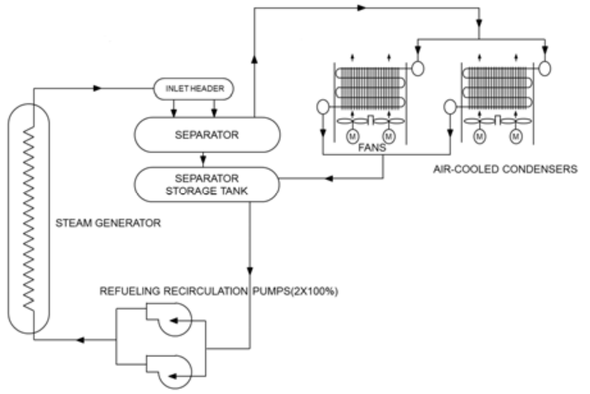
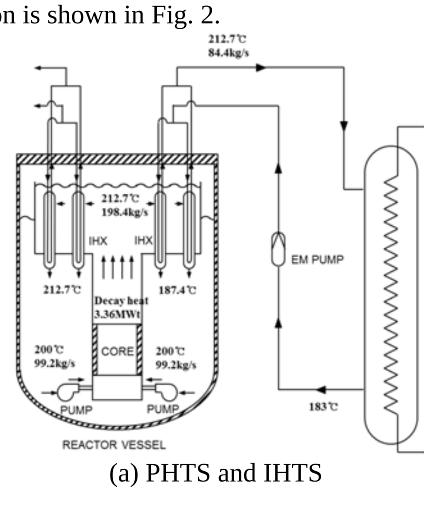
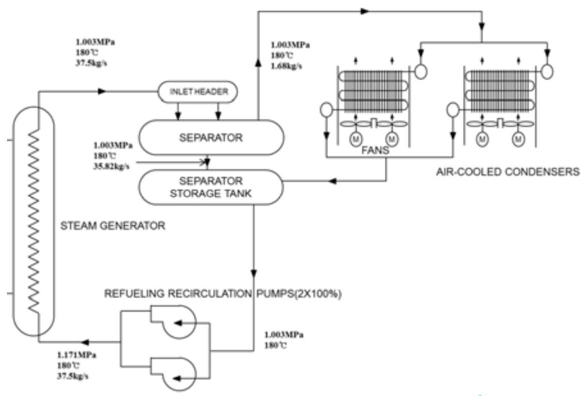


Fig. 1 Schematic of RDHRS

To design equipment of the RHDRS, it is required to determine the heat balance for the PHTS, IHTS (Intermediate Heat Transport System), and RDHRS at the refueling operation condition. That is, it is necessary to determine the required heat removal capacity, flow rates, and inlet and outlet temperatures for both shell and tube sides of the IHX (Intermediate Heat Exchanger) and the steam generator. The schematic of heat balance of systems at the refueling operation condition is shown in Fig. 2.



(a) PHTS and IHTS



(b) RDHRS

Fig. 2 Schematic of heat balance of systems at the refueling operation condition

The operating conditions for the IHX and steam generator are shown in Table 1 and 2, respectively. They are determined utilizing SHXSA [6] and HSGSA [7] codes which have capability of thermal sizing and performance analysis for the shell-and-tube type and counter-current flow heat exchanger unit.

Table 1. Operating conditions for the IHX (1ea)

Design parameter		Value
Shell-side (Sodium)	Inlet/outlet temp. (°C)	212.7/187.4
	Inlet/outlet pressure (MPa)	0.133/0.168
	Flow rate (kg/s)	49.6
	Heat transfer (MWt)	1.68
Tube-side (Sodium)	Inlet/outlet temp. (°C)	183/212.7
	Inlet/outlet pressure (MPa)	0.54/0.51
	Flow rate (kg/s)	42.2
	Heat transfer (MWt)	1.68

Table 2. Operating conditions for the steam generator

Design parameter		Value
Shell-side (Sodium)	Inlet/outlet temp. (°C)	212.7/183
	Inlet/outlet pressure (MPa)	0.445/0.666
	Flow rate (kg/s)	84.4
	Heat transfer (MWt)	3.36
Tube-side (Water)	Inlet/outlet temp. (°C)	180/180
	Inlet/outlet pressure (MPa)	1.24/1.003
	Flow rate (kg/s)	37.5
	Heat transfer (MWt)	3.36

3. System Components

3.1 Separator

The separator comes into service for the RDHRS when two-phase stream is generated from the steam generator. The steam water separator separates a two-phase mixture, and the saturated steam flows to the air-cooled condenser while the water is collected in the separator storage tank. Since the flow rate entering the separator is relatively high, a horizontal type separator shown in Fig. 3 was used. The main design parameters for the separator are summarized in Table 3.

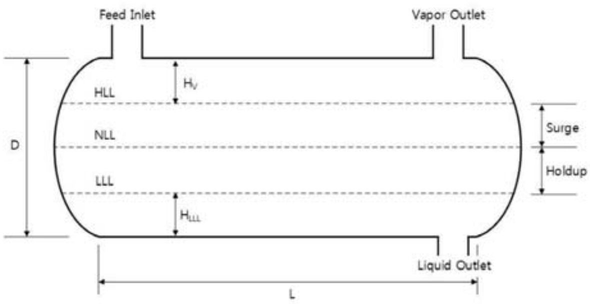


Fig. 3 Horizontal separator

Table 3. Main design parameters for the separator

Design parameter	Value
Vapor volumetric flow rate (m^3/s)	0.33
Liquid volumetric flow rate (m^3/s)	0.04
Vertical terminal vapor velocity (m/s)	0.21
Tank diameter (m)	2.27
Tank length (m)	7.67

3.2 Refueling recirculation pump

The function of the refueling recirculation pump is to recirculate the water from the separator storage tank to the steam generator and maintain the reactor at the temperature of the refueling operation. The main design parameters for the refueling recirculation pump are summarized in Table 4.

Table 4. Main design parameters for the pump

Design parameter	Value
Rated capacity (m^3/min)	2.5
Total head (m)	30.6
Rotational speed (rpm)	1782
Specific speed (rpm, m^3/min, m)	220
$NPSH_R$ (m)	3.2
Efficiency (%)	80
Motor power (kW)	17

3.3 Air-cooled condenser

The RDHRS condenser is steam to air heat exchanger where the steam separated by the separator from the two-phase mixture is condensed. An air-cooled finned tube condenser was selected and steam condenses inside the tubes. The location of condenser is important in the aspect of safety and will be determined through the detailed design phase. The main design parameters for the air-cooled condenser are summarized in Table 5.

Table 5. Main design parameters for the condenser

Design parameter	Value
Thermal duty (1ea) (MWt)	1.68
Height (mm)	1216
Depth (mm)	512
Length (mm)	3850
Volume (m^3)	2.4

4. Conclusions

A preliminary design of the RDHRS for the PGSFR was performed. The RDHRS was designed to provide decay heat removal capability during the refueling operation and has 3.36 MWt which is found to be adequate for the RDHRS requirements.

ACKNOWLEDGEMENT

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