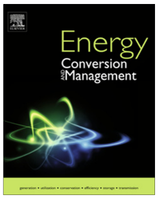
Energy Conversion and Management 80 (2014) 535–542

Contents lists available at ScienceDirect

Energy Conversion and Management

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



Entransy analysis of irreversible Carnot-like heat engine and refrigeration cycles and the relationships among various thermodynamic parameters

Emin Açıkkalp *

Department of Mechanical and Manufacturing Engineering, Engineering Faculty, Bilecik S.E. University, Bilecik, Turkey

A R T I C L E I N F O

Article history:
Received 5 August 2013
Accepted 30 January 2014
Available online 24 February 2014

Keywords:
Entransy analysis
Entransy dissipation
Entropy generation
Exergy output
Power output

A B S T R A C T

Because of the energy needs of the world and the issues involved with global warming, analyzing and optimizing power cycles have increased in importance. In this paper, the concepts of entransy dissipation, entropy generation, power output, exergy output, energy, exergy efficiencies for irreversible heat engine cycles and entransy dissipation, entropy generation, power inputs, exergy input, entropy generation, COP and the exergy of efficiency for the irreversible refrigeration cycle are applied as a means of analyzing them. The results are obtained numerically, and the optimum or critical values are determined for a dimensionless temperature ratio and a dimensionless heat conductance ratio. Finally, recommendations on the design and range of operating conditions for the cycles are presented. Values of T_C/T_E (x), can be selected between 0.5 and 0.55 and values of k_E/k_C (y) in the range of 0.3–0.5 can be selected for high performance and low losses in a heat engine. Choosing values of T_C/T_E (x) and k_C/k_E (y) as low as possible for high performance, besides low thermodynamic losses (entropy generation and entransy dissipation) for the refrigeration cycle.

1. Introduction

Heat transfer is thermal energy flow resulting from a temperature difference, one of the most common physical phenomena in the world, especially in energy systems. Estimates of all of the worldwide energy utilization suggest that over 80% of the energy systems involve heat transfer processes. Thus, improved heat transfer performance offers a huge potential for both conserving energy and reducing CO_2 emission, thereby reducing global warming [1]. Because of these benefits, the optimization of heat transfer processes have increased in importance, which led to the development of a concept known as entransy. Entransy can be described as the heat transfer potential of a system. Thermodynamically, heat transfer is a non-equilibrium and irreversible process, and there is always entransy dissipation during a heat transfer process. Heat transfer dissipation is similar to entropy generation because they are a measurement of irreversible processes and both of them always increase. Entransy has been derived by using an analogy of electrical capacitance and can be defined as [2] (see Table 1).

$$\dot{G} = \frac{1}{2}\dot{Q}T \tag{1}$$

where G is quantity of entransy (kW K), $\dot{Q}$ is the heat stored in the object (kW) and T is the temperature of the object (K). Using an analogy with electric capacitance, $\dot{Q}$ represents the thermal charge, which is similar to the electric charge, and T represents the thermal potential, which is similar to the electrical potential. An entransy balance equation can be written from the thermodynamic point of view as follows [3]:

$$\dot{G}_H - \dot{G}_L - \dot{G}_d - \dot{G}_w - \dot{G}_{lk} = 0 \tag{2}$$

where $\dot{G}_H$ is the entransy flow at the hot temperature heat source, $\dot{G}_L$ is the entransy flow at the heat low temperature heat source, $\dot{G}_d$ is the entransy dissipation, $\dot{G}_w$ is the work entransy and $\dot{G}_{lk}$ is the heat leak entransy.

Although there are papers in the literature regarding entransy [1–33], very few studies exist on the entransy analysis of thermodynamic cycles [2–6]. In this paper, entransy analyses of irreversible Carnot-like heat engine and refrigeration cycles are conducted. In addition, the entransy dissipation value of the systems are defined and the relationships between the power output, exergy output, entropy generation and entransy dissipation values for a heat engine and the relationships between power input, exergy input, entropy generation and entransy dissipation for a refrigeration cycle are defined.

---

* Tel.: +90 (228) 2160061; fax: +90 (228) 216 05 88.
E-mail addresses: eacikkalp@gmail.com, emin.acikkalp@bilecik.edu.tr

http://dx.doi.org/10.1016/j.enconman.2014.01.056
0196-8904/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

c	heat conductance for the heat leak (kW/K)
COP	coefficient of performance
Ex	exergy output (kW)
G	entransy (kW K)
I	internal irreversibility parameter
k	heat conductance (kW/K)
q	heat leak (kW)
$\dot{Q}$	heat (kW)
T	temperature (K)
S	entropy (kW/K)
$\dot{W}$	power kW
x	ratio of heats
y	ratio of the heat conductances
z	sum of the heat conductances

Subscripts

o	environment
C	condenser
d	dissipation
E	evaporator
gen	generation
H	high
L	low
lk	leak
R	reversible
w	work

Greek letters

η	energy efficiency
φ	exergy efficiency

2. System description and thermodynamic analysis

2.1. System description and assumptions

A heat engine is described as a machine that produces work by absorbing heat from a high temperature heat source and rejecting a proportion of this heat to low temperature heat sink. The most widely known heat engine is the Carnot engine developed by Sadi Carnot. This engine is assumed to be totally reversible, and it provides scientists or engineers the upper limits of the work that can be generated in a system and the maximum thermal efficiencies obtained from it. Similar to Carnot engines, Carnot refrigeration can be defined. A Carnot refrigeration system operates as a Carnot heat engine in reverse, i.e., work is obtained from environment to the machine to transfer heat from the low temperature heat source to high temperature heat sink. As with a Carnot heat engine, a Carnot refrigerator is assumed as totally reversible. Hence, a Carnot refrigerator uses the minimum amount of work and has the maximum COP (coefficient of performance). However, a reversible cycle does not exist in reality. As a result, models defining the correct potentials and limits of the heat engine and refrigeration irreversible cycle must be described and analyzed. The irreversible Carnot-like heat engine and refrigeration models studied in this paper are shown in Figs. 1 and 2, respectively. The assumptions made in the thermodynamic analyses are as follows:

- The system operates in steady state conditions.
- All processes are irreversible.
- The environmental conditions are $T_o = 298.15$ K and $P_o = 100$ kPa.

The thermodynamic calculations were performed according to the model used by Chen et al. [34]. Although similar analyses and methods exist in the literature [35–39], they do not include an entransy analysis. As previously mentioned, thermodynamic analyses and the investigated parameters in this paper contains an entransy analysis and its effect on the systems. The optimum parameters used in this paper are the temperature ratio and the heat conductance ratio. These parameters have significant effects on the system and therefore are important design parameters.

Table 1
Values used in the considered cycles.

Considered cycle	T_H (K)	T_L (K)	c (kW/K)	z (kW/K)
Heat engine	1000	400	0.02	10
Refrigerator	300	285	0.02	10

2.2. Thermodynamic analysis of the irreversible heat engine

The heat absorbed by the system ($\dot{Q}_H$, kW) from the high temperature heat source at the evaporator, the heat rejected by the system ($\dot{Q}_L$, kW) to the low temperature heat sink at the condenser and the heat leakage ($\dot{q}$, kW) can be defined as follows:

$$\dot{Q}_H = k_H(T_H - T_E) \tag{3}$$

$$\dot{Q}_L = k_L(T_E - T_L) \tag{4}$$

$$\dot{q} = c(T_H - T_L) \tag{5}$$

where k_H and k_L are the heat conductances (kW/K) of the evaporator and the condenser, respectively, c is the heat conductance of the heat leak (kW/K), T_H, T_L, T_E and T_C are the temperature of the hot temperature heat source, the temperature of the low temperature heat source, the evaporator temperature and the condenser temperature (K). Because heat transfer in the condenser and evaporator does not occur at a constant temperature, all of the heat transfer

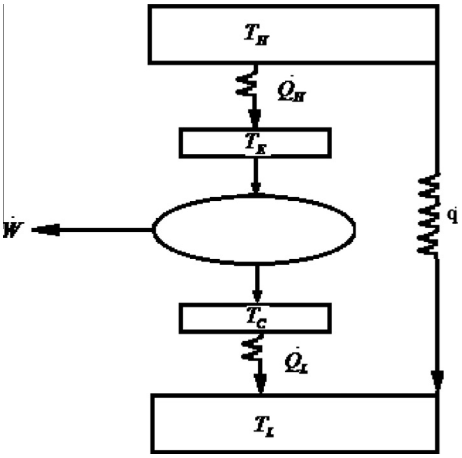


Fig. 1. Schematic of the irreversible heat engine.