A Study on Supercritical CO_2 Brayton Cycle for a Molten Salt Reactor

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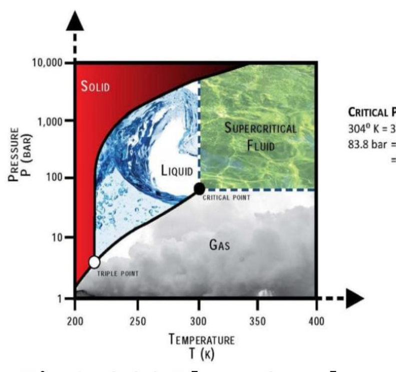
1. Introduction

▶ Research Objectives

- Design and simulate the large scaled Brayton Cycle applicable to MSR
- Optimization to improve cycle efficiency

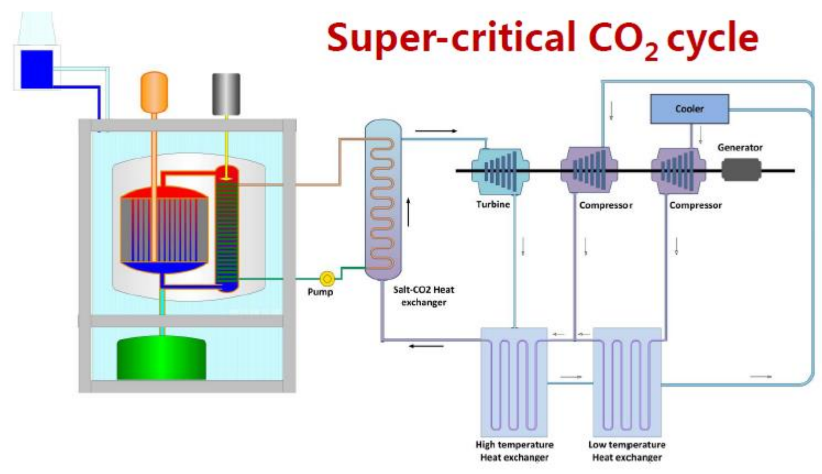
▶ What is s-CO_2?



- Supercritical state has both liquid and gas properties.
- s-CO_2 has low critical point compare to the steam.
- s-CO_2 is important to improve the cycle efficiency.

Fig 1. CO2 Phase Graph

▶ What is MSR?



- Molten Salt Reactor (MSR) is one of the Gen-IV models, and is currently being studied in many countries, including the U.S., China, and the U.K.
- MSR is expected to operate at higher temperatures than SFR and LFR with operating temperature range of 500-750 ℃.
- MSR has high safety and excellent thermal efficiency.

Fig 2. Schematic diagram of MSR power plant with s-CO2 Brayton cycle

2. Design & Optimization Methodology of SCBC for MSR

▶ Optimization Process

- The simulation cycle was constructed using a Daniel Wagner Simulator(DWSIM) chemical process simulation program.
- The initial values of cycle design are based on the TSMR-LF1 from China.
- To achieve high cycle efficiency, it was designed as a Brayton cycle power conversion system with a recuperative and recompression cycle.
- There are two recuperators and one main compressor and one recompression compressor.

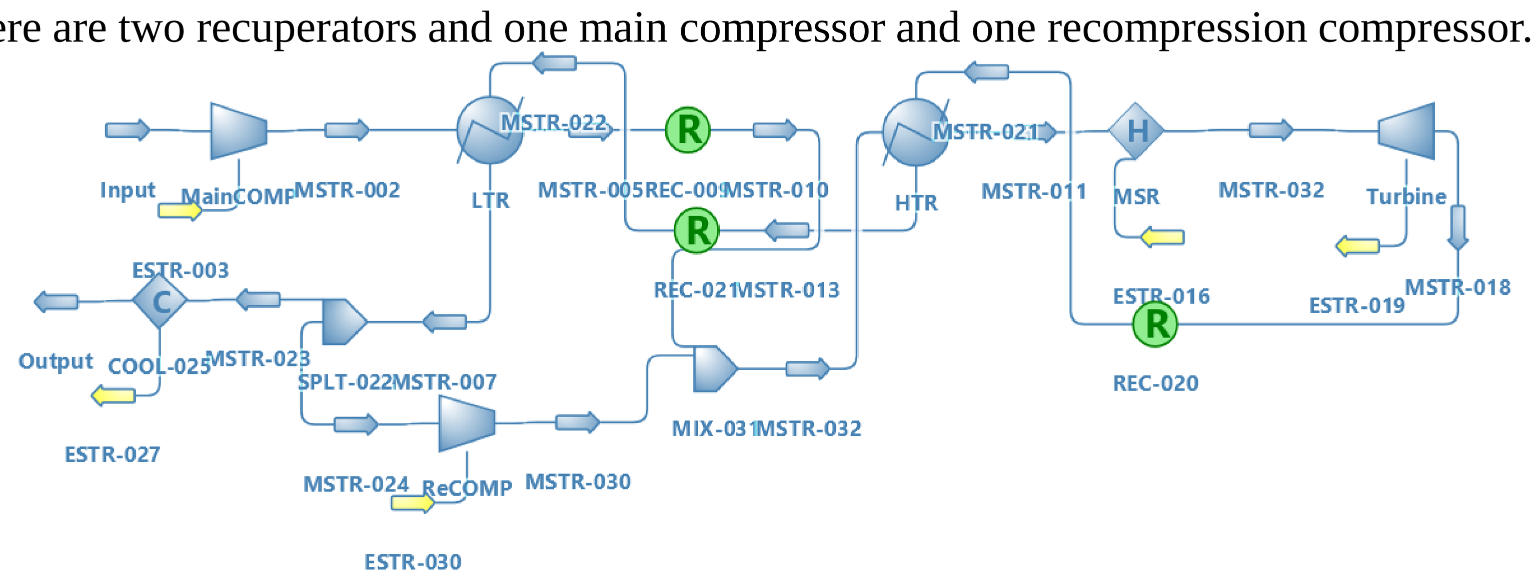


Fig 3. Schematic diagram of design of SCBC for MSR using DWSIM

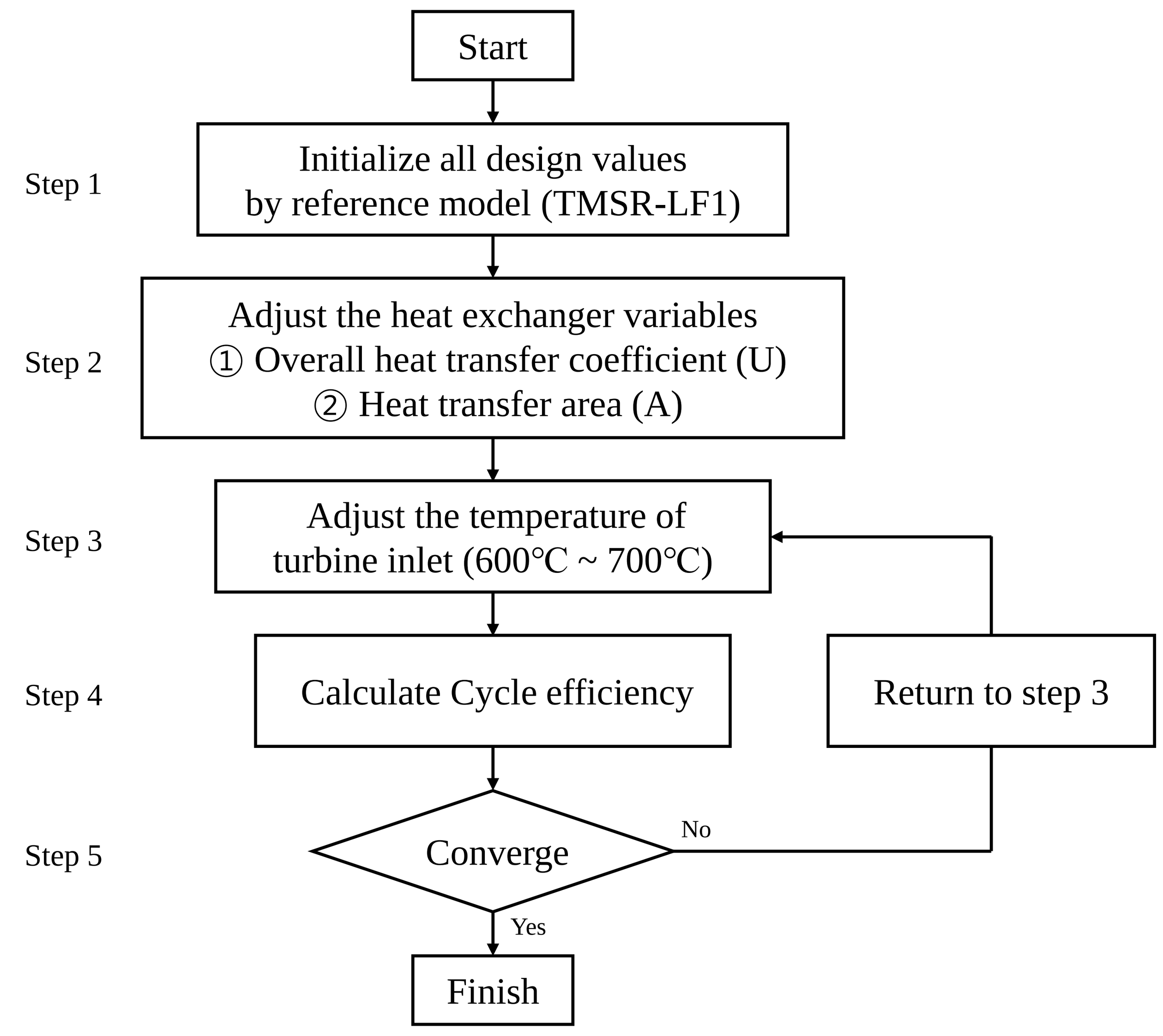


Fig 4. Experiment Process

3. Simulation Results

▶ Results analysis

- The variables for the optimization process of the cycle are overall heat transfer coefficient(U), Heat exchanger area(A), and turbine inlet temperature.
- Optimization efficiency is selected by comparing theory efficiency and simulation efficiency.
- The designed SCBC for MSR has a thermal power of 386.648 MWth and produce electric net power of 173.7 MWe and the cycle net efficiency is 45%.
- This is almost identical to or better than the conceptual design content of the reference model TMSR-LF1, 395 MWth of thermal power and 168 MWe of electric power output.
- This result is 3% more higher than the expected cycle efficiency of the reference model(TSMR-LF1)

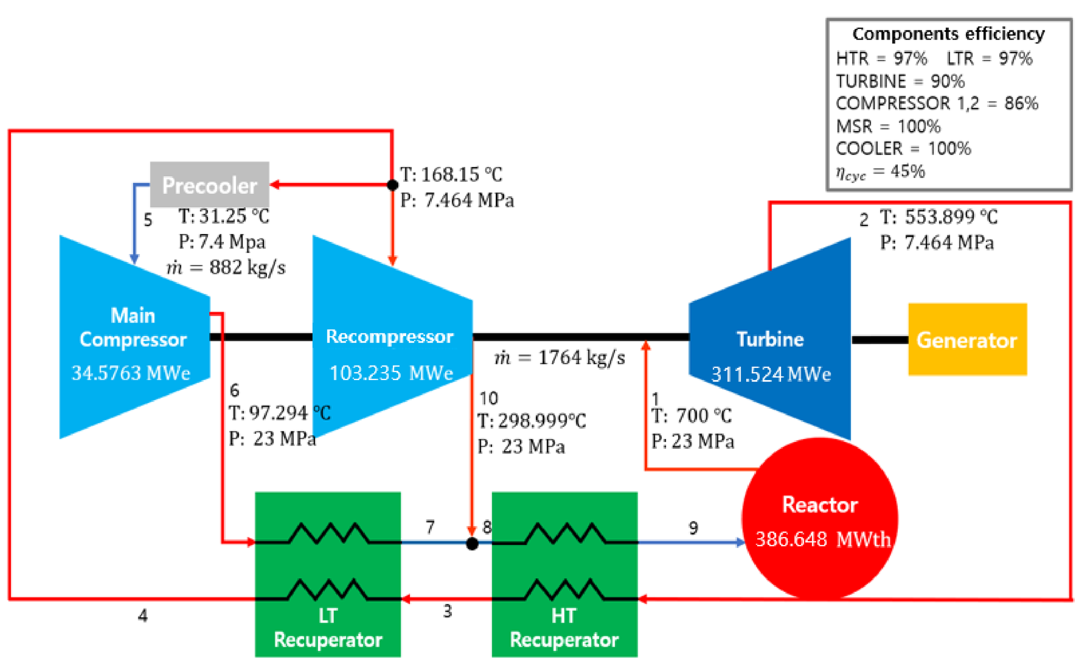


Fig 5. Layout of SCBC for MSR

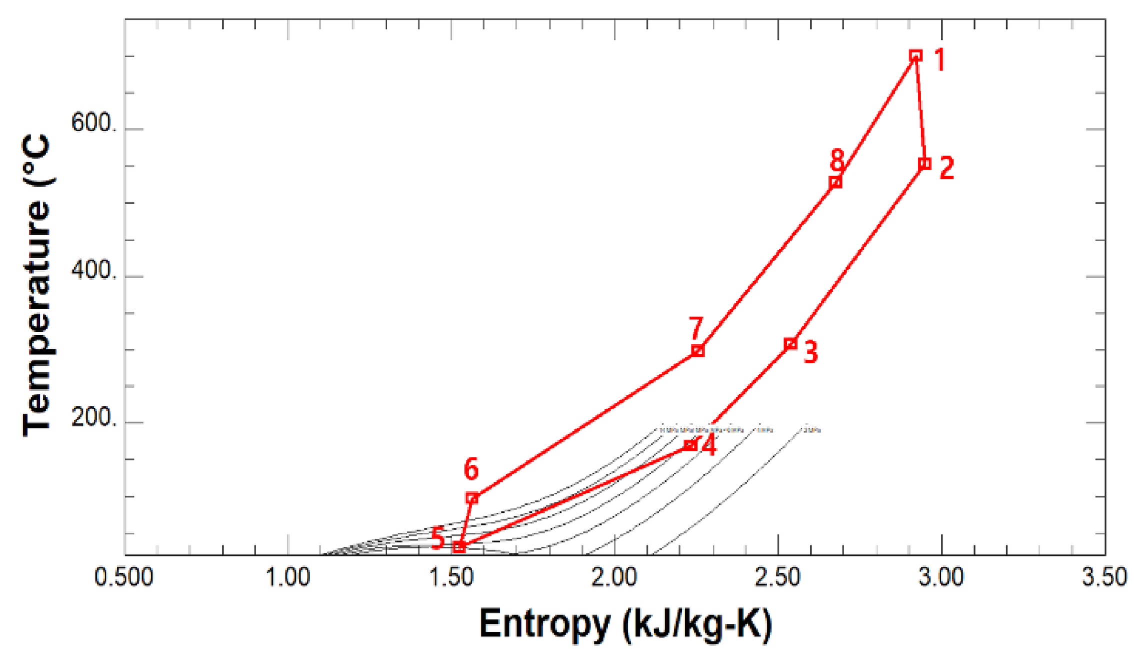


Fig. 6. Temperature-entropy diagram of designed SCBC for MSR

Table 1. Cycle design conditions and performances of SCBC for MSR

Specification	Unit	Value
Mass flow rate of CO_2	[kg/s]	1764
HTR heat exchange area	[m²]	25587.8
LTR heat exchange area	[m²]	7712.55
Cycle net efficiency	[%]	45
HTR overall heat transfer coefficient	[W/m²K]	1341
LTR overall heat transfer coefficient	[W/m²K]	1241
Thermal input power	[MWth]	386
Turbine generated power	[MWe]	311.5

Table 2. Specified state point of CO_2 in SCBC for MSR

	Temperature (℃)	Pressure (MPa)	Density (kg/m³)	Entropy (kJ/kg-K)
1	700.00	23.000	118.91	2.9222
2	552.86	7.4000	46.948	2.9489
3	307.80	7.4000	68.811	2.5394
4	169.37	7.4000	96.977	2.2331
5	31.250	7.4000	368.61	1.5247
6	97.294	23.000	563.52	1.5637
7	298.10	23.000	221.46	2.2562
8	527.83	23.000	146.43	2.6771

4. Conclusion

- To evaluate and verify the suitability of applying s-CO_2 Brayton cycles to MSR power plants, we designed a large scaled s-CO_2 Brayton cycle (SCBC) for MSR using a DWSIM program.
- Using the optimization process, we confirm that the simulation efficiency is 45% when the turbine inlet temperature is 700℃.
- By comparing the reference model(TMSR-LF1) and the simulation results, the cycle efficiency of the designed cycle increased by 3% compared to the reference data of TMSR-LF1.
- Simulation results show that the designed cycle has a thermal power of 386.648 MWth, with 174.4 MWe generating electric power. This is similar to the conceptual design of the reference model, 395 MWth of thermal power and 168 MWe of electric power output.