Energy Conversion and Management 171 (2018) 1052–1062

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Multi-objective optimization and decision making of endoreversible combined cycles with consideration of different heat exchangers by finite time thermodynamics

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ARTICLE INFO

Keywords:
Finite time thermodynamics
Irreversible combined cycle
Multi-objective optimization
TOPSIS
NSGA-II

ABSTRACT

The primary purpose of present work is to evaluate and optimize the internal reversible combined cycle in operational conditions. Therefore, the effects of finite heat transfer are considered in different heat exchangers. In this study, the problem of the irreversible combined cycle is discussed by different heat exchangers. The total power of the combined cycle, energy efficiency, exergy destruction and the ecological function are calculated based on decision variables including the primary temperature ratio, secondary temperature ratio, and common temperature ratio and thermal conductance of combined cycle heat exchangers. Mono-objective optimization was performed based on simplex, conjugate-direction, and genetic algorithm methods. For the optimization of multi-objective ecological function, it is used from the elitist non-dominated sorting genetic algorithm (NSGA-II). Results of Mono-objective optimization demonstrate that the maximum dimensionless power, maximum efficiency in simplex, conjugate-direction and genetic algorithm methods, minimum exergy destruction are approximately 0.1855, 77.14%, 75.91%, 72.11%, 0.0007804, respectively. Furthermore, results of multi-objective optimization of the ecological by NSGA-II show that the dimensionless power, energy efficiency, exergy destruction, and the ecological function is about 0.14, 68.21%, 0.0091 and 0.1312 in the graphical method of decision making. In order to select the optimal solution, the technique for order preferences by similarity to an ideal solution (TOPSIS) method is used. As a result, the dimensionless power, energy efficiency, exergy destruction and the ecological function is approximately 0.1216, 70%, 0.0061, and 0.1155 by TOPSIS method. For the design and development of combined cycles, finite time thermodynamics and analysis criteria such as dimensionless power and ecological function are used. Finite time thermodynamics can be a new tool for designing combined cycles. This research shows the importance of choosing the thermodynamic criterion.

1. Introduction

The Classical thermodynamics deals with reversible processes and equilibrium, while real processes have finite time, finite size, internal irreversibility, and external irreversibility. In the real systems, reversible process is an infinite slow time and zero-power. The effect of time on the Carnot cycle causes the Carnot cycle to be a theoretical cycle. So, real system analysis by classical thermodynamics can be misleading. Finite time thermodynamics is in fact an enhanced form of classical thermodynamics and includes the effects of internal, and external irreversibilities, finite heat transfer, and physical limitations. From a more comprehensive point of view, finite time thermodynamics is similar to the minimization of generated entropy [1].

Finite time thermodynamics was developed by Andresen et al. [2]. Endoreversible Carnot cycle or Curzon-Ahlborn's cycle was the beginning of interest in endoreversible heat engines among researchers. Assuming finite thermal resistance, Curzon and Ahlborn [3] discussed on irreversible Carnot cycle, or extended Carnot cycle in order to achieve the maximum power, Curzon-Ahlburn's cycle operates between a heat source at T_H and a heat sink at T_L and receiving heat and rejecting heat occur during isothermal processes. Finite heat transfer takes place due to the difference between temperatures of thermal reservoirs and working fluid. Heat transfer in this cycle occurred only in boundaries. Hence the extended Carnot cycle is endoreversible. Curzon-Ahlborn's model analysis is performed assuming steady state, constant heat transfer area, and limited capacity heat source [3–6]. Fig. 1 shows temperature – entropy diagram for Curzon-Ahlborn's model. Curzon-Ahlborn's heat engine is the simplest irreversible heat engine which has studied the irreversibility and heat transfer effects at the boundaries. Curzon and Ahlborn [3] reveal that power depends temperatures of the

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https://doi.org/10.1016/j.enconman.2018.06.046
Received 5 May 2018; Received in revised form 12 June 2018; Accepted 13 June 2018

Nomenclature

A	area (m^2)
$\dot{Q}$	heat transfer rate (kW)
r	thermal conductance ratio
T	temperature (k)
U	overall heat transfer rate (kW/m^2 K)
$\dot{W}$	power (kW)
Eco	ecological (kW)

Greek symbols

σ	secondary temperature ratio
τ	primary temperature ratio
η	efficiency

Subscripts

h	high Temperature
l	low Temperature
T	total
mp	maximum power
$HTHE$	high temperature heat engine
$LTHE$	low temperature heat engine

thermal sources and sink, and thermal conductance and Curzon and Ahlborn's efficiency does not depend thermal conductance at the maximum power (Eq. (1)).

$$\eta_{\mathrm{mp}} = 1 - \frac{T_c}{T_W} = 1 - \sqrt{\frac{T_L}{T_H}} \tag{1}$$

A heat engine, which operates between a high-temperature heat source with finite heat capacity and a low-temperature reservoir with infinite heat capacity studied and presented by Yan and Chen [7], this cycle consists of two adiabatic and two isobaric processes. These assumptions were a hot source with finite heat capacity and an infinite low-temperature reservoir, and substituting Newtonian heat transfer law by inverse heat transfer law. In mentioned work, they discussed the calculation of favorable efficiency and power output. Moreover, they derived the relation between maximum power output and efficiency. Their other results included a comparison of Carnot cycle efficiency based on Newtonian heat transfer law with extended case. Chen and Yan [8] investigated an endoreversible cycle with two heat sources at different states of heat transfer laws (for different values of n). As a result, a correlation between optimum efficiency and output power for each value of n in terms of variations in heat transfer coefficients was yielded. They found out that the maximum power is dependent on heat transfer coefficient and heat transfer law as well as temperatures of the sources. Wu [9] discussed a finite time Carnot heat engine with finite heat capacity heat sink and source. The maximum power output of as-mentioned heat engine and compared the performance of finite time Carnot heat engine with a real plant was calculated and evaluated. Wu's results indicate that the cycle of finite time Carnot heat engine is more realistic than ideal Carnot cycle. Chen and Yan [5] pointed out to the difference between the concept of Carnot efficiency and Curzon-Ahlborn efficiency and stated that this difference is due to the internal irreversibility of the system. Therefore, Curzon-Ahlborn efficiency cannot be considered as the upper bound of the heat engine. These results showed that only Carnot heat engine must be considered as the upper bound of heat engine efficiency in the evaluation of systems. This result is of significant importance in the development of finite time thermodynamics. De Vos [10] discussed thermoeconomic an endoreversible plant. He optimized an endoreversible plant in terms of investment cost and fuel cost. Results of this research indicate that optimum efficiency ranges between Carnot efficiency and maximum power efficiency.

Chen and Wu [11] discussed an irreversible combined cycle, they show that combined cycle efficiency at maximum power may be equal to Curzon-Ahlborn efficiency and also discussed optimum temperature of working fluid in the heat exchanger. They calculated that maximum

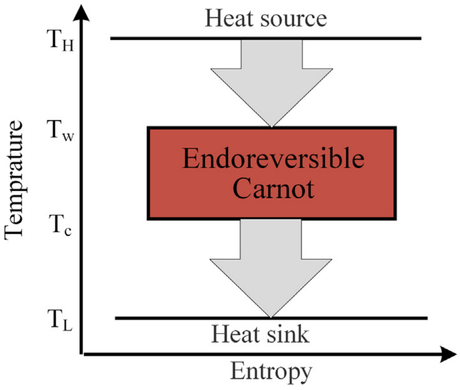

Fig. 1. Temperature-entropy diagram for Curzon–Ahlborn model.

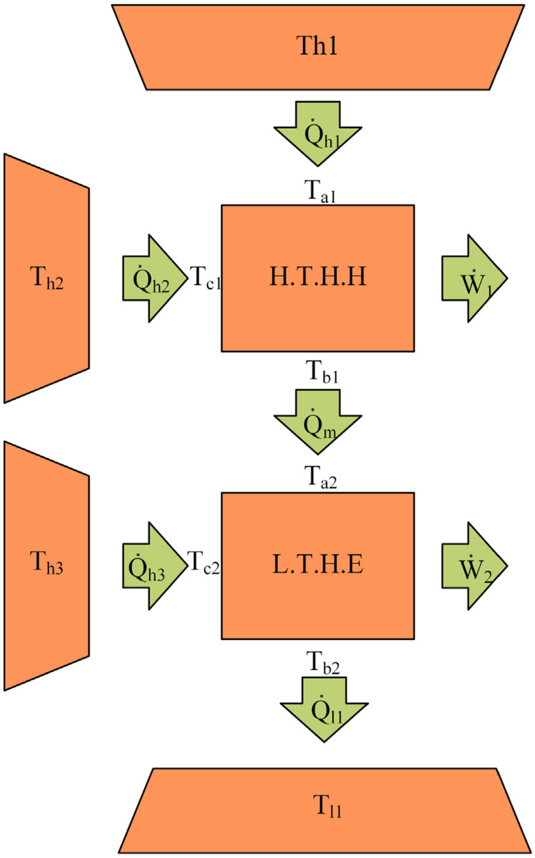

Fig. 2. Schematic system studied.