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Three-objective optimization of a novel triple-effect absorption heat transformer combined with a water desalination system

S.M.S. Mahmoudi *, S. Salehi, M. Yari

Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran

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ABSTRACT

A novel triple-effect absorption heat transformer is proposed and compared with a most studied configuration of triple-effect absorption heat transformer and a modified form of it from the viewpoint of exergoeconomics. All systems are integrated with water desalination system to produced distilled water. Sensitivity analyses are performed to identify the influence on the systems' performance of such decision parameters as the temperatures of evaporator, condenser, absorber and absorbing evaporators for all the configurations. Then a three-objective optimization is accomplished to specify the optimal design points for the purpose of minimizing the product unit cost and maximizing the exergy coefficient of performance as well as the distilled water mass flow rate. In this regard, the Pareto frontiers are plotted for all the systems. The results show that, under the optimized conditions, the exergy coefficient of performance and distilled water mass flow rate for the proposed configuration can be higher by 16% and 38% with respect to the corresponding values in the other two systems. In addition, it is observed that the maximum gross temperature lift in the proposed system is about 20–40% higher than those in the other systems.

1. Introduction

In today societies, the fossil fuels shortage and their adverse effects on global warming and atmospheric pollution are matters of considerable concerns. In addition, the problems regarding water resources revival and fresh water production intensify these concerns and force researchers to find some technologies for reducing fuel consumptions and environmental pollution [1,2]. In this regard, utilizing low temperature heat sources can be of great help. A major part of these sources however, is at such a low temperature that it needs to be upgraded for efficient usage [3]. Absorption heat transformers (AHTs) can be utilized for upgrading heat energies used for running low temperature cycles such as organic Rankine cycles [4], Kalina cycles [5,6], Ejector refrigeration cycles [7] and absorption refrigeration systems [8]. Industrial waste heat can also be upgraded to be used more effectively for running bottoming cycles [9,10]. The AHTs can also be used for the purpose of desalination [11]. Several configurations have been proposed and analyzed for heat transformers in the literature. Single-stage absorption heat transformers (SSHTs) achieve coefficients of performance (COP) of about 0.5 and a temperature lift of around 50 °C [12,13]. This COP value indicates that approximately half of the fuel energy is upgraded to a higher temperature. A higher gross temperature lift (GTL) is obtained by using double absorption heat transformers (DAHTs) which are more complicated than SSHT systems [14]. A GTL of around 80 °C can be achieved by DAHT systems with a COP value of about 0.36 [15]. For a GTL of higher than 80 °C, as needed for desalination processes, triple-effect absorption heat transformers (TAHTs) are appropriate.

The effects of different working solution on AHT systems' performance have been investigated. Ayou et al. [16] used a new working pairs composed of ionic liquids (1-ethyl-3-methylimidazolium tetrafluoroborate and 1-butyl-3-methylimidazolium tetrafluoroborate) as absorbent and 2,2,2-trifluoroethanol (TFE) as refrigerant. The results showed that the new working pairs are applicable candidates to replace the conventional working pairs ($LiBr/H_2O$) in order to avoid crystallization and corrosion. Kurem and Horuz [17] compared two different working pairs i.e., NH_3/H_2O and $LiBr/H_2O$ as working fluids in absorption heat transformers. They demonstrated that the $LiBr/H_2O$ system has a comparatively higher COP under all analyzed conditions while it has a slightly higher flow ratio.

Several research works have been carried out on absorption heat transformers integrated with water purification systems.

* Corresponding author.
E-mail address: s_mahmoudi@tabrizu.ac.ir (S.M.S. Mahmoudi).

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Nomenclature

A	heat transfer surface are (m^2)
AE	absorbing evaporator
AEA	absorbing evaporator assembly
AHT	absorption heat transformer
AHP	absorption heat pump
c	cost per exergy unit ($/GJ and $/kg)
$\dot{C}$	cost flow rate ($/hr)
Conf.	configuration
CRF	capital recovery factor
e	specific exergy (kW/kg)
DAHT	double absorption heat transformer
EES	engineering equation solver
$\dot{E}x$	exergy flow rate (kW)
f	thermoeconomic factor
GA	generator assembly
GTL	gross temperature lift
h	specific enthalpy (kJ/kg)
HX	heat exchanger
i	interest rate
$\dot{m}$	mass flow rate (kg/s)
M	molecular weight (kg/kmol)
N	system life (yr)
PEC	purchased-equipment cost
$\dot{Q}$	heat transfer rate (kW)
r	relative cost difference (%)
$\bar{R}$	gas constant (kJ/kmol K)
RP	refrigerant pump
s	specific entropy (kJ/kg K)
Sol	solution
SP	solution pump
SSHT	single-stage absorption heat transformer
T	temperature (K)
TAHT	triple effect absorption heat transformer
TCI	total capital investment
$\dot{W}$	work (kW)
X	concentration
Y	ratio of exergy destruction ratio (or loss)
$\dot{Z}$	investment cost of the system components ($/hr)

Greek letters

β	coefficient expressing accounts for the fixed operating and maintenance costs depends upon the total investment cost for a system component
γ	maintenance factor
ε	exergy efficiency (%)
τ	number of system operating hours (hr)

Superscripts

Ch	chemical
CI	capital investment
dis	dissolution
Ph	physical
OM	operation and maintenance

Subscripts

Abs	absorber
AE	absorbing evaporator
Con	condenser
D	exergy destruction
dw	distilled water
e	outlet
Eva	evaporator
F	fuel
Gen	generator
i	inlet
k	the *k*th component of the system
L	exergy losses
m	motor
o	environment
OPT	optimal
p	product
P	pump
R	reference
0	standard state

Parham et al. [18] investigated the performances of three main categories of AHT systems including single, double and triple absorption heat transformers coupled to water purification system. The results showed that the highest gross temperature lift can be obtained with the TAHT while this configuration possesses the lowest COP, among the other studied types. In another study, Parham et al. [19] coupled a single-stage absorption heat transformer with a desalination system. They showed that the modified considered system can produce distilled water with a mass flow rate of 0.2435 kg/s. Hamidi et al. [20] examined the effects of absorber, condenser, generator and feed water temperatures on the overall performance. The results showed that for an open-type absorption heat transformer integrated with the single-effect desalination system, the COP and rate of produced distilled water are constant with an increase in the absorber or waste feed water temperature. Gomri [21] proposed a combined system including solar flat plate collectors, absorption heat transformer and a desalination system. The proposed system produced about 500 l of drinking water per day in July time. In another study, Gomri [22] investigated the rate of produced distilled water by a single and a double absorption heat transformer integrated with water desalination system and showed that a higher distilled water mass flow rate is produced by the former. Liu et al. [23] evaluated the performance of a 100 kW steam generation system with a solar-assisted absorption heat transformer in China. They concluded that the solar irradiation is more effective than the ambient temperature on the system performance. Sekar and Saravanan [24] performed an experimental study on an absorption heat transformer coupled with a water desalination system of 5 kg/h distilled water capacity. They reported that the maximum flow rate of distilled water was 4.1 kg/h and that the COP was in the range of 0.3–0.38. Siqueiros and Romero [25] investigated another combined system including an absorption heat transformer and a water desalination system. They showed that the proposed system is capable of increasing the original value of COP by more than 120%, by recycling some part of the energy from a water purification system. Demesa et al. [26] presented some new configurations for the integration of an absorption heat transformer with a water desalination system for performance enhancement. The best result is obtained when the sensible heat is provided to the system between the condenser and evaporator. Donnellan et al. [13] presented six different configurations of triple absorption heat transformers and used heat exchange network modeling into determine the optimum number and locations of internal heat exchange units within the systems. Khamooshi et al. [27] improved the presented systems by Donnellan et al. [13] and integrated them into a water desalination system. The results showed that the COP and fresh water productivity of modified configurations of TAHTs are higher than those of