Preliminary evaluation of operating condition in SFR integrated with TES

Ji-Woong Han *, Dehee Kim, Huee-Youl Ye and Jewhan Lee

Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-Gu, Daejeon, Republic of Korea, 34057
**Corresponding author: jwhan@kaeri.re.kr*

***Keywords :** HELIOS, IHTS, TES, SFR, pinch temperature

1. Introduction

To accommodate the high volatility of renewable energy sources while retaining the role of a reliable baseload provider, advanced nuclear concepts integrated with Thermal Energy Storage (TES) have been actively proposed. TerraPower's Natrium plant, a sodium-cooled fast reactor (SFR) coupled with a molten salt TES, recently secured a construction permit from the U.S. Nuclear Regulatory Commission (NRC) [1]. This system allows the reactor to maintain a constant, high-efficiency core output, diverting excess thermal energy to molten salt tanks during low-demand periods. Consequently, during peak demand or sudden drops in renewable generation, the stored thermal energy can be rapidly discharged to drive auxiliary turbines. This architectural synergy offers both robust baseload power and rapid load-following flexibility, effectively mitigating the intermittency of renewable energy.

Korea Atomic Energy Research Institute (KAERI) has also been spearheading the development of advanced TES technologies coupled with nuclear systems. KAERI has developed a high-temperature sodium-cooled TES test facility to verify the technical feasibility and long-term structural integrity of liquid metal storage media [2]. The experimental facility is designed to evaluate thermal hydraulic performance at high operating temperature. KAERI has extended its research scope to explore nuclear-renewable hybrid energy configurations by coupling Small Modular Reactors (SMRs) with TES systems.

HELIOS, Hybrid Energy-storage Long-life InnOvative SFR, is the TES-integrated SFR under development at KAERI. It is in the conceptual design stage. The establishment of the heat balance of the plant is a starting point for the design and the sizing of components of a new reactor concept.

In this research, the preliminary heat balance diagram of HELIOS and the related procedure are described.

2. Analysis Procedure

Fig. 1 shows the overall process for calculating operating conditions in HELIOS. Q, W, m, Thi, Tho, Tci, Tco, and η represent heat transfer rate, power, mass flow rate, temperature of hot side inlet and outlet, temperature of cold side inlet and outlet, and efficiency. Subscripts p, i, t, ihx, shx, sg, and fw represent primary heat transport system, intermediate heat transport system, thermal energy storage system, intermediate heat exchanger, sodium-salt heat exchanger, steam generator and feedwater. The thermophysical properties of sodium and solar salt were determined using reference data from reliable sources [3,4]. One of the important factors in the design of the heat transport system is finding an optimal pinch temperature for the heat exchanger design. The pinch point of the heat exchanger is the minimum temperature difference between hot side and cold side. The selection of an optimal pinch temperature is very important to balance cost and efficiency with respect to heat exchanger design. Too small a pinch temperature increases the required heat transfer area. Too large a pinch temperature reduces the thermal efficiency. Limiting the temperature difference is also critical to mitigating thermal stress.

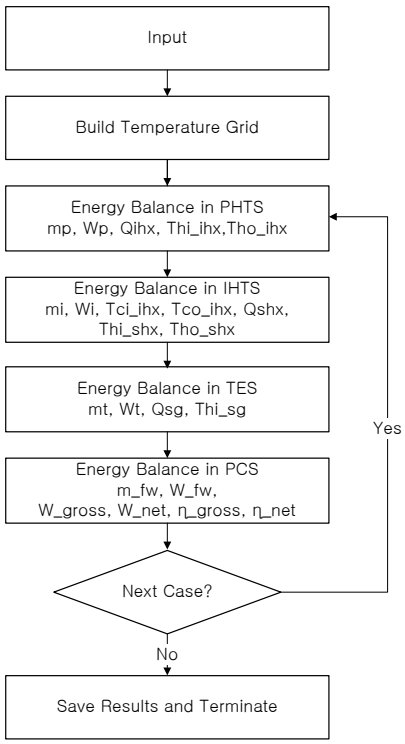


Fig. 1 Flow chart for energy balance estimation

3. Results

Figs. 2 to 5 show the core inlet and outlet temperature difference, feedwater temperature, steam temperature, and steam pressure, all based on the core outlet temperature. The colored symbols, such as ALMR, ABTR, PGSFR, and SALUS, represent data from metal-fueled SFRs [5,6]. The core outlet temperature of most metal-fueled SFRs is relatively low compared to ceramic-fueled SFRs, except for PGSFR. HELIOS is a long-fuel-cycle, metal-fueled SFR. Therefore, it adopted the operating conditions designed for SALUS, which is based on a long-cycle core concept. The respective value is written in each figure.

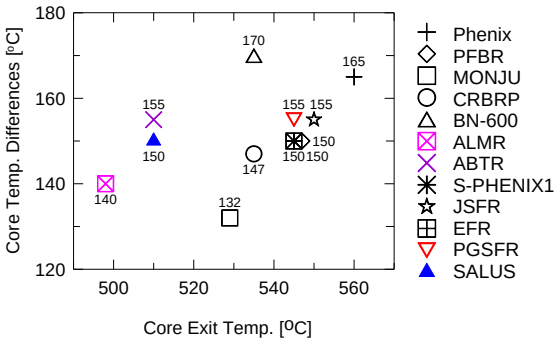


Fig. 2 Core temperature differences with respect to core exit temperature in various reactor design

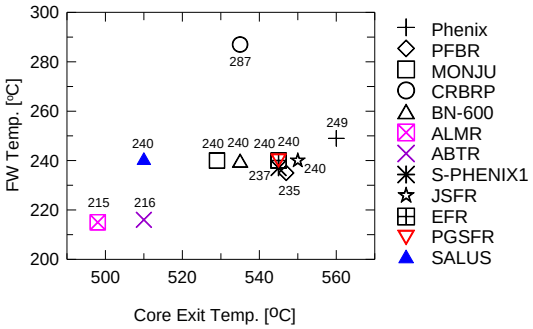


Fig. 3 Feedwater temperature in various reactor design

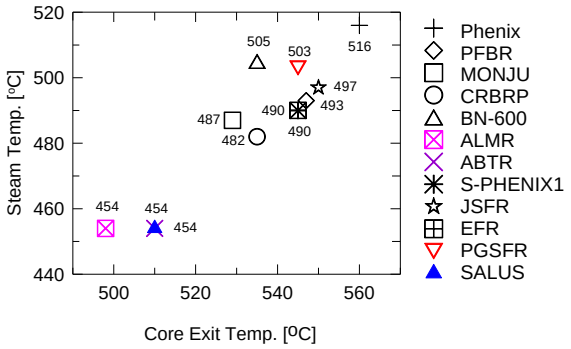


Fig. 4 Steam temperature in various reactor design

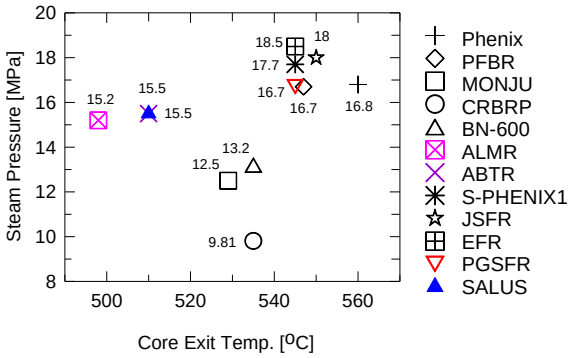


Fig. 5 Steam pressure in various reactor design

The TES temperature is determined by considering system characteristics within the limits imposed by the physical properties of solar salt, the freezing and decomposition thresholds. However, as the designs for the TES and the power conversion system (PCS) has not yet been finalized, temperature of 480°C and 300°C, respectively, have been assumed for the current stage.

Fig. 6 shows the available UA with respect to the pinch temperature of the intermediate heat exchanger (IHX) and the sodium-salt heat exchanger (SHX). Fig. 7 shows the plant net efficiency with respect to the pinch temperature of the IHX and SHX. The inlet and outlet temperatures of the IHX and SHX should be determined by considering factors such as equipment size, maintenance, and operational costs. However, since sizing calculations for the individual heat exchangers have not yet been started and an economic analysis has not been conducted, the initial pinch temperature candidate was determined around the temperature which can minimize the UA of both IHX and SHX simultaneously with maintaining high net plant efficiency. The initially determined pinch temperature for IHX and SHX is 13.9 and 15.1, respectively. In the near future, once the heat exchanger sizing and economic analysis methods are established, the heat exchanger layout and economic feasibility will be evaluated to update the heat balance diagram. The flowrate was calculated using heat transfer rate and temperature difference.

The preliminary heat balance diagram under normal operating conditions is presented in Fig. 8. Since the TES design has not yet proceeded, the current heat balance diagram does not consider any heat exchange with the TES during various plant operating conditions at this stage. The determined values of the core thermal power, net electric power, and net efficiency of the plant are 546.7 MWt, 203.3 MWe, and 37.18%, respectively.

This heat balance is subject to future updates following an analysis of component size, layout, costs, and design data for the TES and PCS.

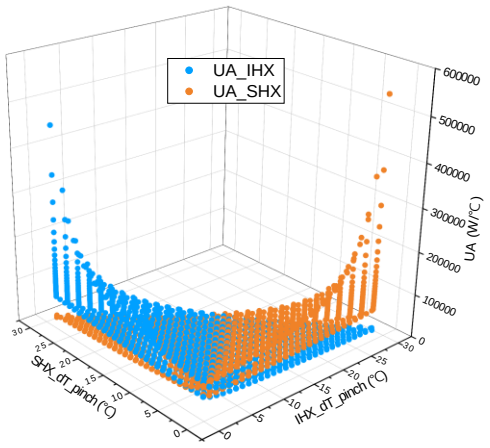


Fig. 6 UA with respect to pinch temperature

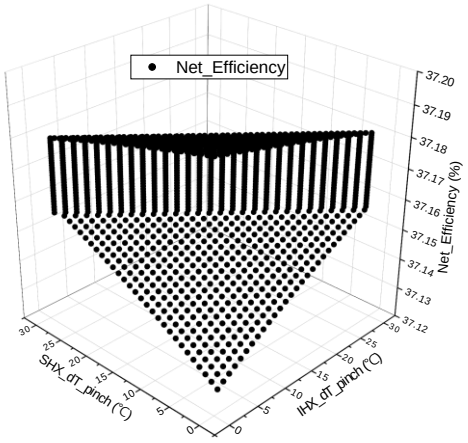


Fig. 7 Plant net efficiency with respect to pinch temperature

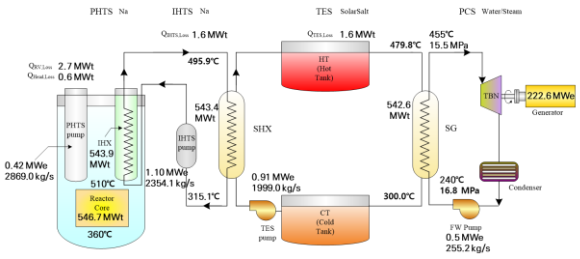


Fig. 8 Preliminary heat balance diagram

4. Conclusions

As the initial step in the HELIOS design process, a range of potential operating conditions was identified based on the operational parameters of existing metal-fueled reactors. By comparing the UA values of the IHX and SHX across various pinch temperatures, operating condition was selected to minimize these values while maintaining high net plant efficiency, and a preliminary heat balance was established. The values of the core thermal power, net electric power, and net efficiency of the plant are 546.7 MWt, 203.3 MWe, and 37.18%, respectively. This information will serve as the basis for initial equipment sizing.

5. Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT). (No. RS-2025-16012975).

References

[1] https://www.energy.gov/ne/articles/nrc-issues-construction-permit-terrapowers-natrium-advanced-reactor.
[2] Jewhan Lee, Jung Yoon, Yong-Hoon Shin and Hyeonil Kim, “Basic Design of High-Temperature Sodium Thermal Energy Storage (TES) Verification Test Facility,” Transactions of the KNS Spring Meeting, 2022.
[3] NIST Chemistry WebBook, SRD 69.
[4] Alexis B. Zavoico, Solar Power Tower Design Basis Document Rev.0, SAND2001-2100, 2001.
[5] IAEA, “Fast Reactor Database 2006 Update,” IAEA-TECDOC-1531, 2006.
[6] Ji-Woong Han and Huee-Youl Ye, “Preliminary study on heat balance of 100MWe sodium-cooled fast reactor,” Transactions of the Korean Nuclear Society Autumn Meeting, 2021.