PERGAMON

Energy Conversion and Management 42 (2001) 1085–1093

ENERGY CONVERSION & MANAGEMENT

www.elsevier.com/locate/enconman

Performance analysis of an endoreversible heat engine based on a new thermoeconomic optimization criterion

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Received 8 March 2000; accepted 15 September 2000

Abstract

A new kind of finite time thermoeconomic optimization analysis for an endoreversible heat engine has been performed. The objective function has been taken as the power output per unit total cost. The optimum performance parameters that maximize the objective function are investigated. In this perspective, some analytical equations for the optimum working fluid temperatures, optimum thermal efficiency, optimal distributions of heat exchanger areas and optimum specific power output were found in terms of economical and technical parameters. The effects of the design parameters on the optimal conditions have been discussed.

Keywords: Finite time thermodynamics; Thermoeconomic optimization; Endoreversible heat engine

1. Introduction

The thermal efficiency of a reversible Carnot cycle is an upper limit of efficiency for heat engines. According to classical thermodynamics, the Carnot efficiency is

$$\eta_C = 1 - T_L/T_H = 1 - \tau, \tag{1}$$

where T_L and T_H are the temperatures of the cold and hot reservoirs, respectively. The thermal efficiency in Eq. (1) can only be achieved through the infinitely slow processes required by thermodynamic equilibrium. Therefore, it is not possible to obtain a certain amount of power output ($\dot{W}$) by using heat exchangers with finite heat transfer areas. If we require a certain amount of power output, the necessary heat exchanger areas would be infinite. Thus, the thermal efficiency

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0196-8904/01/$ - see front matter
PII: S0196-8904(00)00120-5

Nomenclature

a	investment cost parameter for heat exchangers
A	heat transfer area
b	fuel consumption cost parameter
C	cost
F	objective function
f	$b/(a+b)$
k	a/b
ncu	national currency unit
$\dot{Q}$	rate of heat transfer
S	entropy
T	temperature
$\dot{W}$	power output
U	overall heat transfer coefficient
η	thermal efficiency

Subscripts

AB	Angulo-Brown
C	Carnot
DV	De Vos
f	fuel consumption
H	heat source
i	investment
L	heat sink
mp	maximum power
mpd	maximum power density
opt	optimum
S	specific
X	hot working fluid
Y	cold working fluid

Superscript

*	optimum conditions

given in Eq. (1) does not have great significance and is a poor guide for the performances of real heat engines. Chambadal [1], Novikov [2] and Curzon and Ahlborn [3] extended the reversible Carnot cycle to an endoreversible Carnot cycle by taking the irreversibility of finite time heat transfer into account and found that the efficiency at maximum power as,

$$\eta_{\rm mp} = 1 - \sqrt{\tau}. \quad (2)$$

Other than power maximization, Wu [4,5], Chen and Wu [6,7] and Chen et al. [8] have maximized specific power output (power output per unit total heat transfer area), and at the optimum conditions, they obtained the same result with maximum power conditions. Sahin et al. [9] performed power density (defined as the ratio of power to the maximum volume in the cycle) maximization analysis for the endoreversible heat engine cycle model and found the thermal efficiency at maximum power density conditions as,

$$\eta_{\rm mpd} = 1 - (1-b)\tau \Big/ \left(\sqrt{b + (1-b)\tau} - b\right), \quad (3)$$

where the conductance allocation parameter $b = U_{\rm H}A_{\rm H}/(U_{\rm L}A_{\rm L} + U_{\rm H}A_{\rm H})$. Angulo-Brown [10] proposed an ecological optimization criterion for performance analysis for the endoreversible heat engine and found that the thermal efficiency at maximum ecological objective function conditions is in good agreement with the arithmetic mean of the Carnot and the maximum power efficiencies, i.e.

$$\eta_{\rm AB} = \eta_{\rm C}\frac{1 + 2\tau + 1.5\sqrt{2(\tau+\tau^2)}}{1 + 3\tau + 2\sqrt{2(\tau+\tau^2)}} \approx \frac{\eta_{\rm C} + \eta_{\rm mp}}{2}. \quad (4)$$