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Multi-objective thermodynamic optimization of an irreversible regenerative Brayton cycle using evolutionary algorithm and decision making

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Multi-objective optimization;
Decision making methods

Abstract Brayton heat engine model is developed in MATLAB simulink environment and thermodynamic optimization based on finite time thermodynamic analysis along with multiple criteria is implemented. The proposed work investigates optimal values of various decision variables that simultaneously optimize power output, thermal efficiency and ecological function using evolutionary algorithm based on NSGA-II. Pareto optimal frontier between triple and dual objectives is obtained and best optimal value is selected using Fuzzy, TOPSIS, LINMAP and Shannon's entropy decision making methods. Triple objective evolutionary approach applied to the proposed model gives power output, thermal efficiency, ecological function as (53.89 kW, 0.1611, −142 kW) which are 29.78%, 25.86% and 21.13% lower in comparison with reversible system. Furthermore, the present study reflects the effect of various heat capacitance rates and component efficiencies on triple objectives in graphical custom. Finally, with the aim of error investigation, average and maximum errors of obtained results are computed.

1. Introduction

Brayton cycles have been broadly used in gas power plants, airplanes, ship propulsion and numerous industrial usages. Intercooler compression, reheater expansion, regeneration and isothermal heat addition are few amendments [1–20] which have been acknowledged theoretically to upgrade the performance of Brayton cycles. In recent years, significant consideration has been given to single objective optimization of Brayton heat engine through range of objective functions

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Nomenclature

A	area (m^2)
C	heat capacitance rate ($kW\ K^{-1}$)
k	specific heat ratio
P	power output (kW)
Q	heat transfer rate (kW)
T	temperature (K)

Greek letters

η	thermal efficiency
ε	effectiveness

Subscripts

H	heat source side
L	heat sink side
R	regenerator side
s	ideal/reversible adiabatic
t	turbine
c	compressor
W	working fluid

including power output [14–17], power density [20], thermal efficiency [5,6], ecological function [13,18,19], entropy generation [7,8] and thermo-economic function [9,10]. Wu [1] studied an endoreversible Brayton cycle and optimized power output with respect to working fluid temperature. Real compression and expansion processes are amalgamated with Brayton heat engine by Wu and Kiang [2]. It has been observed that power output and thermal efficiency are strong functions of compressor and turbine efficiencies. The power output and thermal efficiency are further enhanced through the combination of Brayton heat engine with intercooler and regenerator by Chen et al. [5]. Angulo-Brown [3] proposed an ecological function ($E = P - T_L S_{gen}$) which is defined as power output minus the product of sink temperature and entropy generation rate. Yan [4] modified ecological function proposed by Angulo-Brown [3] with replacing sink temperature for surrounding temperature. The modified ecological function ($E = P - T_0 S_{gen}$) is considered as third objective in present study and optimized simultaneously with power output and thermal efficiency. The optimization of the ecological function represents a compromise between power output, P and power loss, $T_0 S_{gen}$, which is produced by entropy generation in the system and surroundings. Ecological optimization of endoreversible and irreversible Brayton cycle is achieved by Cheng and Chen [7,8]. They found momentous reduction in entropy generation rate with a little detriment in power output. The optimal operating conditions of endoreversible and irreversible Brayton heat engines are studied by Wang et al. [16,17] and Kaushik et al. [11,12] respectively. Nevertheless, two or more objective functions must be optimized at the same time. Few of the researchers [25–31] have investigated thermal energy conversion systems based on multi-objective evolutionary approach [21–24].

In this paper performance analysis and multi-objective optimization of irreversible Brayton heat engine cycle have been done for simultaneous optimization of power output, thermal efficiency and ecological function. There is no parallel study available in the literature on optimization of proposed system with pressure drop irreversibility existing in regenerator part. Multi-objective optimization is helpful in designing real heat engine as it provides a trade-off between the obtained solutions of various chosen objectives with minimum computation time. The major outcome of this research is the evaluation of specific optimal points for various input parameters while designing real irreversible Brayton heat engine. Various input parameters included effectiveness of source-side heat exchanger (ε_H), effectiveness of sink-side heat exchanger (ε_L), effectiveness of regenerator-side heat exchanger (ε_R), pressure recovery coefficients (α_1, α_2), source temperature (T_{H1}) and temperature of the working fluid (T_4) are considered. The present work shows triple objective (P–η–E) and dual objective (P–η, P–E, η–E) optimization for an irreversible regenerative Brayton cycle based on NSGA-II. The Pareto frontier in objective space is achieved based on evolutionary algorithm. The optimal values of various input parameters are chosen from Pareto frontier implementing four decision making approaches including Fuzzy, TOPSIS, Shannon's entropy and LINMAP methods. The effect of efficiency of turbine and compressor and heat capacitance rates on triple objective has been studied in detail and the results are presented on graphs.

2. Thermodynamic analysis

Fig. 1 shows temperature–entropy (T–S) diagram of proposed Brayton heat engine model with a finite heat source and heat sink. Point 1 is entrance for working medium at compressor which gets compressed up to point 2. Then the working medium goes to regenerator to attain some degree of heat through

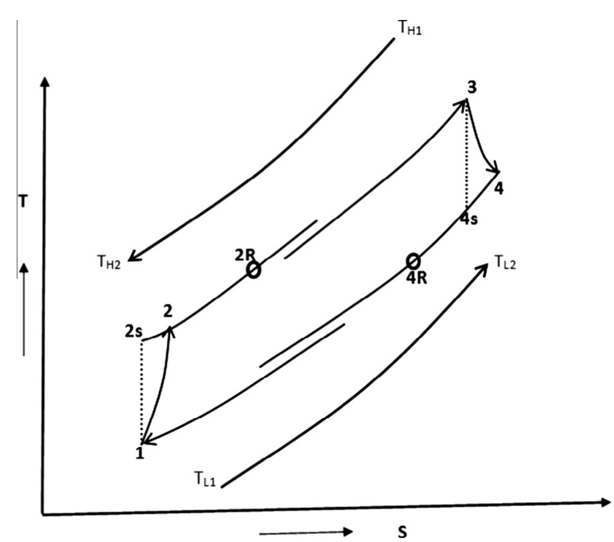

Figure 1 T–S diagram for irreversible regenerative Brayton heat engine cycle.