

Sizing of Open-Air Brayton Cycle System for Molten Salt Reactor

Joohyung Jung^a, Taejun Song^a, Seongmin Son^a *

^aDepartment of Convergence & Fusion System Engineering, Kyungpook National Univ., Daegu, 41566, Republic of Korea

*Corresponding Author: seongminson@knu.ac.kr

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1. Introduction

Molten Salt Reactor (MSR) is a type of Generation IV nuclear reactor that uses molten salt containing dissolved nuclear fuel as both the fuel and the coolant. This system offers advantages in terms of compactness, higher operating temperatures compared to conventional pressurized water reactors (PWRs), and operation at near-atmospheric pressure which eliminating the need for large pressurization systems. Owing to their advantages, MSRs are increasingly being recognized for their potential in a variety of multi-purpose applications. While the secondary system of MSRs typically adopts the conventional steam Rankine cycle used in large-scale nuclear power plants, their high-temperature characteristics also make them compatible with alternative power conversion systems [1]. Among these alternatives, the Open-Air Brayton Cycle (OABC) is particularly promising due to its simple configuration, use of air as the working fluid—which facilitates easy supply—and reduced number of components, leading to simplified maintenance [2]. These features make the OABC especially well-suited for integration with high-temperature reactors such as MSRs and VHTRs, enabling efficient thermal energy conversion. However, the OABC is inherently designed with a lower expansion ratio compared to conventional gas turbines or Rankine cycles, which results in relatively larger turbomachinery sizes for the same power output. This structural limitation restricts its scalability to high-power systems and poses a bottleneck when applying the cycle to large-scale nuclear power plants. Although various turbomachinery sizing approaches have been explored for other heat sources, there has been limited analysis specifically targeting the MSR–OABC combined cycle. Therefore, this study aims to investigate the sizing characteristics of the turbine in an MSR–OABC system based on different power output conditions and to propose appropriate operating ranges and turbomachinery design criteria for this integrated cycle.

2. Heat Source Specifications and Determination of Optimal Operating Point

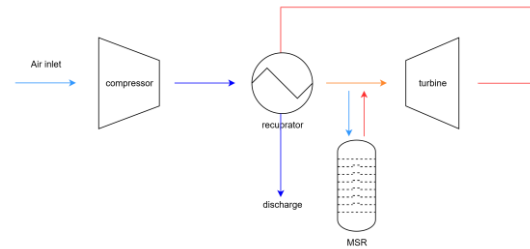


Fig. 1. OABC-MSR combined cycle

Fig. 1 illustrates a schematic of the power generation process in a cycle that integrates a MSR with an OABC. The system is composed of a compressor, heat source (MSR), turbine, and a recuperator. Atmospheric air is first compressed through the compressor. The compressed air then receives thermal energy from the heat source and passes through the turbine, where it generates power. Since the turbine exhaust air remains at a relatively high temperature due to the low turbine expansion ratio, it is utilized through a recuperator before being discharged to the atmosphere. In this process, heat is transferred from the turbine exhaust to the compressed air exiting the compressor. This preheating reduces the thermal load on the MSR and contributes to improving the overall thermodynamic efficiency of the cycle.

Table 1: input condition of OABC-MSR cycle [3][4]

Component	Spec
Recuperator effectiveness	95%
Recuperator P ratio	99%
Turbine Eff	90%
Turbine inlet temperature	790 K
Compressor Eff	90%
Compressor P ratio	Calculated
Atmosphere pressure	1 atm
Atmosphere temperature	288 K
Ratio of exhaust pressure to atmosphere pressure	98%

This study was conducted under the component performance specifications and system constraints summarized in Table 1. Referring to conditions from previous studies on gas turbines, the temperature at the turbine inlet after receiving heat from the thermal source was set to 790 K [4]

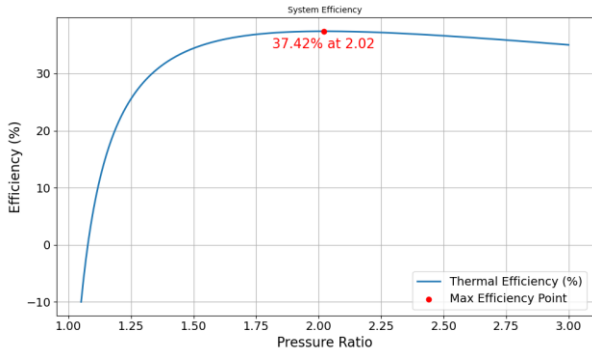


Fig. 2. Optimal pressure ratio

Fig. 2 presents the results of the cycle analysis based on the parameters listed in Table 1. The optimal pressure ratio that yields the maximum thermodynamic efficiency was found to be 2.02, at which point the cycle achieves a maximum efficiency of 37%.

3. Turbomachinery Sizing Methodology

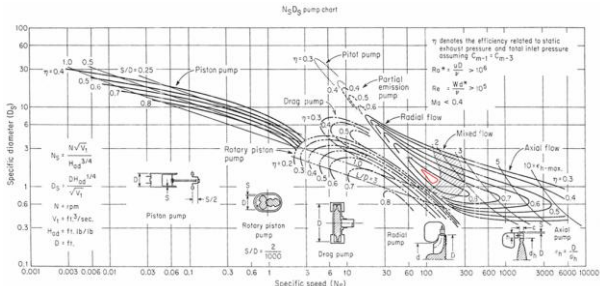


Figure 3. Balje's pump chart and scope of compressor efficiency area [5]

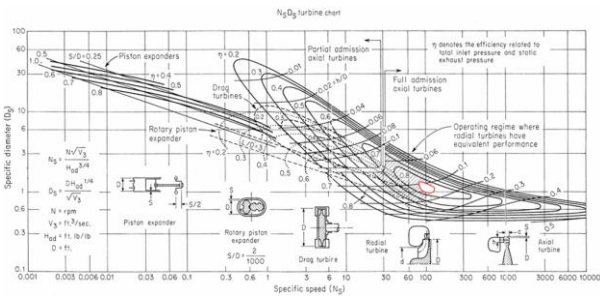


Figure 4. Balje's turbine chart and scope of turbine efficiency area [5]

The Balje's chart is a representative performance map used for the design and performance prediction of turbomachinery such as turbines, compressors, and pumps, and it plays a critical role in turbomachinery sizing. This chart enables efficient estimation of appropriate machine types and dimensions under given output and operating conditions. The key parameters for turbomachinery sizing, Specific Speed (N_s) and Specific Diameter (D_s), are defined as follows:

$$N_s = \frac{N\sqrt{V_1}}{H_{ad}^{3/4}} \quad (1)$$

$$D_s = \frac{DH_{ad}^{1/4}}{\sqrt{V_1}} \quad (2)$$

Where ' N ' denotes the rotational speed, ' V ' the volumetric flow rate, ' H_{ad} ' the total head, and ' D ' the impeller diameter. Based on these parameters, Figs. 3 and 4 present the feasible operating ranges of the turbine and compressor, respectively, as derived from Balje's chart with an assumed isentropic efficiency of 0.9. This efficiency value was determined with reference to the distribution characteristics of Balje's chart, in which an efficiency of approximately 0.9 is generally observed in the central region enclosed by the 0.8 efficiency contour. In this study, this central region was approximately delineated and represented as the 0.9 efficiency point.

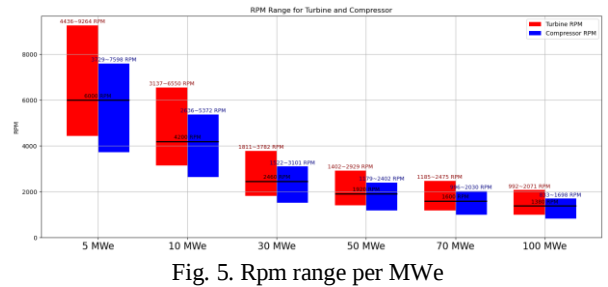


Fig. 5. Rpm range per MWe

Fig. 5 presents the calculated rotational speed results derived within the predefined ranges of N_s and D_s , visualizing the operating RPM ranges of the turbine and compressor across varying power outputs. In the graph, the red bars represent the turbine RPM range, while the blue bars indicate the compressor RPM range. As power output increases, the required RPM for both components gradually decrease, reflecting the typical trend in which larger turbomachinery diameters associated with higher power led to lower rotational speeds.

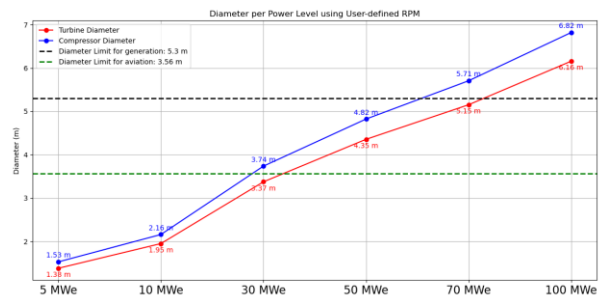


Fig. 6. diameter per MWe

The RPM values shown in the graph correspond to the diameter ranges presented in Fig. 6 and are used to describe the actual operating conditions associated with each specific D_s value.

4. conclusion

In this study, a performance-based analysis was conducted on an OABC system using an MSR as the thermal source. The variations in turbine and compressor

diameters were examined under given thermal output conditions, and the appropriate sizing range was derived based on operating RPM. Using non-dimensional coefficients corresponding to an isentropic efficiency of 0.9 from Balje's chart, the turbine diameters were calculated and visualized across different power output levels to identify the thermodynamic feasibility of each operating condition. According to the analysis presented in Fig. 6, the mechanically viable operating range of the MSR–OABC system is estimated to lie between 30 MWe and 70 MWe, beyond which the excessive turbomachinery size and associated structural limitations pose significant challenges to practical implementation. These results indicate that there exists an optimal combination of RPM and diameter for each power level, emphasizing the importance of determining the appropriate turbomachinery sizing to ensure both system efficiency and physical feasibility. Furthermore, the findings of this study are expected to serve as a valuable reference for engineering decisions in the future commercialization and demonstration design stages of MSR–OABC integrated power systems, particularly with respect to turbomachinery constraints.

Acknowledgement

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REFERENCES

- [1] Zhao, H., Wu, J., Chen, S., Cui, Y., Chen, J., & Cai, X. (2023). Conceptual Design of a Novel Megawatt Molten Salt Reactor Cooled by He-Xe Gas. *International Journal of Energy Research*, 2023(1), 8825501.
- [2] Song, M., Qian, Y., Leng, Y., Liu, T., Yu, L., & Chen, W. (2024). Multi-objective optimization research of open and closed air Brayton cycle. *International Journal of Advanced Nuclear Reactor Design and Technology*, 6(1), 21-31.
- [3] Zohuri, B., McDaniel, P. J., & De Oliveira, C. R. (2015). Advanced nuclear open air-Brayton cycles for highly efficient power conversion. *Nuclear Technology*, 192(1), 48-60.
- [4] Olaru, D., Cuciumita, C. F., & Vilag, V. A. (2017). Test bench configuration to facilitate gas turbine in-situ combustion experimentation. *Energy Procedia*, 112, 306-313.
- [5] PE, K. E. N. (2020). How to select turbomachinery for your application. *Barber-Nichols Inc.*, accessed March, 2.