Available online at www.sciencedirect.com

ScienceDirect

Applied Thermal Engineering 28 (2008) 767–776

APPLIED THERMAL ENGINEERING

www.elsevier.com/locate/apthermeng

Performance of real absorption heat-transformer with a generalized heat transfer law

Xiaoyong Qin, Lingen Chen *, Fengrui Sun

Postgraduate School, Naval University of Engineering, Wuhan 430033, PR China

Received 15 February 2007; accepted 2 June 2007
Available online 28 June 2007

Abstract

An irreversible four-temperature-level absorption heat-transformer cycle model with a generalized heat transfer law of $Q \propto \Delta(T^n)$ $(n \neq 0)$ is established, which considers effects of heat resistance, heat leak and internal irreversibilities. The general relation between the COP (coefficient of performance) and the heating load is deduced. The fundamental optimal relation and the performance limit, the optimal temperatures of working substance, as well as the optimal heat transfer surface area distributions with linear phenomenological heat transfer law are derived. Moreover, effects of heat transfer law, heat leak, and internal irreversibilities on the performance of absorption heat-transformer are analyzed; and the performance comparison is performed for the distribution of the total heat transfer surface area is optimized or not by numerical example. The results obtained herein are useful for optimal design and performance improvement of absorption heat-transformer cycles.

Keywords: Finite-time thermodynamics; Four-temperature-level absorption heat-transformer cycle; Heat transfer law; Irreversible cycle; Generalized thermodynamic optimization

1. Introduction

Absorption heat-transformers can be driven by 'low-grade' heat energy, such as waste heat from various industries, solar energy and geothermal energy, and have a large potential for reducing the waste of the major energy and decreasing the heat pollution to the environment. Thus, absorption heat-transformers for industrial uses are generating renewed interest throughout the world [1]. In recent years, finite-time thermodynamics (or finite surface thermodynamics, or endoreversible thermodynamics, or entropy generation minimization) [2–9] has been applied to the performance study of absorption heat-transformers. Chen [10,11], Feidt [12,13], Goktun and Deha Er [14] and Chen [15] analyzed the performance of the three-heat-reservoir absorption heat-transformer cycle with heat resistance loss, with losses of heat resistance and internal irreversibilities and with losses of heat resistance, heat leakage and internal irreversibilities, respectively, with linear (Newtonian) heat transfer law.

A three-heat-reservoir absorption heat-transformer cycle is a simplified model of an absorption heat-transformer that the temperature of the generator is equal to that of the evaporator, but a real absorption heat-transformer usually is not. Gordon et al. [16–18] established a universal four-heat-reservoir modeling for absorption chillers and confirmed by experiments. Chen [19] established an endoreversible four-heat-reservoir absorption heat-transformer cycle model. Qin et al. [20] established a generalized irreversible four-heat-reservoir absorption heat-transformer cycle model with linear (Newtonian) heat transfer law, which included the heat resistance, the heat leak from

* Corresponding author. Tel.: +86 27 83615046; fax: +86 27 83638709.
E-mail addresses: lgchenna@yahoo.com, lingenchen@hotmail.com (L. Chen).

1359-4311/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2007.06.017

Nomenclature

A	total heat transfer surface area of the heat exchangers, m^2
A_1	heat transfer surface area of the absorber, m^2
A_2	heat transfer surface area of the generator, m^2
A_3	heat transfer surface area of the evaporator, m^2
A_4	heat transfer surface area of the condenser, m^2
b	distribution ratio of the heat input rate from evaporator in the total heat input rate
I	irreversibility factor
K_L	heat leakage coefficient, kW/K^n
n	heat transfer exponent
Q_L	rate of heat leakage, kW
Q_1	rate of heat transfer in the absorber, kW
Q_2	rate of heat transfer in the generator, kW
Q_3	rate of heat transfer in the evaporator, kW
Q_4	rate of heat transfer in the condenser, kW
T_a	heat reservoir temperature in the absorber, K
T_g	heat reservoir temperature in the generator, K
T_e	heat reservoir temperature in the evaporator, K
T_c	heat reservoir temperature in the condenser, K
T_1	temperature of working fluid in the absorber, K
T_2	temperature of working fluid in the generator, K
T_3	temperature of working fluid in the evaporator, K
T_4	temperature of working fluid in the condenser, K
U_1	heat transfer coefficients of the absorber, kW/(m^2 K^n)
U_2	heat transfer coefficients of the generator, kW/(m^2 K^n)
U_3	heat transfer coefficients of the evaporator, kW/(m^2 K^n)
U_4	heat transfer coefficients of the condenser, kW/(m^2 K^n)
UA	total heat exchanger inventory, kW/K^n

Greek symbols

Π	heating load, kW
Π_m	maximum heating load, kW
ψ	COP
ψ_m	maximum COP

Subscripts

A	after optimizing the distribution of the total heat transfer surface area
UA	after optimizing the distribution of the total heat exchanger inventory
Π	at maximum heating load point
ψ	at maximum COP point

the heated space to the environmental reservoir and the internal irreversibilities due to the internal dissipation of the working substance, and analyzed the optimal performance of the real four-heat-reservoir absorption heat-transformer cycle with linear (Newtonian) heat transfer law.

Real heat transfers between heat reservoirs and working substance do not always obey linear (Newtonian) heat transfer law. Chen et al. [21] studied the performance of the three-heat-reservoir endoreversible absorption heat-transformer cycle with another linear heat transfer law, i.e., linear phenomenological heat transfer law, $Q \propto \Delta(T^{-1})$. Qin et al. [22] studied the performance of the four-heat-reservoir endoreversible absorption heat-transformer cycle with heat transfer law of $Q \propto \Delta(T^n)$ ($n \neq 0$), where n is a heat transfer exponent. The generalized heat transfer law $Q \propto \Delta(T^n)$ ($n \neq 0$) includes some special cases. When $n = 1$, the heat transfer obeys Newtonian law; when $n = -1$, the heat transfer obeys linear phenomenological law used in irreversible thermodynamics, the heat transfer coefficients in this case are the so-called kinetic coefficients by Callen [23], and they should be negatives; when $n = 2$, the heat transfer is applicable to radiation propagated along a one-dimensional transmission line [24], and the heat transfer coefficient in this case is equal to $\pi^2k^2/(6h)$, where h is the Planck's constant and k is the Stefan–Boltzmann constant; when $n = 3$, the heat transfer is applicable to radiation propagated along a two-dimensional surface [25]; when $n = 4$, the heat transfer obeys radiative law if all the bodies are black, and the heat transfer coefficient in this case is related to the Stefan–Boltzmann constant.

Whether the three-heat-reservoir cycle model or the four-heat-reservoir cycle model, the working substance must work in four different temperature levels. Therefore, the aim of this paper is to establish an irreversible four-temperature-level absorption heat-transformer cycle model with heat transfer law of $Q \propto \Delta(T^n)$ ($n \neq 0$), which are more general and close to a real absorption heat-transformer cycle, and analyze the performance of the real absorption heat-transformer cycle. The results obtained herein are general and useful. They can provide the theoretical bases for the optimal design and operation of a real absorption heat-transformer operating at realistic temperature differences. This paper also provides an additional criterion for use in the performance evaluation and the suitability of an absorption heat-transformer.

2. Physical model

A four-temperature-level absorption heat-transformer cycle consists of an absorber, a generator, an evaporator