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Performance analysis of a solar-driven heat engine with external irreversibilities under maximum power and power density condition

Ahmet Koyun

Department of Mechanical Engineering, Yildiz Technical University, 34349 Besiktas, Istanbul, Turkey

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Abstract

Thermodynamic optimizations based on the maximum power and maximum power density criteria have been performed for a solar-driven heat engine with external irreversibilities. In the analysis, it is assumed that the heat transfer from the hot reservoir is to be in the radiation mode and the heat transfer to the cold reservoir is to be in the convection mode. The power and power density functions have been derived, and maximization of these functions has been performed for various design parameters. The obtained results for the maximum power and power density conditions have been compared.

Keywords: Solar driven; Power density; Finite time thermodynamics; Thermodynamics optimization

1. Introduction

Power optimization studies of heat engines using finite time thermodynamics were started by Chambadal [1] and Novikov [2] and were continued by Curzon and Ahlborn [3]. Firstly, Curzon and Ahlborn [3] studied the performance of an endoreversible Carnot heat engine at maximum power output. During the last decade, many power optimization studies for heat engines based on endoreversible and irreversible models have been performed [4]. Wu [5], Chen and Wu [6] and Chen et al. [7] have taken specific power output (power output per unit total heat transfer area) as the optimization criterion. The first finite time thermodynamic analysis was performed for a solar-driven heat engine by Sahin [8]. He showed the optimum operating conditions for a solar-driven

E-mail address: koyun@yildiz.edu.tr (A. Koyun).

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Nomenclature

C	heat transfer coefficient
$\dot{Q}$	rate of heat transfer
S	entropy
T	temperature
$\dot{W}$	power output
η	efficiency
χ	$= C_H T_H^3 / C_L$
τ	$= T_L / T_H$
θ	$= T_X / T_H$

Subscripts

C	Carnot
CA	Curzon–Ahlborn
H	heat source
L	heat sink
mp	maximum power condition
mpd	maximum power density condition

Superscript

$^{-}$	dimensionless

heat engine under maximum power output, and he also developed his model by considering the collective role of radiation and convection heat transfer from the hot reservoir [9].

Sahin et al. [10–12] performed optimization studies for an endoreversible Carnot heat engine and for reversible and irreversible Joule–Brayton heat engines using the power density as a new criterion. They showed that the power density analysis takes the effect of the engine size into account as related to the investment cost.

This paper analyzes the maximum power and the maximum power density performances for a reversible Carnot cycle with external irreversibilities of heat transfer of a solar-driven heat engine and, by comparison with published results, shows that the published results that employ finite time thermodynamics and endoreversibility are entirely equivalent to the same case analyzed by the classical reversible Carnot cycle with external irreversibilities of heat transfer.

2. The theoretical model

The concept of an equilibrium and reversible Carnot cycle has played an important role in the development of classical thermodynamics. The reversible Carnot cycle has been used as an upper bound for heat engines. This upper bound of performance can only be achieved through a continuum of equilibrium states required for thermodynamically reversible processes, i.e. the equilibration rate for a change of state is infinitely faster than the rate of change of state.