Ambient Temperature Sensitivity Analysis of an Open Air Brayton Cycle Using GAMMA+

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***Keywords :** Molten Salt Reactor, Open Air Brayton Cycle, GAMMA+ Code, Ambient Temperature

1. Introduction

Molten Salt Reactors (MSRs) are gaining significant attention due to their inherent safety features and ability to operate at high temperatures. Open air Brayton cycle is particularly advantageous for MSRs due to its high efficiency, operational simplicity, and ability to adapt to high temperature environments. However, its performance remains highly sensitive to ambient temperature variations, which requires careful control and optimization strategies to maintain stable operation.

In industry, an ambient temperature of 15℃ is commonly assumed [1]. However, depending on the location and weather conditions of the system, ambient temperature often deviates from this value, leading to fluctuations in system performance. These deviations are typically considered off-design conditions. This study analyzes the sensitivity of cycle performance to variations in ambient temperature, exploring how changes in ambient temperature affect the cycle operation using GAMMA+ code. The results of this analysis offer valuable insights into the cycle's behavior and control strategies required to adapt to different ambient temperatures.

2. Methods and Results

2.1 Ambient Temperature and Design Considerations

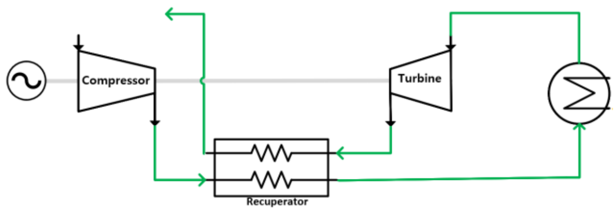

Fig 1 Open Air Brayton Cycle Layout

Fig 1 illustrates the open air Brayton cycle configuration considered in this study. Ambient air is drawn into the compressor at the atmospheric condition and compressed to the cycle high-pressure level. The compressed air is then routed to the recuperator, where it is preheated by the turbine exhaust stream, thereby reducing the required reactor-side heat input. After recuperation, the working fluid enters the intermediate heat exchanger (IHX) and receives additional heat from the MSR heat transport loop to reach the target turbine inlet condition. The heated air subsequently expands through the turbine to produce shaft work, which is used to drive the compressor and generate electricity. Downstream of the turbine, the exhaust air transfers its remaining sensible heat to the recuperator on the hot side and is finally discharged to the atmosphere. As a result, the compressor inlet temperature is directly coupled to ambient temperature, and seasonal or site-specific temperature variations inherently lead to off-design operation and corresponding changes in cycle performance.

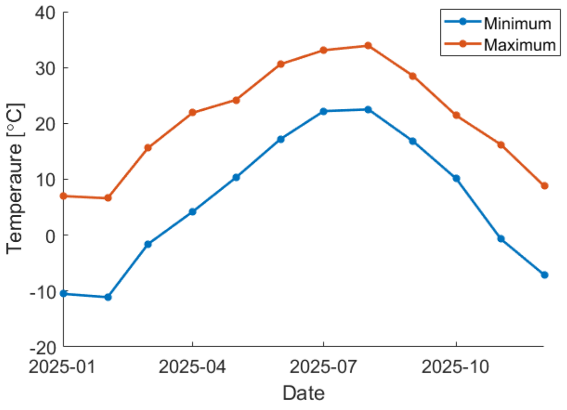

Fig 2 Maximum & Minimum Ambient Temperature in 2025, South Korea **[2]**

The target ambient temperature variation is chosen based on the monthly-averaged maximum and minimum ambient temperature of South Korea in 2025. As shown in Fig 2, the minimum temperature was -11.1℃ and the maximum temperature was 33.1℃. Thus, the target ambient temperature range was set to -15℃ to 35℃, conservatively. For each ambient temperature, the cycle performance and controllability were evaluated using the GAMMA+ code with coupled shaft-speed dynamics.

2.2 Control Strategies

In grid-connected operation, the required electrical power is dictated by the grid-side demand, while the shaft rotational speed varies according to the shaft dynamic equation.

$$(I_T - I_C - I_G)\omega \frac{\partial \omega}{\partial t} = \eta_T E_T - \frac{E_C}{\eta_C} - \frac{E_G}{\eta_G} \qquad (1)$$

In the present GAMMA+ simulations, any instantaneous mismatch between the net work and generator load results in acceleration or deceleration of the rotating shaft, thereby shifting the rotational speed from its nominal value. Maintaining the shaft speed close to the design setpoint is advantageous because turbomachinery performance is strongly speed-dependent. Thus, a PID controlled turbine bypass valve is adopted to control rotational speed to a design value, enabling stable cycle operation under ambient temperature induced off-design conditions.

On the other hand, as bypassing the turbine and intermediate heat exchangers leads to an increase in thermal input, additional control is required to prevent excessive heat production. Thus, a throttling valve is added to the exhaust of the recuperator to regulate the exhaust air mass flow rate, ensuring that the thermal output does not exceed the design limits. The locations of the control valves are shown in Fig 3.

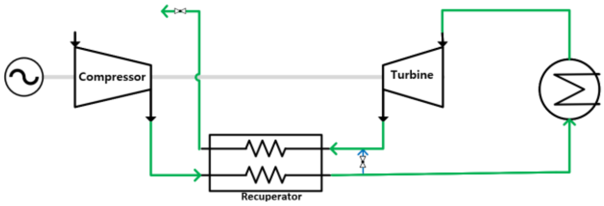

Fig 3 Turbine bypass/throttling valve positions

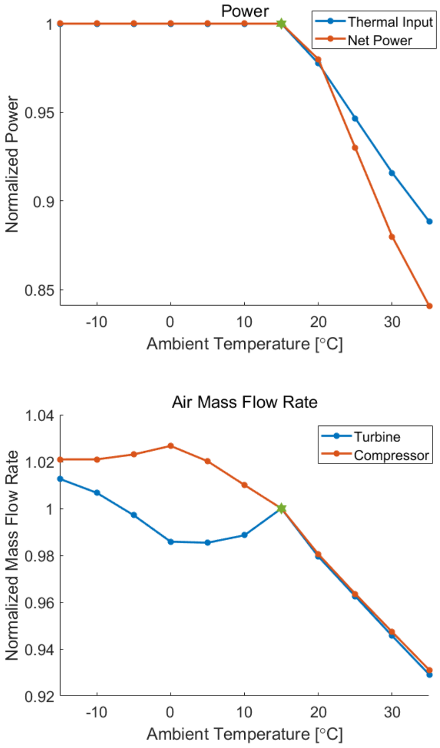

Fig 4 Normalized Cycle thermal input, net power and air mass flow rate over different ambient temperature
*(Design values are shown with green hexagram)

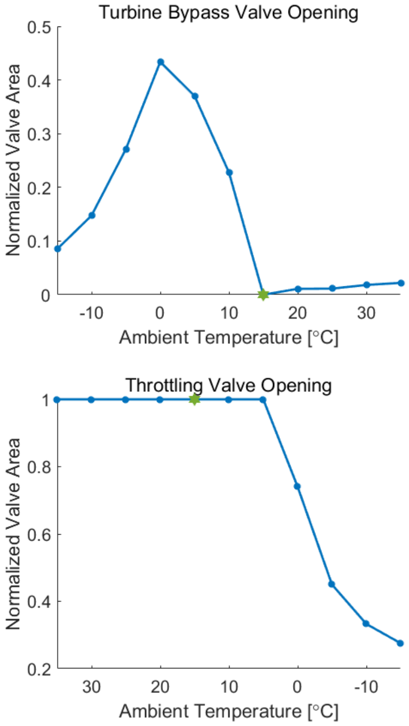

Fig 5 Normalized control valves area
*(Design values are shown with green hexagram)

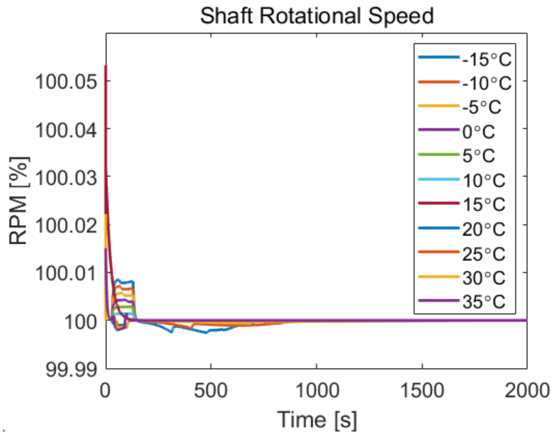

Fig 6 Shaft Rotational Speed

Fig 4 and 5 illustrate the cycle responses across a range of ambient temperatures. For $T_{amb} \geq 15$°C, the increase in ambient temperature leads to a decrease in inlet air density, reducing mass flow rate. As a result, compression work increases and the net electrical output decreases, which drives a reduction in shaft speed [3]. To maintain stability of the turbomachinery, the turbine bypass valve is controlled with PID controller to adjust the bypass flow, ensuring that the shaft speed is kept close to the design value. However, when the ambient temperature rises, the turbine bypass valve is fully closed, leaving no additional control authority to further recover power. Consequently, maintaining the design power level becomes difficult, and the maximum achievable electrical output decreases monotonically as ambient temperature increases, reaching approximately 84% power at 35°C. The thermal input also decreases in this range, showing that the net power is reduced more rapidly than the thermal input, which indicates a degradation in cycle efficiency under high ambient temperatures.

In contrast, for $T_{amb} \leq 15℃$, the cycle exhibits a reduction in compression work, which results in an increase in shaft speed. To stabilize the system, the turbine bypass valve opens, adjusting the flow to maintain the design shaft speed. The thermal input remains at its nominal level without requiring additional constraints by 0℃. However, as the temperature drops below 0℃, the reduced compression work leads to an increase in thermal input. In this case, a throttling valve is employed to control the thermal input. The throttling valve progressively closes to increase exhaust pressure, thereby reducing the air flow and maintain thermal input at the design level. As the total air mass flow rate decreases, the bypass flow is reduced, and the turbine bypass valve gradually moves toward a more closed position, ensuring that the shaft speed remains at the design value while preventing thermal input overshoot.

3. Conclusions

This study performed an ambient temperature sensitivity analysis to quantify how ambient temperature variations affect the performance and controllability of an MSR coupled open air Brayton cycle. The ambient temperature was varied from -15℃ to 35℃, and cycle behavior was evaluated using the GAMMA+ code. For hot ambient temperature conditions ($T_{amb} \geq 15℃$), increased compressor inlet temperature reduces air mass flow rate and compression work, leading to a monotonic reduction in the maximum achievable net electrical power under design shaft speed. The net power decreased to approximately 84%.

For cold ambient temperature conditions ($T_{amb} \leq 15℃$), the rated net power and thermal input could be maintained through turbine bypass and throttling control. While the turbine bypass valve regulates the shaft speed, the throttling valve suppresses thermal input overshoot by increasing exhaust pressure. The results highlight that shaft speed and thermal input control can ensure stable operation over a wide range of ambient temperatures. However, at high ambient temperatures, the current cycle design and control strategy approach practical limits in terms of achievable power. This does not imply that the open air Brayton cycle is unfeasible in high temperature environments, but rather that the design and control strategies require further refinement to optimize performance under such conditions. Future work should focus on improving control strategies and adapting the cycle design to accommodate higher ambient temperatures, thereby expanding the operational range and ensuring reliable performance even in various conditions.

NOMENCLATURE

MSR	Molten Salt Reactor
IHX	Intermediate Heat Exchanger
$I_{T,C,G}$	Moment of inertia of turbine, compressor, or generator
$E_{T,C,G}$	Power of turbine, compressor or generator
$\eta_{T,C,G}$	Efficiency of turbine, compressor or generator
ω	Shaft Rotational Speed
T_{amb}	Ambient Temperature

ACKNOWLEDGEMENT

This work was supported by Korea Research Institute for defense Technology planning and advancement(KRIT) grant funded by the Korea government(DAPA(Defense Acquisition Program Administration)) (21-107-F00 018(KRIT-CT-22-017), Next Generation Multi-Purpose High Power Generation Technology(Development of Power Generating System Core-Technologies for Liquid Fuel Heat Generator), 2022)

REFERENCES

[1] T. Komuro, E. Ito, T. Sonoda, Y. Tomita, K. Hidaka and S. Shibutani, "Power Output Augmentation of Gas Turbine Combined Cycle by Inlet-Air Cooling System of Chiller Type under High Ambient Air Temperature," Mitsubishi Heavy Industries Technical Review, 2010.

[2] Korea Meteorological Administration (KMA), "Climate Statistics Analysis: Temperature Analysis," Weather Data Service (KMA Data Portal), [Online]. Available: https://data.kma.go.kr/stcs/grnd/grndTaList.do?pgmNo=70. [Accessed 22 Feb 2026].

[3] Turbomachinery Magazine, "How ambient temperature affects gas turbine types," 26 April 2021. [Online]. [Accessed 22 Feb 2026].