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Three-objective optimization of water desalination systems based on the double-stage absorption heat transformers

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HIGHLIGHTS

- Five configurations of double absorption heat transformers are analyzed.
- About 120 °C temperature lift is obtained for a low-temperature heat source.
- A second low efficiency of 0.451 is achieved for absorption heat transformer.
- A minimum value of 115.6 $/GJ is obtained for the upgraded exergy unit cost.

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ABSTRACT

A new type of double-stage absorption heat transformer integrated with water desalination system is proposed and compared with four other types of absorption heat transformers i.e. a conventional type of double-stage and three different types of double-effect absorption heat transformers from the viewpoint of exergoeconomics, using Engineering Equation Solver software. Considering product unit cost, exergy coefficient of performance and mass flow rate of distilled water as objective functions, a three-objective optimization is performed to specify the optimal design point for all studied systems. The temperatures of evaporator, condenser, absorber and absorbing evaporator (low-pressure absorber for double-stage absorption heat transformers) are considered as decision variables and the related Pareto Fronts are plotted for all the studied cycles. The results show that the maximum gross temperature lift in the proposed type of double-stage absorption heat transformers is about 18–27% higher than that in other considered systems. Therefore, its evaporator temperature can be risen by up to about 120 °C. It is also observed that, under optimized conditions, the exergy coefficient of performance however, is found to be the highest for the type in which there is no split for the absorber inlet an exit streams (type 3).

1. Introduction

In order to reduce the fossil fuels consumption and to reuse large amounts of industrial low-temperature waste heat, absorption heat transformers (AHT) which can upgrade low-temperature waste heat are utilized in many industries. The temperature lift for single-stage absorption heat transformers (SAHT) is in the range between 30 and 50 °C. Double-stage absorption heat transformers (DSAHT) which consist of two single stage AHT systems are used to lift the temperature more than the above-mentioned range. Double-effect absorption heat transformers (DEAHT) on the other hand, provide the possibility of the required temperature lift and being simple compared to DSAHT systems.

Numerous researches have been conducted on DEAHT system thermodynamically. Yin et al. [1,2] and Rivera et al. [3,4] presented the first type of DEAHT system shown in Fig. 1 (Type 1). Zhao et al. [5] studied the second type of DEAHT system thermodynamically and claimed that the second analyzed type of DEAHT is superior compared to the cycle presented by Yin et al. [1,2] and Rivera et al. [3,4] from the viewpoint of system stability, temperature lift and coefficient of performance (COP). The cycle investigated by Zhao et al. [5] is shown in Fig. 2 (Type 2). Finally, the third type of DEAHT system reported by Mostofizadeh and Kulick [6] shown in Fig. 3 (Type 3), which was more stable compared to the previous two analyzed DEAHT systems. Zhao et al. [7] compared the three above-mentioned systems from the viewpoint of energy and showed that the temperature lift and COP of type 3 is higher compared to other DEAHT systems. In addition to the three types of DEAHT systems, 2 cycles of double-stage absorption heat transformer shown in Figs. 4 and 5 are investigated in the present study. Ji and Ishida

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Nomenclature

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 ($/h)
CRF	capital recovery factor
e	specific exergy (kW/kg)
DAHT	double absorption heat transformer
DSAHT	double-stage absorption heat transformer
DEAHT	double-effect absorption heat transformer
$\dot{E}x$	exergy flow rate (kW)
f	thermoeconomic factor
GA	generator assembly
GTL	gross temperature lift
h	specific enthalpy (kJ/kg)
HRP	high-pressure refrigerant pump
HSP	high-pressure solution pump
i	interest rate
LRP	low-pressure refrigerant pump
LSP	low-pressure solution pump
$\dot{m}$	mass flow rate (kg/s)
M	molecular weight (kg/kmol)
N	system life (yr)
PEC	purchased-equipment cost
Q	heat transfer rate (kW)
r	relative cost deference (%)
$\bar{R}$	gas constant (kJ/kmol·K)
s	specific entropy (kJ/kg·K)
SP	solution pump
T	temperature (K)
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 ($/h)

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 (h)

Superscripts

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

Subscripts

Abs	absorber
Abs1	low-pressure absorber
Ch	chemical
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

[8] studied the basic type of DSAHT system (Fig. 4) from the viewpoint of energy and tried to improve its performance by modifying the generator and absorber. They showed that the modified cycle has higher COP compared to the basic cycle.

Absorption heat transformers also are vastly used in desalination of seawater and a number of studied have been carried out on the performance of AHT systems integrated with water desalination system. Parham et al. [9] coupled single-stage absorption heat transformers into desalination system. They showed that the modified considered systems can produce distilled water at a mass flow rate of 0.2435 kg/s. Gomri [10] investigated the rate of produced distilled water in single and double absorption system integrated with water desalination system and showed that single absorption can achieve higher rate of distilled water compared to double absorption heat transformers. Sekar and Seravanan [11] performed an experimental study on absorption heat transformer coupled into water desalination system with a water production capacity of 5 kg/h. They showed that the maximum flow rate of distilled water was 4.1 kg/h with a COP of 0.3 to 0.38.

In the present study, a new type of double-stage absorption heat transformer (DSAHT) coupled into water desalination system is proposed and compared with a conventional type of double-stage absorption heat transformer (DSAHT) and three different types of double-effect absorption heat transformers (DEAHT) from the viewpoints of thermodynamics and exergoeconomics. As mentioned before, researchers have tried to apply some modification in different aspect of double absorption heat transformers (including DEAHT and DSAHT systems) and improve the thermodynamic performance of them. These studies have focused on the thermodynamic performance of the double absorption heat transformers (DAHT) and to our knowledge, there is a lack of information on the selection of more efficient DAHT cycle, which has higher exergy efficiency and lower product (distilled water) unit cost. In addition, since there are several decision parameters affecting the DAHT systems performance, specification of the optimal design point with minimized product unit cost and maximized ECOP and distilled water flow rate seems necessary. The present work is an attempt to fulfill this lack of information about economic properties and the specification of optimal design points by providing a thorough comparison among the different configurations of double-effect and double-stage absorption heat transformers from the viewpoint of thermoeconomics and multi-objective optimization solution. In this regard, the effects on performance parameters are studied of such decision parameters as the temperature of condenser, evaporator, absorber and absorbing evaporator in DEAHT systems and low-pressure absorber in DSAHT for the considered cycles. Thereafter, the thermoeconomic parameters are investigated using the Engineering Equation Solver (EES) software. Finally a three-objective optimization in which the objective functions are product unit cost, ECOP and distilled water mass flow rate, is performed to specify the optimal design point for each studied systems using genetic algorithm.