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Exergetic sustainability evaluation of irreversible Carnot refrigerator

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HIGHLIGHTS

- An irreversible refrigeration is considered.
- Exergetic sustainability index is derived for refrigeration cycles.
- Calculations are conducted for endoreversible and irreversible cycles.
- Numerical results are presented and discussed.

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ABSTRACT

Purpose of this paper is to assess irreversible refrigeration cycle by using exergetic sustainability index. In literature, there is no application of exergetic sustainability index for the refrigerators and, indeed, this index has not been derived for refrigerators. In this study, exergetic sustainability indicator is presented for the refrigeration cycle and its relationships with other thermodynamics parameters including COP, exergy efficiency, cooling load, exergy destruction, ecological function and work input are investigated. Calculations are conducted for endoreversible and reversible cycles and then results obtained from the ecological function are compared. It is found that exergy efficiency, exergetic sustainable index reduce 47.595% and 59.689% and rising at the COP is 99.888% is obtained for endoreversible cycle. Similarly, exergy efficiency and exergetic sustainability index reduce 90.163% and 93.711% and rising of the COP is equal to 99.362%.

1. Introduction

Industrial progress began with invention of steam engines. Day by day, increasing of the efficiency and power output of the thermal systems were focused by the engineers and scientists. First study about the determining efficiency limits of a thermal cycle was performed by Sadi Carnot. He presented the famous Carnot engine, which is totally reversible, has the maximum efficiency and the maximum power. However, Carnot engine does not provide to determine the optimum operating conditions for the actual cycles (irreversible thermal cycles). That is why, a new thermodynamic branch was developed called as the Finite Time Thermodynamics (FTT). It can be said that Curzon–Ahlborn–Novikov (CAN) engine [1,2] that is endoreversible was the first example of it. Detail information about FTT can be found in Refs. [3–7]. FTT has gained importance because of the increasing environmental concerns. Thus, a lot of criteria were presented to evaluate irreversible cycles. The first of these is the Ecological Function (ECF) submitted by Angulo-Brown [7]. However, Yan proposed a modifi-

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Nomenclature

a	A coefficient (kW K^{-1})
b	A coefficient (kW K^{-1})
C	Heat capacity (kW K^{-1})
$\dot{E}$	Exergy output rate (kW)
H	Enthalpy (kJ)
K	Heat conductance (kW K^{-1})
$LMTD$	Logarithmic temperature difference (K)
P	Pressure (kPa)
S	Entropy (kJ K^{-1})
$\dot{Q}$	Heat (kW)
T	Temperature (K)
$\dot{W}$	Work output (kW)

Subscripts

C	Condenser
E	Evaporator
H	Heat source
HI	Input temperature of the hot temperature heat sink
HO	Output temperature of the hot temperature heat sink
L	Heat sink
LI	Input temperature of the cold temperature heat sink
LO	Output temperature of the cold temperature heat sink
m	Mean

Greek letters

π	COP
ϕ	Exergetic efficiency
θ	Exergetic sustainability index

cation on the ECF [8]. In the open literature, there are papers about ECF and they can be found in Refs. [8–48]. The second and third criteria were called as the Ecological Coefficient of Performance (ECOP) [49–59] and Exergetic Performance Coefficient [60–63]. In addition to these, maximum work obtained from the cycle (or minimum work supplied to the cycle) is researched and finite-time exergy concept was submitted in Refs. [64–75]. In Refs. [76,77] a method based on finite-time exergy was presented and it is called as Maximum Available Work (MAW) criteria. Another index is called exergetic sustainability index that include exergy output of the system and exergy destruction and exergy loss of the system [78–82].

In the literature, there are a lot of papers to evaluate irreversible cycles. However, in this paper an irreversible refrigerator is investigated by using exergetic sustainability index first time and this index is adapted for the refrigeration cycles. Exergetic sustainability index enables someone to determine the environmental impacts of the system. In addition, relations between the power input, cooling load, exergy destruction, COP and exergetic efficiency with exergetic sustainability index are investigated and numerical results are submitted.

2. System description and thermodynamic analysis

Investigated irreversible refrigeration cycle is shown in Fig. 1. In the calculations heat source and heat sink are assumed as finite capacity and system is irreversible. Environmental temperature and pressure are (298.15 K) and (100 kPa). Heat addition to the system (kW) is [83]:

$$\dot{Q}_H = C_H (T_{HO} - T_{HI}) = K_H LMTD_C \tag{1}$$

where K_H and C_H are the heat conductance of the condenser (kW/K) and the heat capacity of the fluid in the condenser (kW/K). Logarithmic temperature of the condenser (K) [83]:

$$LMTD_C = \frac{(T_C - T_{HI}) - (T_C - T_{HO})}{\ln\left(\frac{T_C - T_{HI}}{T_C - T_{HO}}\right)} \tag{2}$$

where T_{HI} is the input temperature and T_{HO} is the output temperature of the heat source. T_{HO} (K) is described as Eq. (3) [83]: