Energy Conversion and Management 138 (2017) 12–21

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Effects of the generator and evaporator temperature differences on a double absorption heat transformer—Different control strategies on utilizing heat sources

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ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form 17 December 2016
Accepted 29 January 2017

Keywords:
Exergy destruction rate
Double absorption heat transformer
Generator temperature
Evaporator temperature
Heat source temperature
Control strategies

ABSTRACT

The combination of the absorption heat transformer with renewable energy systems, like solar thermal systems, is raising more and more concern. In those combined systems the strategies on utilizing heat sources can affect system thermodynamic performance significantly. Therefore, this study presents a detailed analysis on the effect of the heat source temperature and different heat source flow patterns on the performance of a double absorption heat transformer (DAHT). A detailed comparative study is carried out to clarify the impact of the generator and evaporator temperature differences (GETD) on the coefficient of performance (COP), exergy efficient (ECOP), exergy destruction rates in the individual components and heat transfer areas needed for each component. The results show that the generator, condenser and absorber-evaporator are responsible for most of the exergy destruction rate in the DAHT system; the parallel-flow configuration (the generator temperature is equal to the evaporator temperature) performs better under the high gross temperature lift conditions; in the case of the counter-flow configuration (the generator temperature is relatively higher), better performance can be obtained in both the COP and ECOP under the proper heat source temperature (85 and 95 °C); the fair-flow configuration (higher temperature in the evaporator) is not recommended in this paper due to no advantages found in either thermodynamic performance or system size.

1. Introduction

Large-scale use of fossil fuels results the worldwide energy shortage and the environment pollution [1,2]. In this respect, many countries are devoting effort to develop devices to use energy efficiently and utilize renewable energy sources [3–7]. Among these devices, absorption heat transformer (AHT) is very promising in reducing energy consumption and protecting the environment since it can make good use of waste heat and apply to renewable energy, like geothermal energy and solar energy [7–11]. In various AHT devices, the single-stage AHT and double absorption heat transformer (DAHT) are the most commonly used systems. The latter which can obtain higher gross temperature lift (GTL) and exergy efficiency (ECOP) has received a lot of attention [12–16].

Martinez and Rivera [17] used the first and second laws of thermodynamics to analyze a DAHT operating with water-lithium bromide mixture. The result revealed that the maximum exergy deduction happens in the generator, accounting for about 40% of the total destruction. Zhang and Li [18] proposed a DAHT with a new solution cycle and analyzed the exergy destruction rate using the second law of thermodynamics. The result revered that this novel cycle can obtain not only higher exergy efficiency but also wider available working range of the absorber-evaporator temperature. Gomri [19] conducted a comparative study to analyze the possibilities of using single-effect and double-effect absorption heat transformer systems in the seawater desalination. The simulation result compared two systems from the view of energy efficiency, exergy efficiency and fresh water production. Saito et al. [20] evaluated the performance of double-lift absorption heat transformer from the experimental and numerical ways. The numerical results were validated by the experimental results. In

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http://dx.doi.org/10.1016/j.enconman.2017.01.076
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Nomenclature

A	heat transfer area (m^2)
AHT	absorption heat transformer
COP	coefficient of performance
DAHT	double absorption heat transformer
ECOP	exergy efficiency
$E_{\mathrm{D,abs}}$	exergy destruction rate in the absorber (kW)
$E_{\mathrm{D,AE}}$	exergy destruction rate in the absorber-evaporator (kW)
$E_{\mathrm{D,ec1}}$	exergy destruction rate in the first economizer (kW)
$E_{\mathrm{D,ec2}}$	exergy destruction rate in the second economizer (kW)
$E_{\mathrm{D,evap}}$	exergy destruction rate in the evaporator (kW)
$E_{\mathrm{D,gen}}$	exergy destruction rate in the generator (kW)
$E_{\mathrm{D,total}}$	total exergy destruction rate (kW)
f	flow ratio
GTL	gross temperature lift (°C)
h	specific enthalpy (kJ kg^{-1})
LiBr	lithium bromide
m	mass flow rate (kg s^{-1})
m_{h}	heat source mass flow rate (kg s^{-1})
P	pressure (kPa)
Q	energy transfer rate (kW)
s	specific entropy (kJ kg^{-1} K^{-1})
T	temperature (°C)
T_0	the ambient temperature (°C)
$T_{\mathrm{a,in}}$	absorber inlet heating fluid temperature (°C)
$T_{\mathrm{c,in}}$	condenser inlet cooling water temperature (°C)
T_{h}	heat source temperature (°C)
GETD	generator and evaporator temperature differences (°C)
W	mechanical power (kW)
x	absorbent mass fraction
Δt_a	heating fluid temperature rise (°C)
Δt_c	cooling water temperature rise (°C)

Subscripts

1,2,...,18	thermodynamic state points
AE	absorber-evaporator
abs	absorber
con	condenser
evap	evaporator
ec1	the first economizer
ec2	the second economizer
gen	generator
in	inlet
out	outlet
pump	refrigerant and solution pumps
ref	refrigerant

Greek symbols

ε	efficiency of economizers
η	isentropic efficiency of pumps
$\sum$	summation

their studied systems, high temperature steam approximately 180 °C can be obtained with the driven heat water source below 90 °C. Also a model-scale and a practical-scale apparatus were designed and built in their research. Khamooshi et al. [21] employed the first law of thermodynamics to compare two different DAHT configurations. The performance of these two different cycles was studied and compared in detail. Additionally, both configurations were optimized by considering the water production. Horuz and Kurt [22] analyzed two DAHT cycles, namely parallel and series DAHT, in an industrial application to generate vapor. Two systems were compared from the view of COP and production of water vapor, and the result showed that the parallel DAHT can generate more vapor.

Generally, in the operating of DAHT system, a heat source at intermediate temperature is supplied to both of the generator and evaporator to heating the solution and refrigerate, but the generator temperature and evaporator temperature can be different under various heat source flow patterns. Many researchers [14,19,21] assumed that the generator temperature and evaporator temperature are equal; others [20,22] utilized different ideas in their research. No much justification. Studies conducted in the single-stage AHT system [23,24], absorption refrigeration system [25], etc. indicate that a proper control strategy on utilizing heat source is very critical in improving system performance, especially under the condition that the heat source temperature can be controlled, for example, the heat source from solar thermal systems. Therefore, from the view of both the first and second laws of thermodynamics, a detailed analysis is carried out to clarify the influence of the generator and evaporator temperature difference (GETD) on the DAHT performance. The COP, ECOP, detailed exergy destruction rate and heat transfer area of the individual components are compared under different heat source temperature and various heat source flow patterns.

2. Description of the system

A schematic diagram of the DAHT system, operating with the working fluid H_2O/LiBr, is depicted in Fig. 1. As shown in Fig. 1, the DAHT analyzed in the present paper basically consists of a generator, a condenser, an absorber-evaporator (noted as AE in Fig. 1), an absorber and two economizers. In this cycle, a heat source at intermediate temperature is supplied to the generator and evaporator to heat the solution and refrigerant (H_2O). The vaporized water (state point 1) is condensed in the condenser at a low pressure. Then, the condensed water (state point 2) is separated into two streams. One stream is pumped into the absorber-evaporator and evaporated into saturated vapor (state point 6) at a high pressure. In the absorber, this high-pressure vapor is absorbed by the strong solution (state point 13) coming from the generator. The absorption process happens in the absorber will provide high temperature heat for practical use. The other stream is pumped into the evaporator and evaporated into saturated vapor (state point 5) at a middle temperature. This part of vapor is fed to the absorber-evaporator and absorbed by the strong solution (state point 18) also from generator. The heat delivered in the absorber-evaporator is used to vaporize the first stream of water. After the absorption process in the absorber and absorber-evaporator, the weak solution (state point 14 and state point 7, respectively) flow back to the generator. Two economizers are arranged between absorber and generator, absorber-evaporator and generator, respectively, to improve thermodynamic performance.

Generally, if the heat source is delivered to the evaporator and generator separately (namely the parallel-flow configuration), the evaporator temperature and generator temperature can be assumed equal; but if the heat source goes through the evaporator first and then go to the generator (namely the fair-flow configuration),