International Journal of Heat and Mass Transfer 114 (2017) 252–257

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Ecological performance of four-temperature-level absorption heat transformer with heat resistance, heat leakage and internal irreversibility

Xiaoyong Qin, Lingen Chen *, Shaojun Xia

Institute of Thermal Science and Power Engineering, Naval University of Engineering, Wuhan 430033, China
Military Key Laboratory for Naval Ship Power Engineering, Naval University of Engineering, Wuhan 430033, China
College of Power Engineering, Naval University of Engineering, Wuhan 430033, China

A R T I C L E I N F O

Article history:
Received 21 April 2017
Received in revised form 2 June 2017
Accepted 9 June 2017
Available online 23 June 2017

Keywords:
Absorption heat transformer
Irreversible cycle
Four-temperature-level cycle
Ecological function
Finite time thermodynamics

A B S T R A C T

Based on irreversible four-temperature-level (FTL) cycle model of absorption heat transformer (AHT) plants with heat resistance, heat leakage and internal irreversibility, an exergy-based ecological criterion function of is proposed, which can attain a compromise in inter restricted relations between exergy output and exergy loss of AHT plants. When all losses are considered and different losses are ignored, detailed expressions and simplified expressions among ecological function, exergy output, exergy loss, and various loss factors are derived. Using illustrative calculations, the effects of various loss factors on the general characteristics and the optimal ecological characteristics are analyzed. The expressions and conclusions obtained herein are general, which can provide some new guidelines about parameter selection for practical AHT plants.

1. Introduction

Low-grade heats can be upgraded to higher temperature levels by absorption heat transformer (AHT), and the working fluid utilized by AHT can be environmental friendly. Thus, many scholars have studied AHT technologies for industrial uses [1–3] and analyzed AHT cycles by using finite time thermodynamics (FTT) [4–18]. Ordinary, AHT was modeled as a three-heat-reservoir (THR) [19–22], a four-heat-reservoir (FHR) [22–24] or a four-temperature-level (FTL) cycle [25,26] (including THR cycle and FHR cycle). An irreversible FTL AHT cycle model has been established by Qin et al. [26], and the heating load and the COP performance have been analyzed. Similarly, many scholars have analyzed and optimized the performances of absorption refrigeration [27–32] and absorption heat pump [33–35] cycles by using FTT.

Ecological performance analysis can obtain some important results, which are different from the COP and the heating load performance. Ecological function are introduced firstly by Angulo-Brown [36], and then revised by Yan [37]. Ecological function can be established by energy-based viewpoint and exergy-based viewpoint, respectively. For all of the thermodynamic cycles, the exergy-based ecological optimization objective function $E = EX - T_s\sigma$ was established by Chen et al. [38], where EX is the exergy output rate, T_s is the environmental temperature, and σ is the entropy generation rate of the cycle. Different type heat engines, two-heat-reservoir, three- heat-reservoir, and four-heat-reservoir refrigerators and heat pumps have been analyzed and optimized by using this exergy-based ecological function as optimization objective function [39–60].

Based on irreversible FTL AHT cycle models [26] and the exergy-based ecological objective function [38], the exergy-based ecological objective function of AHT plants will be established and the ecological performance will be analyzed and optimized in this paper.

2. Exergy-based ecological function and performance

2.1. Irreversible FTL AHT cycle model

An irreversible FTL AHT cycle and the corresponding irreversible model are shown in Fig. 1(a) and (b) [26]. The heat exchange rates Q'_i $(i = a, c, e, g)$ between external heat reservoir and internal working fluid are $Q'_g = U_gA_g(T_g - T'_g)$, $Q'_a = U_aA_a(T'_a - T_a)$, $Q'_c = U_cA_c(T'_c - T_c)$, and $Q'_e = U_eA_e(T_e - T'_e)$. The heat leakage rates Q^l_i $(i = a, c, e, g)$ between external heat reservoir and surroundings are $Q^l_g = K^l_g(T_g - T_s)$, $Q^l_a = K^l_a(T_a - T_s)$,

* Corresponding author at: Institute of Thermal Science and Power Engineering, Naval University of Engineering, Wuhan 430033, China.
E-mail addresses: lgchenna@yahoo.com, lingenchen@hotmail.com (L. Chen).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2017.06.064
0017-9310/

Nomenclature

A total heat transfer surface area of all heat exchangers, m^2
$A_i(i=a,c,e,g)$ heat transfer surface area of the heat exchanger, m^2
b distribution ratio of the heat addition
E exergy-based ecological function
EX exergy output rate
I irreversibility factor
$K_i^l(i=a,c,e,g)$ heat leakage coefficient of heat reservoir, kW/K
$Q_i(i=e,g)$ heat rejection rate of heat reservoir, kW
$Q_i(i=a,c)$ heat addition rate of heat reservoir, kW
$Q_i^l(i=a,c,e,g)$ heat leakage rate from heat reservoir, kW
$Q_i'(i=a,c,e,g)$ heat exchange rate, kW
$T_i(i=a,c,e,g,s)$ temperature of heat reservoir, K
$T_i'(i=a,c,e,g)$ temperature of working fluid, K
$U_i(i=a,c,e,g)$ heat transfer coefficient, $kW/(m^2\cdot K)$
UA total heat exchanger inventory of all heat exchangers, kW/K

Greek symbols
Π heating load, kW
ψ COP
σ entropy production rate

Subscripts
A after optimizing the total heat transfer surface area
a absorber
c condenser
e evaporator
g generator
max maximum
s surrounding
UA after optimizing the total heat inventory
ψ at maximum COP
E at maximum E

$Q_c^l=K_c^l(T_c-T_s)$, and $Q_e^l=K_e^l(T_s-T_e)$. The internal irreversibilities are denoted by an irreversibility factor $I=(Q_a'/T_a'+Q_c'/T_c')/(Q_g'/T_g'+Q_e'/T_e')\geqslant 1$. The heat addition distribution ratio is denoted by a parameter $b=Q_e'/(Q_g'+Q_e')$. The COP (ψ) can be written as $\psi=Q_a/(Q_g+Q_e)=(Q_a'-Q_a^l)/(Q_g'+Q_e'+Q_g^l+Q_e^l)$, and the heating load ($\Pi$) can be written as $\Pi=Q_a=Q_a'-Q_a^l$.

The expression among the heating load, the COP, the irreversibility factors and other important characteristic parameters of a FTL AHT can be derived as [26]

$$\psi\left(\frac{T_a}{\Pi+Q_a^l}+\frac{1}{U_aA_a}\right)^{-1}+\left[\frac{T_c}{\Pi-(\Pi+Q_a^l+Q_g^l+Q_e^l)\psi}+\frac{1}{U_cA_c\psi}\right]^{-1}-I\left[\frac{T_g}{(1-b)(\Pi-Q_g^l-Q_e^l)\psi}-\frac{1}{U_gA_g\psi}\right]^{-1}-I\left[\frac{T_e}{b(\Pi-Q_g^l-Q_e^l)\psi}-\frac{1}{U_eA_e\psi}\right]^{-1}=0 \tag{1}$$

2.2. Ecological function and expressions among E, σ, Π and ψ

According to Ref. [38], for a FTL AHT cycle, the exergy-based ecological function is

$$E=EX-T_s\sigma=EX_a+EX_c-T_s\sigma \tag{2}$$

where EX_a is the absorber exergy output rate, $EX_a=Q_a(1-T_s/T_a)$; and EX_c is the condenser exergy output rate, $EX_c=Q_c(1-T_s/T_c)$.

According to the cycle model mentioned above, one can obtain

$$Q_a=\Pi,$$
$$Q_g=(1-b)\left(\frac{\Pi}{\psi}-Q_g^l-Q_e^l\right)+Q_g^l,$$
$$Q_e=b\left(\frac{\Pi}{\psi}-Q_g^l-Q_e^l\right)+Q_e^l, \tag{3}$$
$$Q_c=\frac{\Pi(1-\psi)}{\psi}-Q_a^l-Q_g^l-Q_e^l-Q_c^l$$

Substituting Eq. (3) into exergy output rate EX yields

$$EX=\Pi\left[\frac{T_s}{T_c}-\frac{T_s}{T_a}+\left(1-\frac{T_s}{T_c}\right)\frac{1}{\psi}\right]-(Q_a^l+Q_g^l+Q_e^l+Q_c^l)\left(1-\frac{T_s}{T_c}\right) \tag{4}$$

The entropy production rate σ of the cycle is

$$\sigma=\frac{Q_a}{T_a}+\frac{Q_c}{T_c}+\frac{Q_a^l+Q_g^l+Q_e^l+Q_c^l}{T_s}-\frac{Q_g}{T_g}-\frac{Q_e}{T_e} \tag{5}$$

Substituting Eq. (3) into Eq. (5) yields

$$\sigma=\Pi\left[\frac{1}{T_a}-\frac{1}{T_c}+\left(\frac{1}{T_c}-\frac{1-b}{T_g}-\frac{b}{T_e}\right)\frac{1}{\psi}\right]+(bQ_g^l+bQ_e^l-Q_e^l)\left(\frac{1}{T_e}-\frac{1}{T_g}\right)-(Q_a^l+Q_g^l+Q_e^l+Q_c^l)\left(\frac{1}{T_c}-\frac{1}{T_s}\right) \tag{6}$$

Substituting Eqs. (4) and (6) into Eq. (2) yields

$$E=\Pi T_s\left[2\left(\frac{1}{T_c}-\frac{1}{T_a}\right)+\left(\frac{1}{T_s}-\frac{2}{T_c}+\frac{1-b}{T_g}+\frac{b}{T_e}\right)\frac{1}{\psi}\right]-(bQ_g^l+bQ_e^l-Q_e^l)T_s\left(\frac{1}{T_e}-\frac{1}{T_g}\right)-2(Q_a^l+Q_g^l+Q_e^l+Q_c^l)T_s\left(\frac{1}{T_s}-\frac{1}{T_c}\right) \tag{7}$$

Eqs. (1), (4), (6) and (7) are the detailed expressions among E, σ, Π, ψ and some important characteristic parameters of the irreversible FTL AHT.

2.3. Simplified expressions

(1) When heat leakages in the cycle can be ignored (i.e., $K_g^l=K_e^l=K_a^l=K_c^l=0$), Eqs. (1), (6) and (7) become

$$\psi\left(\frac{T_a}{\Pi}+\frac{1}{U_aA_a}\right)^{-1}+\left(\frac{T_c}{\Pi(1-\psi)}+\frac{1}{U_cA_c\psi}\right)^{-1}-I\left(\frac{T_g}{(1-b)\Pi\psi}-\frac{1}{U_gA_g\psi}\right)^{-1}-I\left(\frac{T_e}{b\Pi\psi}-\frac{1}{U_eA_e\psi}\right)^{-1}=0 \tag{8}$$