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Thermodynamic Optimization of Supercritical CO_2 Brayton Cycles

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1. Introduction

The supercritical CO_2 Brayton cycle has been studied for nuclear applications, mainly for one of the alternative power conversion systems of the sodium cooled fast reactor, since 1960's[1, 2]. Although the supercritical CO_2 Brayton cycle has not been expected to show higher efficiency at lower turbine inlet temperature over the conventional steam Rankine cycle, the higher density of supercritical CO_2 like a liquid in the supercritical region could reduce turbo-machinery sizes, and the potential problem of sodium-water reaction with the sodium cooled fast reactor might be solved with the use of CO_2 instead of water [3].

The supercritical CO_2 recompression Brayton cycle was proposed for the better thermodynamic efficiency than for the simple supercritical CO_2 Brayton cycle [3]. Thus this paper presents the efficiencies of the supercritical CO_2 recompression Brayton cycle along with several decision variables for the thermodynamic optimization of the supercritical CO_2 recompression Brayton cycle.

2. Thermodynamic Modeling

Simplified process flow diagram for the supercritical CO_2 recompression Brayton cycle is presented in Fig. 1. The major components are one heat source, one CO_2 turbine, two recuperated heat exchangers, one main CO_2 compressor, one recompression CO_2 compressor, and one cold heat sink. For the current study high pressure supercritical CO_2 is heated up to a specified temperature at the hot heat source. This heat source is generic and the thermal input is specified in Table 1. The process of the supercritical CO_2 recompression Brayton cycle was analyzed with the commercial ASPEN plus code in this study. The fluid properties required were obtained using the NIST REFPROP database [4].

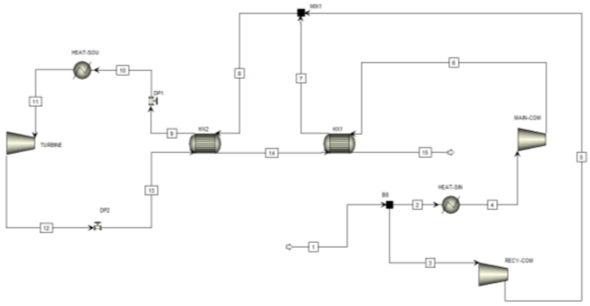

Fig. 1. Process flow diagram of the supercritical CO2 recompression Brayton cycle

Table 1 shows the reference system condition for a base line cycle configuration. This condition is arbitrary and represents a reasonable starting point for the sensitivity analyses that study the thermodynamic optimization. The basic assumptions for this study are steady state conditions and negligible heat losses in the two heat exchangers and piping.

Table 1: Reference system condition

Thermal input	30 MW_{th}
Main CO_2 compressor inlet temperature	32 ℃
Main CO_2 compressor inlet pressure	76 bara
CO_2 compressors outlet pressure	200 bara
CO_2 compressors isentropic efficiency	85 %
Turbine inlet temperature	600 ℃
Turbine isentropic efficiency	90 %
Pressure drop through heat exchanger (hot side)	4 bar
Pressure drop through heat exchanger (cold side)	4 bar
Minimum temperature approach of heat exchangers	10 ℃
Recycle fraction	30 %
Equation of state	Lee-Kesler-Plocker

In addition to the reference system condition, the decision variables are chosen and input to the process model to get the thermodynamic optimization of the supercritical CO_2 recompression Brayton cycle as shown in Table 2.

Table 2: Decision variables

Decision variable	Lower bound	Upper bound
CO_2 compressors outlet pressure	100 bara	400 bara
Recycle fraction	0 %	40 %
Turbine inlet temperature	500 ℃	700 ℃
CO_2 compressors isentropic efficiency	85 %	90 %
Turbine isentropic efficiency	85 %	95 %
Minimum temperature approach	5 ℃	10 ℃

3. Results and Discussion

The presented results for the current study are based on 618 ton/hr mass flow rate of supercritical CO2. Fig. 2 shows the system efficiency along with compressor outlet pressure. The system efficiency achieves its maximum value of 42.9 % at a compressor outlet pressure of 200 bars. It can be seen that the system efficiency drops more rapidly for lower outlet pressure than for the higher outlet pressure based on the maximum system efficiency, while the system efficiency over 200bara is reduced slowly due to much higher compression work for lower density of supercritical CO_2 at the recompression compressor.

The system efficiency versus recycle fraction for different isentropic efficiencies of compressor and turbine is presented in Fig. 3. The system efficiency curves show its maximum values at a recycle fraction of 30 % regardless of isentropic efficiency variations of turbine and compressor. The higher isentropic efficiencies of turbine and compressor show higher system efficiency as expected.

Fig. 4 shows the recycle fraction effect on system efficiency for different minimum temperature approach and turbine inlet temperature. The minimum temperature approach of 5 ℃ at the two heat exchangers shows higher system efficiency than for the cases of 10 ℃, and the higher turbine inlet temperature results in higher system efficiency.

4. Conclusion

As one of the alternative power conversion systems for the sodium cooled fast reactor, the process of the supercritical CO_2 recompression Brayton cycle was investigated to get the system optimization with the several decision variables. The analytic results in this study show that the system efficiency reaches its maximum value at a compressor outlet pressure of 200 bars and a recycle fraction of 30 %, and the lower minimum temperature approach at the two heat exchangers shows higher system efficiency as expected.

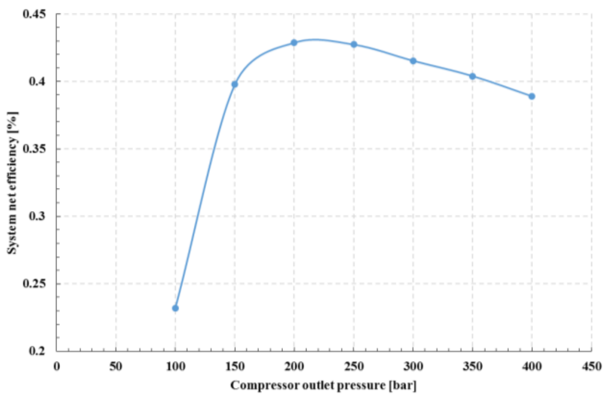

Fig. 2. System efficiency along with compressor outlet pressure

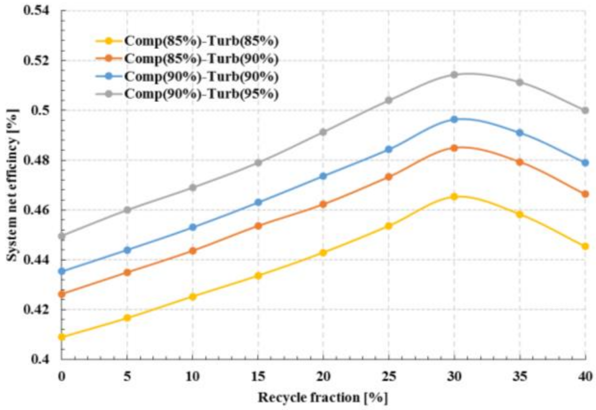

Fig. 3. Recycle fraction effect on system efficiency for different isentropic efficiencies of compressor/turbine

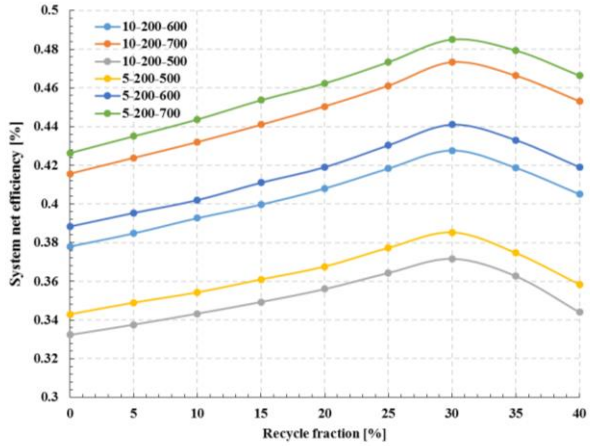

Fig. 4. Recycle fraction effect on system efficiency for different minimum temperature approach and turbine inlet temperature

REFERENCES

[1] J. P. Dievot, The sodium-CO2 fast breeder reactor concept, International Conference on Sodium Technology and Large Fast Reactor Design, Argonne National Laboratory, 1968.

[2] V. Dostal, M. J. Driscoll, P. Hejzlar, and N. E. Todreas, CO2 Brayton cycle design and optimization, Tech. Rep. MIT-ANP-TR-090, 2002.

[3] V. Dostal, M. J. Driscoll, and P. Hejzlar, A supercritical carbon dioxide cycle for next generation nuclear reactors, Tech. Rep. MIT-ANP-TR-100, 2004.

[4] E. W. Lemmon, M. L. Huber, and M. O. McLinden, NIST Standard Reference Database 23: Reference Fluid Thermodynamics and Transport Properties-REFPROP, Version 9.0, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, 2010.