Optimal Design and Thermodynamic Analysis of Gas Turbine and Carbon Dioxide Combined Cycles

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INTRODUCTION

Gas turbine is one of the high-efficient energy conversion systems for natural gas utilization. As gas turbine deliver high temperature exhaust, it is always combined with bottoming heat recovery cycles. Carbon dioxide power cycles are considered as viable choices for waste heat recovery from gas turbines.

GT-CASCADED CO_2 COMBINED CYCLE

This investigation reports a high-efficient gas turbine (GT) and two-stage cascaded supercritical and transcritical CO_2 (s-CO_2/t-CO_2) combined power cycle using thermal oil as a heat transfer fluid, as shown in Fig. 1. GT exhaust supplies input heat to an intermediate s-CO_2 cycle through a heat transfer fluid loop. Waste heat from the s-CO_2 cycle and residual heat from the GT cycle drives a lower temperature t-CO_2 bottoming cycle. Condenser heat from this bottoming cycle evaporates liquefied natural gas (LNG) for the GT cycle. The overall system efficiency of this combined cycle is

$$\eta_{cc} = \frac{P_{gt} + P_{CO2}}{\dot{m}_{fuel}\eta_b LHV}$$

To show the thermodynamic advantages of this bottoming cascaded CO_2 cycle, three other carbon dioxide power cycles are proposed as a comparison. They are termed 'transcritical CO_2 cycle' (t-CO_2), 'supercritical and transcritical CO_2 cycle' (s-t-CO_2), 'recuperative supercritical and transcritical CO_2 cycle' (res-t-CO_2), as shown in Fig. 2.

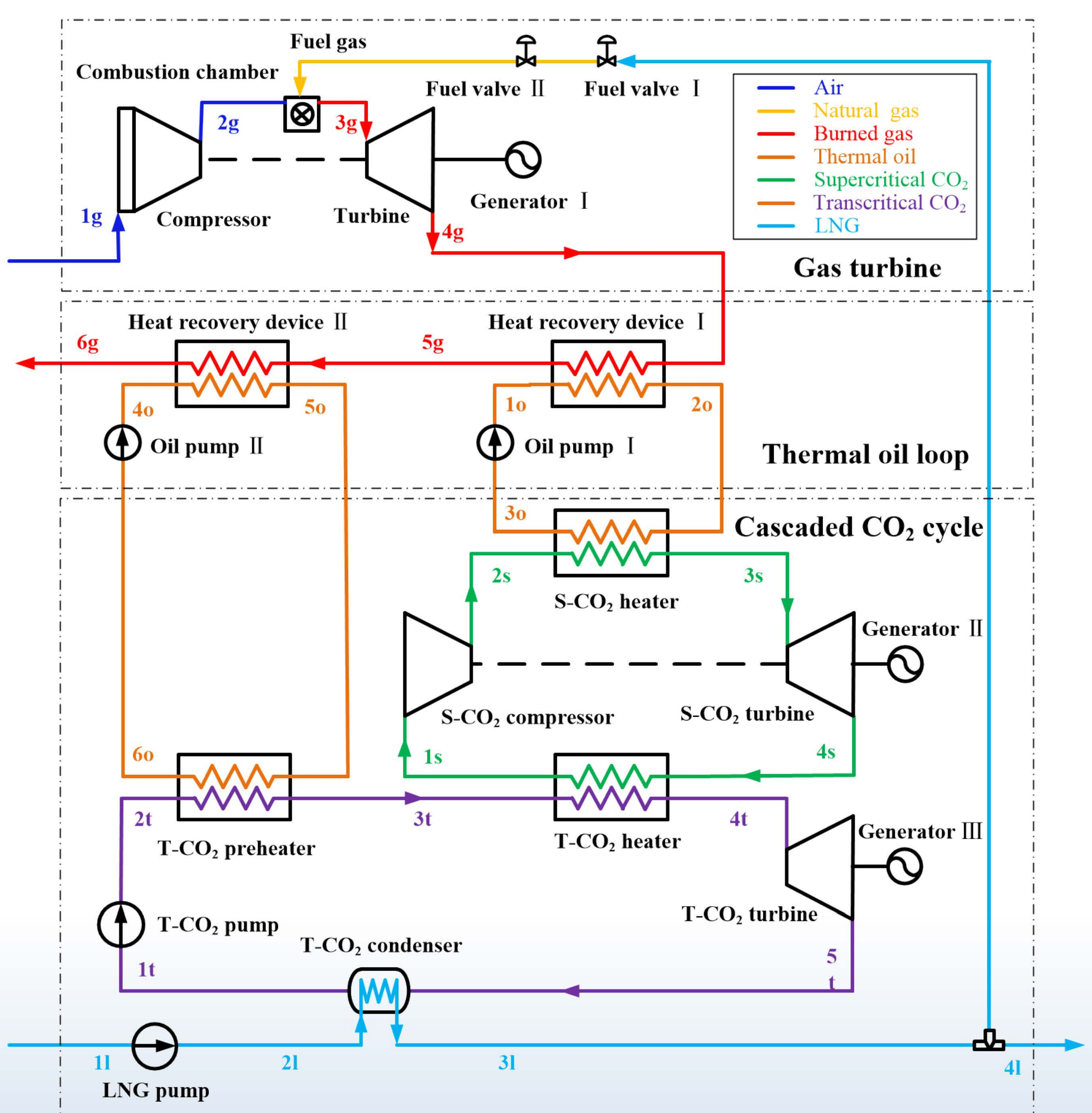

Fig. 1. Schematic of gas turbine and cascaded CO_2 combined cycle.

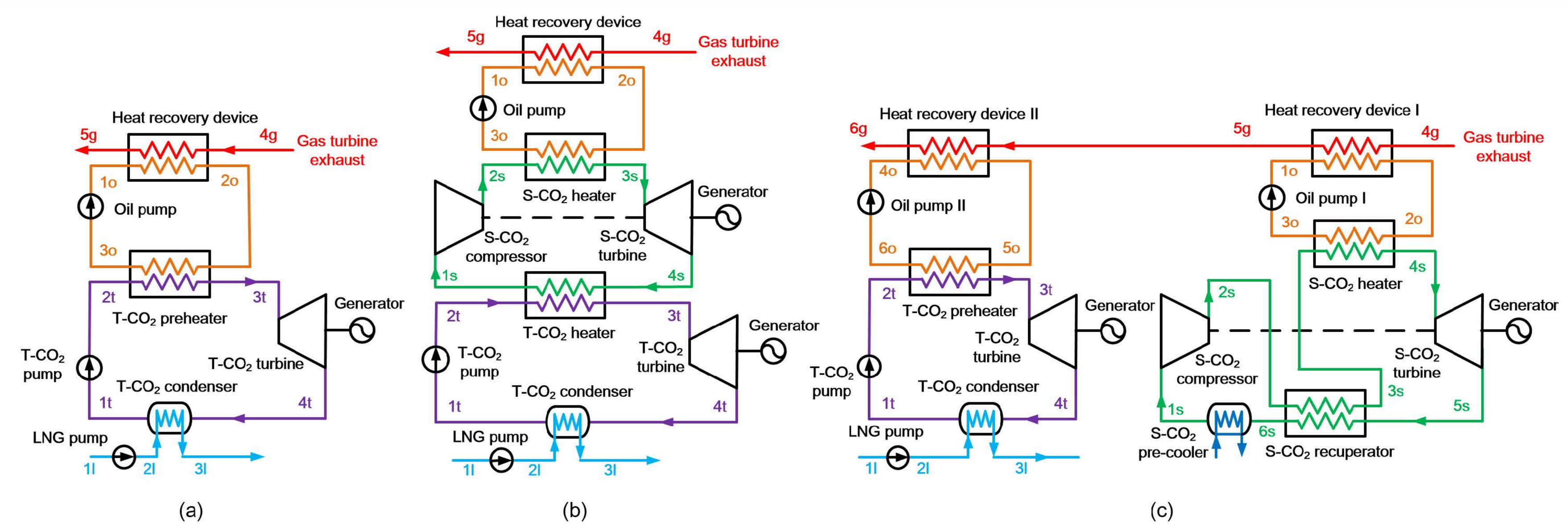

Fig. 2. Schematic of other carbon dioxide power cycles. (a) t-CO_2, (b) s-t-CO_2, and (c) res-t-CO_2.

Table 1. Simulation results for different carbon dioxide power cycles.

	T-CO_2	S-t-CO_2	Res-t-CO_2	Cascaded CO_2 cycle
P_s / MW	-	1.086	1.476	1.086
P_t / MW	3.141	2.045	1.249	2.232
P_{CO2} / MW	3.141	3.131	2.725	3.318
P_{cc} / MW	8.811	8.801	8.395	8.988
η_{cc} / %	48.97	48.92	46.67	49.96
T_{5g} / K	350.0	443.5	547.7	443.5
T_{6g} / K	-	-	350.0	350.0
m_s / kg·s^{-1}	-	19.85	27.76	19.85
m_t / kg·s^{-1}	10.15	12.67	9.17	21.75

RESULTS AND DISCUSSION

The Taurus 60 Gas Turbine, with an output power of 5.67 MW and a thermal efficiency of 31.5%, is selected as the topping cycle. The cycles are simulated using MATLAB, and properties of working fluids are estimated using NIST REFPROP.

Table. 1 presents the cascaded CO_2 cycle has the highest net power of 3.318 MW, which results in a 49.96% overall system efficiency of the combined cycle. It seems that the cascaded CO_2 cycle is the most efficient considered option for using turbine exhaust heat among these carbon dioxide power cycles.

Fig. 3 shows the net power of the cascaded CO_2 cycle can reach a maximum when the s-CO2 compressor inlet pressure and temperature varies. Such variation trends indicate that there may be optimal operating conditions to maximum power output from the cascaded CO_2 cycle.

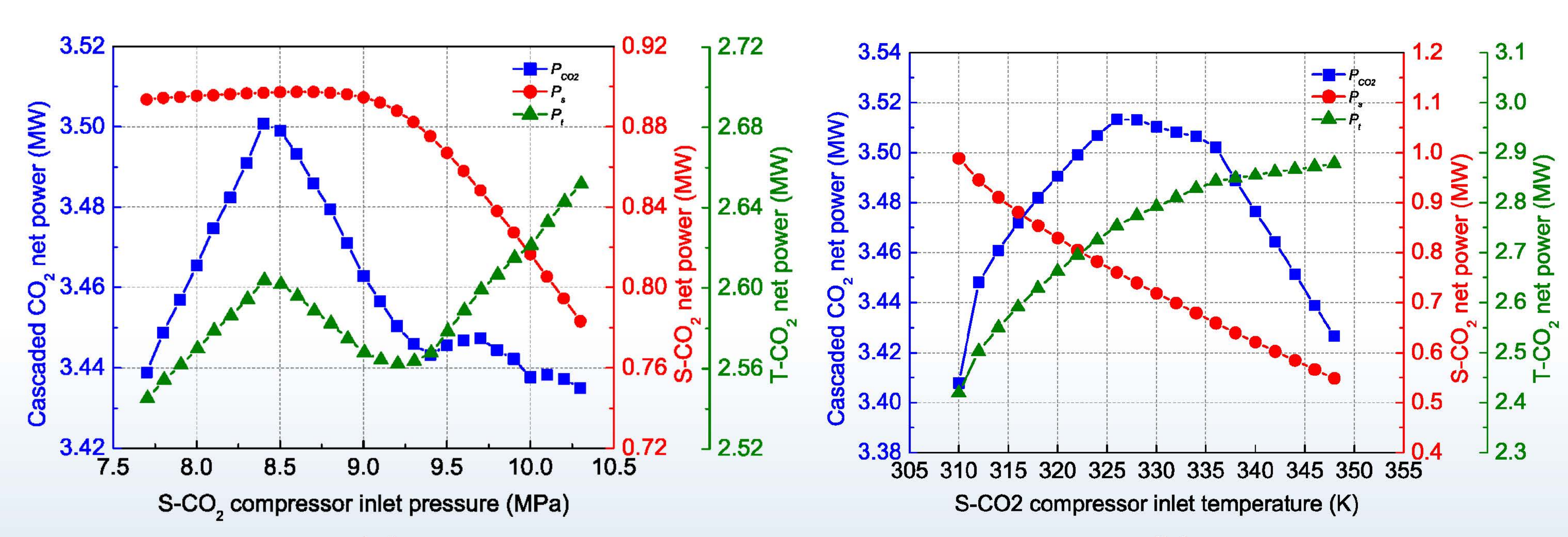

Fig. 3. Effect of s-CO_2 compressor inlet conditions on the net power of the cascaded CO_2 cycle. (a) Pressure, (b) temperature.

The genetic algorithm (GA) optimization method is use to identify the optimal operating conditions for maximizing power. Table 2 shows the peak net power of 3.595 MW can be reached at s-CO_2 turbine inlet conditions of 9.597 MPa and 325.3 K. The overall system efficiency reaches a maximum of 51.50% at this peak net power. Compared with traditional GT-steam Rankine combined cycles, the overall system efficiency of the GT-cascaded CO_2 cycle has an increase of 4.53%.

Table 2. GA optimization results for cascaded CO_2 net power.

Number	η_{cc} / %	P_{CO2} / MW	p_{1s} / MPa	T_{1s} / K
1	51.49	3.593	9.423	325.6
2	51.46	3.588	9.298	326.2
3	51.50	3.595	9.486	325.4
4	51.50	3.595	9.597	325.3
5	51.50	3.594	9.695	325.3
6	51.48	3.592	9.874	325.4
7	51.49	3.594	9.676	325.4
8	51.50	3.595	9.671	325.3
9	51.50	3.595	9.531	325.3
10	51.46	3.588	9.280	326.2

CONCLUSIONS

The main conclusions of this investigation are drawn as follows:

(1) The cascaded CO_2 cycle maybe the most efficient carbon dioxide power cycles for waste heat recovery from gas turbines;

(2) The net power of the cascaded CO_2 cycle can reach a maximum with the variation of s-CO_2 compressor inlet conditions;

(3) The overall system efficiency of the GT-cascaded CO_2 combined cycle can reach 51.50% through GA optimization.

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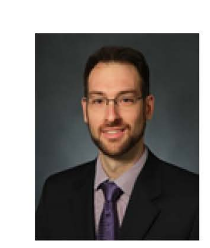

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