Transactions of the Korean Nuclear Society Virtual spring Meeting
May 13-14, 2021

Design of Main Components of Refueling Decay Heat Removal System for the PGSFR

Yohan Jung*, Huee-Youl Ye, Jonggan Hong, Jae-Hyuk Eoh
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 Beon-Gil, Yuseong-gu, Daejeon, Korea
**Corresponding author: yhjung81@kaeri.re.kr*

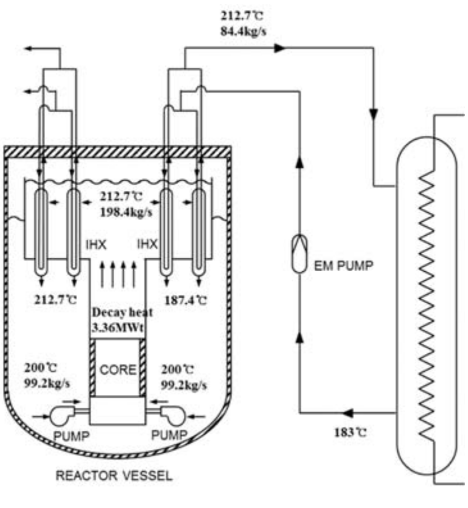
1. Introduction

The 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) which consists of PHTS (Primary Heat Transport System), IHTS (Intermediate Heat Transport System) and DHRS (Decay Heat Removal System). There have been many studies that a new decay heat removal system is necessary for maintaining the hot and cold shutdown conditions [1-5].

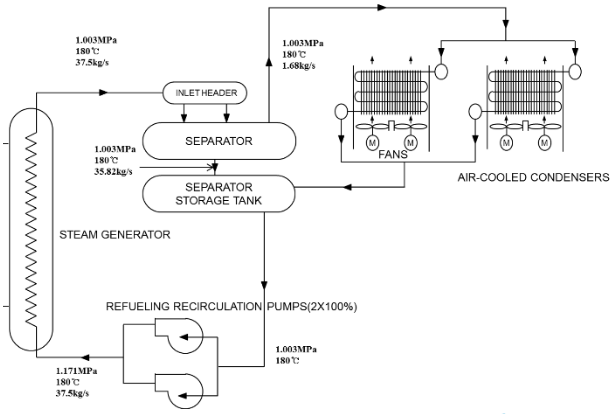
In the PGSFR, during the refueling operation after stopping the reactor, an alternate decay heat removal system is additionally required to perform the non-safety function of maintaining the temperature of the PHTS at the refueling operation temperature. Therefore, the RDHRS (Refueling Decay Heat Removal System) was designed to provide decay heat removal capability during the refueling operation.

2. RDHRS Descriptions

The heat removal capacity of the RDHRS has 3.36 MWt [6], which is the decay heat after 24 hours of the reactor shutdown. It is necessary to determine the heat balance for the PHTS, IHTS, and RDHRS to design components of the RDHRS. The schematic of heat balance of systems at the refueling operation condition is shown in Fig. 1. The RDHRS mainly consists of the separator, pump and condenser.



(a) PHTS and IHTS



(b) RDHRS

Fig. 1 Schematic of heat balance of systems at the refueling operation condition

3. Components design

A conceptual design of main components of the RDHRS was conducted based on the heat balance. Lee et al [7] performed the design of the separator and determined the main design parameters for the separator. In this paper, a design process and results for the RDHRS pump and condenser is presented.

3.1 RHDRS pump

The RDHRS pump provides sufficient circulation flow to the RDHRS so that the residual heat from the core can be properly removed during the refueling operation. The design requirements of the RDHRS pump are as follows.

- Mass flow rate: 37.5 kg/s
- Head: 266 kPa

The mass flow rate is determined by the heat balance for the RDHRS, and the head is determined by the pressure loss generated in the RDHRS. In order to determine the rotational speed of the pump, the efficiency change according to the specific speed as shown in Fig. 2 can be used. In Fig. 2, the specific speed of the pump is a dimensional parameter. The unit of specific speed is [rpm, m^3/s, m]. The specific speed is generally determined as below.

$$N_s = N \frac{Q^{0.5}}{H^{0.75}} \tag{1}$$

Where N is the rotational speed, and Q is the volumetric flow rate, and H is the head of the pump.

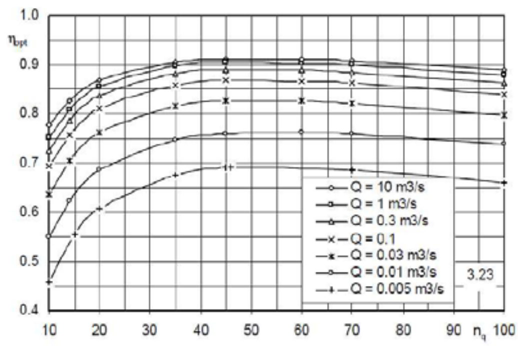


Fig. 2 Efficiency change of the pump according to the specific speed [8]

Since the volumetric flow rate and head of the pump are fixed, the rotational speed can be determined for high efficiency using Fig. 2. The rotational speed of the pump was determined to be 1800 rpm, and the specific speed was determined to be 219 [rpm, m^3/min, m], and the optimal efficiency can reach about 83%.

The $NPSH_R$ (Required Net Positive Suction Head), one of the design requirements of the pump, means the suction head required to operate without cavitation, and can be obtained through the following equations.

$$\sigma = \frac{NPSH_R}{H} \tag{2}$$

$$\sigma = 7.88 \times 10^{-5} N_s^{\frac{4}{3}} \text{ (single suction)} \tag{3}$$

$$\sigma = 5.00 \times 10^{-5} N_s^{\frac{4}{3}} \text{ (double suction)} \tag{4}$$

Where σ is the Thoma's cavitation factor. The $NPSH_R$ can also be obtained through the following equations using the suction specific speed.

$$N_{ss} = N \frac{Q^{0.5}}{(NPSH_R)^{0.75}} \tag{5}$$

$$N_{ss} = 1200 \text{ (single suction)} \tag{6}$$

$$N_{ss} = 1700 \text{ (double suction)} \tag{7}$$

Where N_{ss} is the suction specific speed, and many experiments showed that the suction specific speed is constant for a wide range of specific speeds. The $NPSH_R$ can be obtained by applying the equation for a single suction pump, and the values obtained through the above two methods were almost the same. The $NPSH_R$ was determined to be 3.2 m. The water horse power, shaft horse power, and motor power can be determined through the following equations.

$$L_w = \rho g H Q \tag{8}$$

$$\mathrm{L} = \frac{L_w}{\eta} \tag{9}$$

$$L_d = kL \tag{10}$$

Where η is the efficiency, and k is the coefficient of the motor power. The efficiency is assumed to be 83%, and the coefficient of the motor power is assumed to be 1.2. Therefore the motor power was determined to be 17 kW.

3.2 RHDRS condenser

The RDHRS condenser performs a function of condensing the steam separated from the separator through heat exchange using air. The RDHRS condenser type was selected as a fin-type heat transfer tube air-cooled condenser, which generally increases the heat transfer area by installing fins on the outside of the tube in order to reduce the heat resistance on the air side. Figure 3 shows the schematic of fin-type heat transfer tube air-cooled condenser.

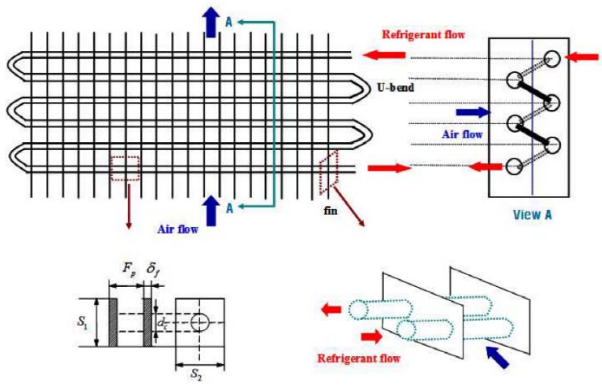


Fig. 3 Schematic of fin-type heat transfer tube air-cooled condenser

In the RDHRS condenser, the heat of the fluid inside the heat transfer tube is transferred to the outside of the heat transfer tube by convection and conduction. The part without fins directly exchanges heat with air, and the part with fins exchanges heat with air through fins. Figure 4 shows the schematic of heat resistance of the RDHRS condenser.

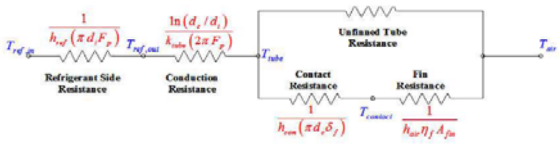


Fig. 4 Schematic of heat resistance of the RDHRS condenser

The design requirements of the RDHRS condenser are as follows.

- Heat removal capacity (per single): 1.68 MWt
- Air inlet temperature: 40 °C
- Air inlet velocity: 3 m/s

- Steam inlet temperature: 180 °C
- Steam inlet pressure: 1.0 MPa

The main design parameters for the RDHRS condenser are summarized in Table 1.

Table 1. Main design parameters for the RDHRS condenser

Design parameter	Value
Number of depth rows	8
Number of tubes per row	19
Longitudinal tube pitch (mm)	64
Transverse tube pitch (mm)	64
Tube OD/ID (mm)	34/30.7
Tube thickness (mm)	1.5
Fin height (mm)	64
Fin thickness (mm)	1.5
Fin pitch (mm)	5.08

4. Conclusions

The RDHRS was designed to provide decay heat removal capability during the refueling operation. A preliminary design of main components of the RDHRS for the PGSFR was performed. The design process and main design parameters for the RDHRS pump and the RDHRS condenser were presented.

ACKNOWLEDGEMENT

This work was supported by the National Research Council of Science & Technology (NST) grant by the Korea government (MSIT) (No. CAP-20-03-KAERI).

REFERENCES

[1] Debru, et al., Decay Heat Removal in SPX-1 and Related Design Basis Conditions, DHR and Natural Convection in FBR, Hemisphere Publishing Corporation, pp.263, 1981.
[2] Braquilanges, et al., Natural circulation tests in SPX-1, In: Proceedings of International Fast Reactor Safety Meet, vol. IV, pp.279.1990.
[3] Gyr, et al., EFR decay heat removal system design and safety studies, In: Proceedings of International Fast Reactor Safety Meet, vol. 3, pp.543, 1990.
[4] Kotake, et al., Application of the PSA method to decay heat removal system in a large scale FBR design, In: IAEA Specialists Meet on Evaluation of DHR by Natural Convection, Oarai, Japan, 1993.
[5] L. Satish Kumar, et al., Design and evaluation of Operation Grade Decay Heat Removal System of PFBR, Nuclear Engineering and Design, Vol. 241, pp.4953-4959, 2011.
[6] Y. Jung, H. W. Lee, H. Y. Ye, S. R. Choi, Preliminary Design of Refueling Decay Heat Removal Systems for the PGSFR, Transactions of the Korean Nuclear Society Autumn Meeting, 24-25 Oct., 2019, Goyang, Korea.
[7] H. W. Lee, Y. Jung, J. W. Han, S. R. Choi, Preliminary Design of Refueling Decay Heat Removal System Steam-water Separator for the PGSFR, Transactions of the Korean Nuclear Society Spring Meeting, 23-24 May, 2019, Jeju, Korea.
[8] J. F. Gülich, Centrifugal Pumps, Springer, 2014.