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Potential Improvement Margin of S-CO_2 Brayton cycle coupled to SMART

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1. Introduction

The supercritical CO_2 recompressing cycle is one of highly promising candidates with its major benefits: high efficiency under comparably low temperature condition, compact size of components, and simpler layout at an equivalent or superior thermal efficiency. However, some of these benefits can be still valid even in the water cooled technologies under Small and Medium sized Reactor(SMR) [1]. SMART is Korean type water cooled SMR developed by KAERI. In this study, the ideal component cycle for the system will be discussed to see the upper bound of total cycle and compared with realistic component cycle analysis for the potential improvement margin of the system.

2. Ideal to Real Cycle Comparison

2.1.Ideal Component Cycle Analysis

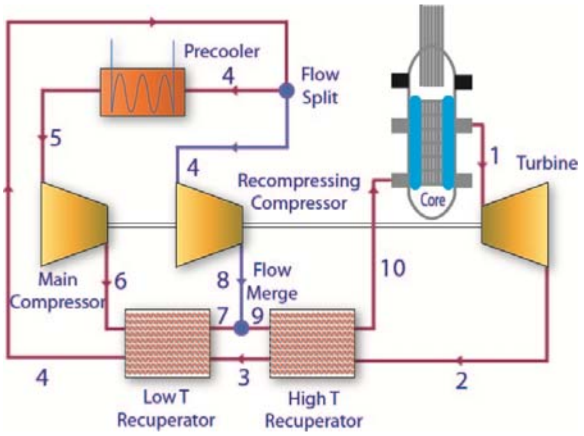

Fig. 1. The layout of S-CO_2 Recompressing Brayton cycle

Fig.1 shows the layout of S-CO_2 recompressing cycle coupled with SMART. The detailed parameters of the system are listed in Table.1. To assess the system, an in-house code developed by KAIST-Khalifa University joint research team was modified to compare the performance of the ideal component cycle to the realistic component cycle [3].

Reactor Outlet Temperature (K)	583.15	Deesigned Efficiency (%)o	30.3
Primary side pressure (MPa)	15	Turbine efficiency	0.9
Compressor efficiency	0.89	Recompressing compressor Efficiency	0.89
Flow split ratio	0.3	Pump Volume (m^3)	22.5
High Temperature Recuperator Volume (m^3)	24	Low Temperature Recuperator Volume (m^3)	36

Table 1. Design specification of the S-CO_2 cycle in SMART condition [1]

The ideal component cycle was designed under several assumptions: 1) Ideal heat exchanger: There is no pressure drop and 100% effectiveness through heat exchangers 2) Ideal turbomahcinery: The process in turbomachineries is reversible adiabatic process 3) The fixed turbine inlet pressure, 7.7 MPa: The cycle efficiency will be evaluated with varying cycle pressure ratio while the turbine inlet pressure is fixed. The reason for a fixed minimum pressure is that CO_2 properties change drastically near the critical point [3].

The cycle pressure ratio is defined as the ratio of the main compressor inlet pressure to the outlet pressure and the cycle pressure ratio range is from 1.7 to 3.2. This corresponds to the range of the cycle maximum pressure from 13MPa to 25 MPa. The recompressing fraction is defined as the ratio of the main compressor mass flow rate to the total mass flow rate. This is fixed for 0.3 in this study.

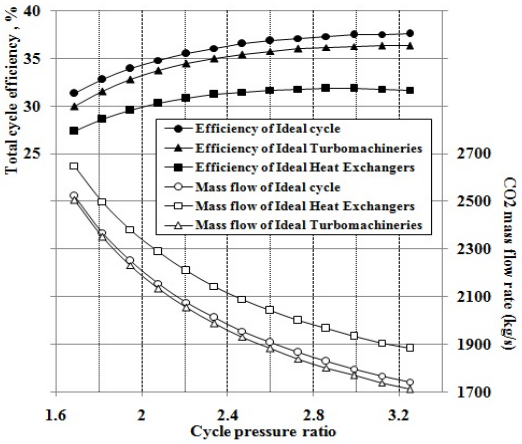

Fig. 2. Total cycle efficiency and mass flow rate for ideal component cycle analysis

Fig.2. shows the trend of total cycle efficiency and CO_2 mass flow rate vs. cycle pressure ratio for ideal component cycle assumption with fixed recompressing fraction. The total cycle efficiency increases steadily when the cycle pressure ratio increases since the net work produced by turbomachineries gradually increases, while the CO_2 mass flow rate decreases due to the heat balance. The total cycle efficiency is varying from 32% to 37% when the cycle pressure ratio is changing from 1.7 to 3.2. In the cases of ideal turbomachineries, it shows better efficiency than that of ideal heat exchangers. In other words, improving the performance of turbomachineries is more important than enhancing the performance of heat exchangers from the reference point.

2.2.Realistic Component Cycle Analysis

To analyze the cycle with real compnents, realistic turbomachinery efficiency, realistic heat exchanger effectiveness and pressure drop were taken into the consideration. The turbomachinery efficiency varies with the type, design and the pressure ratio [4], but it is assumed to be constant in this study. The design parameters in Table.1 were obtained through a sample calculation based on previous works [2&3].

Fig.3 shows the trend of the cycle efficiency and CO_2 mass flow rate vs. cycle pressure ratio for realistic component cycle. The optimal pressure ratio in this system exists at 22MPa, since there are two competing factors. Those are; the power production from the turbine increases as the pressure ratio increases, while the power consumption from the compressors increases as well. After 22MPa, the increase in compressor power consumption starts to exceed the increase in turbine power production due to the pressure ratio increase.

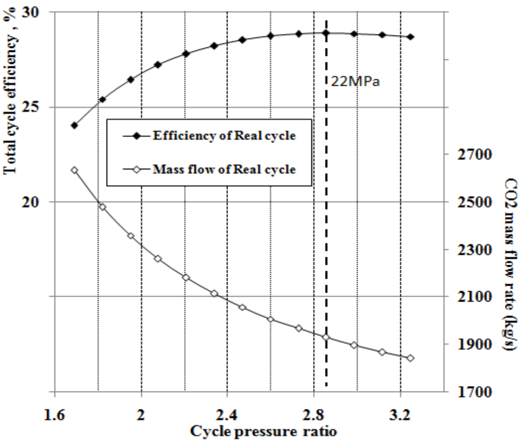

Fig. 3. Total cycle efficiency and mass flow rate for realistic component cycle analysis

3. Conclusion

The cycle efficiency at the optimal point of the system shows 8.5 % lower than that of the ideal component cycle. In other words, the system has 8.5% of potential improvement margin at the optimal point. To recover the lost cycle efficiency designing better turbomachineries and heat exchangers is necessary. Improved design of the cycle components will be followed in the near future which will further prove that the S-CO_2 Brayton cycle can provide improvement to the currently proposed water cooled SMRs.

ACKNOWLEDGMENTS

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