Physica A 436 (2015) 788–797

Contents lists available at ScienceDirect

Physica A

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

Thermodynamic modeling and performance analysis of the variable-temperature heat reservoir absorption heat pump cycle

Xiaoyong Qin, Lingen Chen *, Yanlin Ge, Fengrui Sun

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

HIGHLIGHTS

- An irreversible absorption heat pump cycle model is established.
- It is a variable-temperature heat reservoir four-temperature-level cycle.
- General relationship between heating load and COP is derived.
- Optimal performance characteristics between heating load and COP are obtained.

ARTICLE INFO

Article history:
Received 31 January 2015
Received in revised form 27 April 2015
Available online 19 May 2015

Keywords:
Finite-time-thermodynamics
Absorption heat pump
Variable-temperature heat reservoir
Four-temperature-level

ABSTRACT

For practical absorption heat pump (AHP) plants, not all external heat reservoir heat capacities are infinite. External heat reservoir heat capacity should be an effect factor in modeling and performance analysis of AHP cycles. A variable-temperature heat reservoir AHP cycle is modeled, in which internal working substance is working in four temperature levels and all irreversibility factors are considered. The irreversibility includes heat transfer irreversibility, internal dissipation irreversibility and heat leakage irreversibility. The general equations among coefficient of performance (COP), heating load and some key characteristic parameters are obtained. The general and optimal characteristics are obtained by using numerical calculations. Besides, the influences of heat capacities of heat reservoirs, internal dissipation irreversibility, and heat leakage irreversibility on cycle performance are analyzed. The conclusions can offer some guidelines for design and operation of AHP plants.

1. Introduction

Many low grade heats, for example geothermal energy, solar energy, discharged heat from various enterprises, etc., exist in our surroundings. AHP (the type I absorption heat pump) can utilize these heats, and at the same time, AHP can use environment friendly working substance. Thus, AHPs have active function for decreasing the environment pollution introduced by cycle working substance. Recent 20 years, many scholars have developed many researches about AHP for industrial uses [1–3].

* Corresponding author at: College of Power Engineering, Naval University of Engineering, Wuhan 430033, PR China. Tel.: +86 27 83615046; fax: +86 27 83638709.
E-mail addresses: lgchenna@yahoo.com, lingenchen@hotmail.com (L. Chen).

http://dx.doi.org/10.1016/j.physa.2015.05.081
0378-4371/

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 heat exchanger, m^2
a the distribution ratio of heat rejection rate
C_i $(i = a, c, e, g)$ heat capacity of heat reservoir, kW K^{-1}
E_i $(i = a, c, e, g)$ effectiveness of heat exchanger
I internal irreversibility factor
K_i^l $(i = a, c, e, g)$ heat leakage coefficient of heat reservoir, kW K^{-1}
Q_i $(i = a, c)$ heat addition rate of heat reservoir, kW
Q_i $(i = e, g)$ heat rejection rate of heat reservoir, kW
Q_i^l $(i = a, c, e, g)$ heat leakage rate between heat reservoir and surrounding, kW
Q_i' $(i = a, c, e, g)$ heat exchange rate between heat reservoir and internal working substance, kW
T_i^{in} $(i = a, c, e, g)$ inlet temperature of external heat reservoir, K
T_i^{out} $(i = a, c, e, g)$ outlet temperature of external heat reservoir, K
T_i' $(i = a, c, e, g)$ internal working substance temperature in heat exchanger, K
U_i $(i = a, c, e, g)$ heat transfer coefficient, kW m^{-2} K^{-1}
UA total heat exchanger inventory of all heat exchangers, kW K^{-1}

Greek symbols

Π heating load, kW
ψ COP

Subscripts

a absorber
c condenser
e evaporator
g generator
max maximum
s surrounding
ψ at maximum COP

The performance of AHP can be analyzed by classical thermodynamic and finite time thermodynamics [4–23]. Some new results have been obtained by using finite time thermodynamics analysis, which are not obtained or inconsistent with the results by using classical thermodynamic analysis. In accordance with endoreversible three-heat-reservoir (THR) model, Chen and Andresen [24] discussed performances of AHP cycles on Newtonian heat transfer law ($Q \propto (\Delta T)$). In accordance with irreversible THR model, Goktun [25], Lin and Yan [26], Wu et al. [27], and Ngouateu and Wouagfack [28] discussed characteristics of AHP cycles on Newtonian heat transfer law ($Q \propto (\Delta T)$). In accordance with endoreversible THR model, Su and Yan [29] discussed characteristics of AHP cycles on heat transfer law of $Q \propto (\Delta T^{-1})$.

The THR cycle model assumes that the external heat reservoir temperature and internal working substance temperature are the same in the condenser and absorber. But, internal working substance temperature cannot be the same or the external heat reservoir temperature cannot be the same in the condenser and absorber, in fact. Therefore, a model assumed that the absorber working substance temperature can be different to the condenser working substance is closer to an actual AHP cycle, which is called four-temperature-level (FTL) AHP cycle model [30–37]. In accordance with a FTL endoreversible cycle model, Qin et al. [30] and Ngouateu and Tchinda [31] analyzed characteristics of AHP cycles based on Newtonian heat transfer law. In accordance with a FTL irreversible cycle model, Chen [32], Huang et al. [33], Chen et al. [34], and Zhao et al. [35] analyzed performances of AHP cycles based on Newtonian heat transfer law. In accordance with four-temperature-level cycle models, Qin et al. [36,37] analyzed characteristics of AHP cycles based on heat transfer law of $Q \propto \Delta(T^n)$.

For many thermal energy systems, the heat reservoir heat capacities cannot all be infinite and the heat reservoir temperatures cannot all be constants (variable-temperature heat reservoirs). But, almost all of these studies [24–37] on AHP mentioned above were assumed that all heat reservoir heat capacities are infinite (constant-temperature heat reservoirs). Not all heat reservoir heat capacities of practical AHP plants are finite, too. The effects of heat capacities of heat reservoirs should be taken into account in finite time thermodynamic modeling and performance analyses for AHP cycles. Based on these achievements mentioned above [24–37], a variable-temperature heat reservoir irreversible AHP cycle model coupled to FTL will be established in this paper. The irreversibility induced by finite-rate heat transfer lied in the external heat reservoir and the internal working substance, the irreversibility induced by heat leakage losses between surroundings and the external heat reservoirs, and the irreversibility induced by internal working substance dissipation will be considered. The general equations including coefficient of performance (COP), heating load and some key irreversibility parameters of