Design and Optimization of a High-Efficiency Supercritical CO_2 Brayton Cycle System

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Introduction

In recent years, the development of novel energy conversion systems that simultaneously improve efficiency and reduce environmental impact has remained a key research focus. Among these technologies, the supercritical carbon dioxide (sCO_2) Brayton cycle has garnered significant attention owing to its high thermal efficiency, reduced component count, and compact system configuration. However, the actual cycle efficiencies achieved by existing sCO2 Brayton cycle units remain relatively low, hindering their practical application. The development of high-efficiency systems thus represents a major challenge in advancing this technology. This study focuses on practical sCO_2 Brayton cycle units and investigates strategies for improving system efficiency through cycle layout optimization, and provides insights and guidance for the design and development of advanced sCO_2 Brayton cycle systems. Through structural design and parameter optimization, the system efficiency can reach a maximum of 50.13% under the current research conditions.

Equation

Efficiency:
$$\eta = \frac{W_{net}}{Q}$$
$$W_{net} = W_G - W_M$$

Compressor:
$$\eta_C = \frac{h_{outc,s} - h_{inc}}{h_{outc} - h_{inc}}$$

Turbine:
$$\eta_{TU} = \frac{h_{intu} - h_{outtu}}{h_{intu} - h_{outtu,s}}$$

Boiler:
$$Q = m\left(h_{out} - h_{in}\right)$$

Regenerator:
$$T_{h,out} = T_{c,out} + \Delta T$$
$$m_h(h_{h,in} - h_{h,out}) = m_c(h_{c,in} - h_{c,out})$$

Cooler:
$$m_{CO_2}(h_{CO_2,in} - h_{CO_2,out}) = m_W(h_{W,in} - h_{W,out})$$

Main design parameters of the system

Parameter (Unit)	Value
Efficiency of compressor (%)	89
Inlet temperature of compressor (°C)	32.00
Efficiency of turbine (%)	92
Efficiency of boiler (%)	94.71
Efficiency of pipe (%)	99
Outlet temperature of heater (°C)	650
Pressure loss of the hot side of the regenerator (MPa)	0.1
Pressure loss of the cold side of the regenerator (MPa)	0.1
Regenerator end difference (°C)	8
Pressure loss of CO_2 side of cooler (MPa)	0.1
Pressure loss of the water side of the cooler (MPa)	0.2
Cooling water temperature rise (°C)	10

Key parameters within the optimised system

Point	Temperature/ K	Pressure /MPa	Mass flow rate/(kg/s)
1	334.73	7.90	1428.01
2	305.15	8.00	1428.01
3	318.73	13.64	1428.01
4	305.15	13.54	1428.01
5	325.48	32.85	1428.01
7	459.96	32.75	1428.01
8	459.96	32.75	2062.11
9	666.45	32.65	2062.11
10	660.72	32.65	2225.35
11	838.57	32.55	2225.35
12	923.15	31.90	2480.88
13	883.71	24.09	2480.88
14	923.15	23.94	2480.88
15	859.40	15.04	2480.88
16	923.15	14.89	2480.88
17	846.57	8.40	2480.88
19	675.45	8.30	2480.88
21	467.96	8.20	2480.88
22	467.96	8.20	418.77
23	334.73	8.10	2062.11
24	334.73	8.10	634.10

Schematic diagram of the cycle