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Performance analysis for an irreversible variable temperature heat reservoir closed intercooled regenerated Brayton cycle

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Abstract

In this paper, the theory of finite time thermodynamics is used in the performance analysis of an irreversible closed intercooled regenerated Brayton cycle coupled to variable temperature heat reservoirs. The analytical formulae for dimensionless power and efficiency, as functions of the total pressure ratio, the intercooling pressure ratio, the component (regenerator, intercooler, hot and cold side heat exchangers) effectivenesses, the compressor and turbine efficiencies and the thermal capacity rates of the working fluid and the heat reservoirs, the pressure recovery coefficients, the heat reservoir inlet temperature ratio, and the cooling fluid in the intercooler and the cold side heat reservoir inlet temperature ratio, are derived. The intercooling pressure ratio is optimized for optimal power and optimal efficiency, respectively. The effects of component (regenerator, intercooler and hot and cold side heat exchangers) effectivenesses, the compressor and turbine efficiencies, the pressure recovery coefficients, the heat reservoir inlet temperature ratio and the cooling fluid in the intercooler and the cold side heat reservoir inlet temperature ratio on optimal power and its corresponding intercooling pressure ratio, as well as optimal efficiency and its corresponding intercooling pressure ratio are analyzed by detailed numerical examples. When the heat transfers between the working fluid and the heat reservoirs are executed ideally, the pressure drop losses are small enough to be neglected and the thermal capacity rates of the heat reservoirs are infinite, the results of this paper replicate those obtained in recent literature.

Keywords: Finite time thermodynamics; Brayton cycle; Intercooled; Regenerated; Irreversible

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Nomenclature

C_H, C_L thermal capacity rates of high and low temperature heat reservoirs
C_I thermal capacity rate of cooling fluid in intercooler
C_{wf} thermal capacity rate of working fluid (mass flow rate and specific heat product)
D_1, D_2 pressure recovery coefficients
E_{H1}, E_{L1} effectivenesses of hot and cold side heat exchangers
E_R effectiveness of regenerator
E_{I1} effectiveness of intercooler
N_{H1}, N_{L1} number of heat transfer units of hot and cold side heat exchangers
N_R number of heat transfer units of regenerator
N_{I1} number of heat transfer units of intercooler
k ratio of specific heats
p_1, p_2, p_3, p_4, p_5, p_6 pressures at working states of 1, 2, 3, 4, 5, 6
$\overline{P}_{opt}$ optimal dimensionless power
$\overline{P}_{max}$ maximum dimensionless power
Q_H rate at which heat is transferred from heat source to working fluid
Q_L rate at which heat is transferred from working fluid to heat sink
Q_R rate of heat regenerated in the regenerator
Q_I rate of heat rejected from working fluid to cooling fluid in intercooler
T_1, T_2, T_{2s}, T_3, T_4, T_{4s}, T_5, T_6, T_{6s}, T_7, T_8 temperatures at states of 1, 2, 2s, 3, 4, 4s, 5, 6, 6s, 7, 8
$T_{H\,in}$, $T_{H\,out}$ inlet and outlet temperatures of heating fluid
$T_{L\,in}$, $T_{L\,out}$ inlet and outlet temperatures of cooling fluid
$T_{I\,in}$, $T_{I\,out}$ inlet and outlet temperatures of cooling fluid in intercooler
U_H, U_L conductances of hot and cold side heat exchangers (heat transfer surface area and heat transfer coefficient product)
U_R conductance of regenerator
U_I conductance of intercooler
x working fluid isentropic temperature in low pressure compressor
y working fluid isentropic temperature for whole compression process
1, 2, 2s, 3, 4, 4s, 5, 6, 6s, 7, 8 working states

Greeks
η_c, η_t compressor and turbine efficiencies
η_{opt} optimal efficiency
η_{max} maximum efficiency
π total pressure ratio
π_1 intercooling pressure ratio
$(\pi_1)_{\overline{P}_{opt}}$ intercooling pressure ratio corresponding to optimal dimensionless power
$(\pi_1)_{\eta_{opt}}$ intercooling pressure ratio corresponding to optimal efficiency
τ_1 cycle heat reservoir inlet temperature ratio
τ_2 cooling fluid in intercooler and cold side heat reservoir inlet temperature ratio