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Performance analysis of heat pumps and refrigerators with variable reservoir temperatures

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Abstract

Performance analysis of totally irreversible heat pumps and refrigerators has been developed by means of the second law of thermodynamics. The machine operates steadily between two variable temperature heat reservoirs. The results show that the optimal balance between the sizes of the heat exchangers at the hot and cold ends of the machine is affected by the ratio E (or E'). Also, the heat delivered by the heat pump and the heat removed by the refrigerator varies significantly with E (or E'). Conversely, the coefficient of performance does not depend on E (or E'). Finally, the effect of the internal irreversibility diminishes at $E_h/E_c < 1$, for heat pumps and at $E_h/E_c > 1$, for refrigerators.

Keywords: Heat pumps; Refrigerators; Irreversible; Optimization; Second law

1. Introduction

Nowadays, second law analysis of thermodynamic systems has become a prominent topic in thermal engineering. Since Curzon and Ahlborn [1] published their landmark paper on the efficiency of a Carnot engine at maximum power output in 1975, many studies on second law analysis of thermodynamic systems have been presented by many authors. Most of these studies concern the performance of heat engines [2–11]. Less work

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Nomenclature

A	total heat transfer area
C	thermal conductance or capacitance
COP	coefficient of performance
E	$E = \varepsilon/\text{NTU}$
E'	$E' = U\varepsilon/\text{NTU}$
I	internal irreversiblity parameter
NTU	number of heat transfer units
Q	rate of heat transfer
Q'	dimensionless rate of heat transfer
T	temperature
U	overall heat transfer coefficient
W	input power
W	dimensionless input power
x	thermal conductance ratio

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α	heat transfer ratio
ε	heat exchanger effectiveness
ΔS_H	entropy difference of working fluid at high temperature side
ΔS_L	entropy difference of working fluid at low temperature side
τ_1	temperature ratio (T_{hi}/T_{ci})
τ_2	temperature ratio (T_H/T_L)

Subscripts

c	cold
h	hot
H	high, heat pump
i	inlet
L	low
m	maximum
o	outlet
opt	optimum
R	refrigerator

was devoted to study the performance of heat pumps and refrigerators [12–16]. These studies generally discuss the second law analysis of endoreversible (internally reversible) or totally irreversible (internally and externally) systems with constant reservoir temperatures.

Practically, the heat reservoirs have finite thermal capacitance rates. Consequently, the temperature in the reservoirs is not constant. Therefore, the system performance depends on the magnitude of the thermal capacitance rates and the temperature variations of the