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Cycle analysis of the Recompression Supercritical CO_2 Brayton cycle

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1. Introduction

Reactor systems that employ gas coolants offer the potential for operating as direct Brayton cycles by passing the heated gas directly into a turbine. This Brayton cycle is ideal for single-phase, steady-flow cycles. A closed recompression Brayton cycle with the use of supercritical CO_2 (S-CO_2) as the working fluid is studied. Recently, the research on the power cycle for a next generation reactor has been conducted and the S-CO_2 Brayton cycle is presented as a promising alternative for the present Rankine cycle [1]. Cycle analysis of the recompression supercritical CO_2 Brayton cycle has been carried out.

2. Cycle analysis and results

2.1 Cycle analysis

The recompression S-CO_2 Brayton cycle is shown Figure 1[2, 3]. In the main compressor a fraction of the fluid flow is compressed to high pressure. In the low temperature recuperator it is preheated to the recompressing compressor outlet temperature. Then the fluid is merged with the rest of the fluid flow from the recompressing compressor. The entire fluid flow is then preheated in the high temperature recuperator to the reactor inlet temperature. The heat addition into the cycle takes place in the reactor. The fluid leaves the reactor at the highest cycle temperature at this it enters the turbine, where fluid expansion generates rotational energy, which is converted into electricity in the generator. After leaving the turbine the high temperature fluid is cooled in the high and low temperature recuperators, where available heat is transferred to the cooler high pressure side fluid flow. Before entering the precooler the fluid flow is split. One part is recompressed to high pressure, the other is cooled in the precooler to the main compressor inlet temperature.

For the cycle analysis the equations of the mass balance and energy balance, and the isotropic efficiency of the turbine and the compressors and the effectiveness of the recuperators are formulated. And the simultaneous equations were solved with sequential iteration method. The convergence criteria of a calculated temperature was set to 1.0×10^{-4}.

The equations are as follows.

High temperature recuperator ;

$$h_6 - h_7 = h_4 - h_3$$

$$\varepsilon_H = \frac{T_4 - T_3}{T_6 - T_3}$$

Low temperature recuperator ;

$$m(h_7 - h_8) = m_1(h_{31} - h_2)$$

$$\varepsilon_L = \frac{T_{31} - T_2}{T_7 - T_2}$$

Flow merge ;

$$m = m_1 + m_{10}$$

$$m\ h_3 = m_1\ h_{31} + m_{10}\ h_{11}$$

Recompressing compressor;

$$h_{11} = h_8 + \frac{1}{\eta_C}(h_{11S} - h_8)$$

Main compressor;

$$h_2 = h_1 + \frac{1}{\eta_C}(h_{2S} - h_1)$$

Turbine;

$$h_6 = h_5 - \eta_T(h_5 - h_{6S})$$

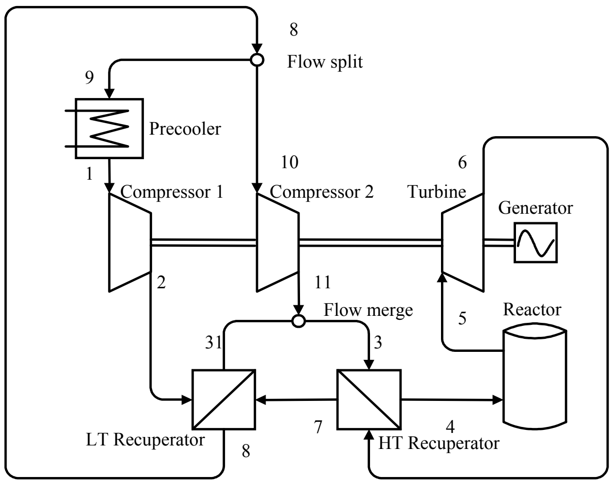

Figure 1. Scheme of recompression Brayton cycle

2.2 Results

Table 1 contains the cycle design value and the component characteristics that were used in the analyses of the recompression Brayton cycle. The cycle was analyzed at a turbine inlet temperature of 550 °C and a main compressor inlet temperature of 32 °C, near to the critical point of CO_2 (7.377 MPa, 30.97 °C). The component efficiencies and effectiveness are regarded as fixed. The cycle efficiency was evaluated over a range of recompressed flow fractions, main compressor inlet temperatures and turbine inlet temperatures.

Table 1. Design values and component characteristics of the cycle

Mass flow rate [kg/s]	3842.2
Main compressor inlet temperature [C]	32
Main compressor inlet pressure [MPa]	7.6
Turbine inlet temperature [C]	550
Main compressor outlet pressure [MPa]	19
Compressor polytropic efficiency [%]	82
Turbine polytropic efficiency [%]	87
HT Recuperator effectiveness [%]	87
LT Recuperator effectiveness [%]	95

For the recompression fraction of 41%. a cycle efficiency of 44.8 % was obtained. The details of the cycle point values are presented in Table 2.

Table 2. Cycle design point values

	T[°C]	P[MPa]	H[kJ/kg]	s[kJ/kg-K]
1	32	7.60	615.47	3.4871
2	62.9	19.00	637.47	3.4989
3	155.6	18.972	838.05	4.0318
4	407.7	18.943	1164.39	4.6373
5	550.0	18.864	1339.40	4.8700
6	445.3	7.628	1223.65	4.8941
7	160.1	7.617	897.32	4.3152
8	67.8	7.605	779.28	4.0083
11	156.0	18.972	838.79	4.0335
31	155.2	18.972	837.54	4.0306

For varying parameters of recompressed flow fractions, main compressor inlet temperatures and turbine inlet temperatures, the cycle efficiency was calculated as shown in Fig. 2, 3 and 4.

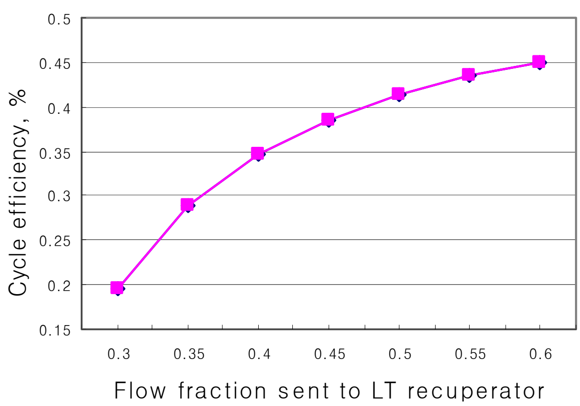

Figure 2. Effect of flow spilit fraction on cycle efficiency

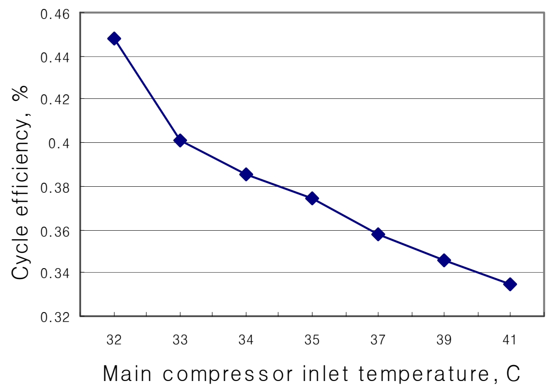

Figure 3. Effect of main compressor inlet temperature on cycle efficiency

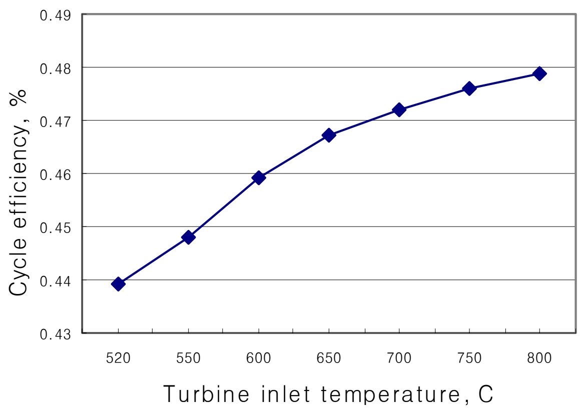

Figure 4. Effect of turbine inlet temperature on cycle efficiency

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