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Design feasibility study on DHRS for 100MWe long fuel cycle sodium-cooled fast reactor

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1. Introduction

The SALUS(Small, Advanced, Long-cycled and Ultimate Safe sodium-cooled fast reactor)[1] is a 100MWe long fuel cycle sodium-cooled fast reactor system that is under development in KAERI. The overall design of SALUS is based on 150MWe PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) design. It is a pool type reactor including two pumps, four IHXs, and four DHXs. The IHTS(Intermediate Heat Transport System) is composed of two loops and the DHRS(Decay Heat Removal System) is composed of two passive trains and two active trains.

As an initial step for designing SALUS, design feasibility study has been started in KAERI. The objective of this study is to evaluate the acceptability of the existing device design and to derive design modification. For the evaluation.

In this work design feature of DHRS[2] is described. Preliminary DHRS design point and preliminary design modification for SALUS is proposed.

2. Design Feature of DHRS

The safety function of DHRS is to remove the generated decay heat from the reactor core to achieve safe shutdown on design basis accident. The DHRS is consists of two Passive DHRS(PDHRS) and two Active DHRS(ADHRS) to accommodate the requirements of redundancy, diversity, and independency. One PDHRS consists of a decay heat exchanger(DHX), a natural-draft sodium-to-air heat exchanger(AHX) with a chimney and loop. One ADHRS is consists of a DHX, a forced-draft sodium-to-air heat exchanger(FHX) with a chimney and loop. The ADHRS shall be operated by an active component, fan, however, it shall also be capable of operating in a passive mode with at least 50% heat removal ability of the design capacity.

The total heat removal capacity of SALUS DHRS is 6.675 MWt, which amounts to about 2.5% of the rated core thermal power. The heat removal capacity of each train amounts to 1.67 MWt.

3. Method and Results

3.1 Governing Equations

The DHRS consists of three coupled natural circulating heat transport paths. They are PHTS path between DHX shell-side and cold sodium pool, DHRS loop path including tube-side of DHX and AHX, and AHX shell-side air path including the air chimney, respectively. The heat transfer rates through DHX and AHX can be defined as following equation[3].

$$Q_{DHX}^{rej} = UA_{DHX} \cdot \Delta T_{LMTD}(T_{PH}, T_{PC}, T_{LH}, T_{LC}) \quad (1)$$

$$Q_{AHX}^{rej} = UA_{AHX} \cdot \Delta T_{LMTD}(T_{LH}, T_{LC}, T_{AH}, T_{AC}) \quad (2)$$

where subscripts *P, L, A, H* and *C* represent the PHTS side(DHX shell side), loop side, AHX shell side, hot fluid, and cold fluid, respectively. Q, U, A, and T represent the heat transfer rates, overall heat transfer coefficient, heat transfer area and temperature, respectively. Superscript *rej* and subscript *LMTD* represents heat rejection and a log mean temperature difference, respectively.

Heat transfer rates at respective heat transport paths such as Q_{DHX}^{rej}, Q_{LOOP}^{rej} and Q_{AHX}^{rej} can also be expressed by following equations.

$$Q_{DHX}^{rej} = \dot{m}_P \cdot (c_P(T_{PH}) \cdot T_{PH} - c_P(T_{PC}) \cdot T_{PC}) \quad (3)$$

$$Q_{LOOP}^{rej} = \dot{m}_L \cdot (c_P(T_{LH}) \cdot T_{LH} - c_P(T_{LC}) \cdot T_{LC}) \quad (4)$$

$$Q_{AHX}^{rej} = \dot{m}_A \cdot (c_P(T_{AH}) \cdot T_{AH} - c_P(T_{AC}) \cdot T_{AC}) \quad (5)$$

Where $\dot{m}$ and c_P represents the mass flow rate and specific heat, respectively. The governing equation for momentum conservation of the DHRS can be represented as the correlations between developing head and pressure loss.

$$C^P \dot{m}_P^2 = \Delta H^P(T_{PH}, T_{PC}, Z_D^+, Z_D^-) \quad (6)$$

$$C^L \dot{m}_L^2 = \Delta H^L(T_{LH}, T_{LC}, Z_D^+, Z_D^-, Z_A^+, Z_A^-) \quad (7)$$

$$C^A \dot{m}_A^2 = \Delta H^A(T_{AH}, T_{AC}, Z_A^+, Z_A^-, Z_{chm}^+, Z_{chm}^-) \quad (8)$$

where *C, ΔH, Z,* superscript +, -, subscript *D* and *chm* represent the flow resistance, developing head, elevation, top and bottom of heat exchanger, DHX and chimney, respectively. The design point can be determined by combining the above equations.

In this work, POSPA-GA[4] code was used, which is one-dimensional system design code employing genetic algorithms. Most of the PGSFR's geometry information is assumed to be preserved in the feasibility evaluation.

3.2 Preliminary Design Parameters of PDHRS

Table 1 shows the differences of the DHRS operating environment between PGSFR[5] and SALUS. The basic strategy is to derive design points while preserving the heat exchanger size as much as possible. Thus the design factors excluding heat exchanger-related factors were changed and design points were evaluated.

Table 1 Differences of operating environment

Design Parameter	PGSFR	SALUS
Cold pool temp. (℃)	390	360
Decay heat removal ratio (%)	2.5%	2.5%
Heat transfer rate (MWt)	2.5	1.67

Table 2 summarizes the preliminarily evaluated design parameters of PDHRS. As shown in table, PDHRS design points can be derived by lowering the chimney height from 25 m to 12.5 m.

Table 2 Preliminary design parameters of PDHRS

Design Parameter	Value
Loop (ea)	1
DHX unit per loop (ea)	1
AHX unit per loop (ea)	1
Heat transfer rate (MWt)	1.67
DHX shell mass flow rate (kg/s)	11.73
Loop mass flow rate (kg/s)	18.16
AHX shell mass flow rate (kg/s)	6.96
DHX shell inlet/outlet temp. (℃)	360/251.1
Hot leg/Cold leg temp. (℃)	314.7/244.7
AHX shell inlet/outlet temp. (℃)	40/284.3
Chimney height/diameter (m)	12.5/2.5

3.3 Design Parameter of the ADHRS

In case of ADHRS it should be operable not only in active mode but also in passive mode. Thus design points were derived in passive mode by modulating chimney design parameters such as diameter and height. Table 3 shows the preliminary evaluated design parameters of ADHRS. As shown in table 3, design parameter can be derived by lowering the chimney height from 25 m to 12.5 m as well as by reducing the chimney diameter from 2.5 m to 1.4 m.

Table 3 Preliminary design parameters of ADHRS

Design Parameter	Value
Loop (ea)	1
DHX unit per loop (ea)	1
AHX unit per loop (ea)	1
Heat transfer rate (MWt)	1.17
DHX shell mass flow rate (kg/s)	10.31
Loop mass flow rate (kg/s)	16.10
FHX shell mass flow rate (kg/s)	4.80
DHX shell inlet/outlet temp. (℃)	360/276.1
Hot leg/Cold leg temp. (℃)	327.8/271.6
AHX shell inlet/outlet temp. (℃)	40/278.95
Chimney height/diameter (m)	12.5/1.4

This is a preliminary evaluation to check whether the PGSFR's heat exchanger can be employed in SALUS or not. The more detailed evaluation will be followed to optimize the DHRS design for SALUS.

3. Conclusions

The design feasibility study on DHRS for 100MWe long fuel cycle sodium-cooled fast reactor has been performed. The preliminary evaluation shows that the PGSFR's DHRS can be employed in SALUS' DHRS with a little modification such as chimney. Further study is needed to optimize the DHRS for SALUS.

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