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Comparative assessment of different categories of absorption heat transformers in water desalination process

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HIGHLIGHTS

- Three classes of absorption heat transformer - desalination systems were studied.
- First and second law thermodynamic analyses were investigated for proposed system.
- AHT systems performances were compared to each other comprehensively.
- Important system characteristics were summarized.

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ABSTRACT

During the last decade, there has been a significant amount of research conducted on absorption heat pumps (AHPs). Second type AHPs, namely absorption heat transformers (AHTs) are useful devices, capable of raising the temperature of waste heat to more useful temperature levels. The excluded heat from AHTs can provide the required energy for desalination. In the present work, performances of three main categories of AHT systems comprising single, double and triple absorption heat transformers (SAHT, DAHT, and TAHT) while they are coupled to water purification system are investigated and compared. A simulation model has been developed in EES (Engineering Equation Solver) to evaluate the effects of several key thermodynamic parameters on the performance of the cycle and amount of desalinated water. The results show that the highest gross temperature lift can be achieved with TAHT while it has the lowest COP among the other types of AHTs. Additionally, a performance optimization performed by using EES shows that SAHT, DAHT, and TAHT can provide fresh water for 853, 796 and 697 residential units respectively if they operate nonstop.

1. Introduction

Fresh water shortage has emerged as a major problem due to population growth and human activities. In various regions of world, sea water desalination is the unique solution of providing potable water [1,2]. Distillation procedure, based on evaporation and condensation processes is one of the most popular approaches for supplying pure water [3]. Detecting and providing thermal energy sources for desalination systems have become an imperative subject for researchers. This thermal energy source can be provided by solar heat [4], geothermal energy [5] or utilized heat of absorption heat transformer cycles [6] as well as other sources [7]. Absorption heat transformers can be applied to utilize the low-grade waste heat from e.g. industrial plants [8]. They are systems, capable of producing useful heat, superior to the one provided by the original source. The temperature level of the upgraded heat from AHTs depends on the number of stages. Single stage absorption heat transformer (SAHT) accesses coefficient of performance (COP) nearby to 0.5 and gross temperature lift (GTL) of 50 °C [9]. The GTL of 80 °C and COP adjacent to 0.35 is accessible by applying DAHTs [10]. For TAHT systems the quantity of GTL increases to 140 °C while possess COP of about 0.2 [11].

Horuz and Kurt [12] performed a study on performance evaluation of two arrangements of double stage absorption heat transformers. The results demonstrated better performance of parallel configuration over series set up. On their subsequent work, different arrangements

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Nomenclature

AHP	absorption heat pump
AHT	absorption heat transformer
COP	coefficient of Performance
D	total amount of distilled water produced (kg/s)
DAHT	double absorption heat transformer
DAHP	Double absorption heat pump
ECOP	exergetic coefficient of performance
f	flow ratio
GTL	difference in temperature between the absorber and the generator (°C)
GTL1	difference in temperature between first absorber and the generator (°C)
GTL2	difference in temperature between second absorber and the generator (°C)
h	enthalpy (kJ/kg)
HEX	heat exchanger (%)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
PR	performance ratio
Q	heat Capacity (kw)
r	vaporization latent heat of water (kJ/kg)
RP	Refrigerant pump
SAHP	single absorption heat pump
SAHT	single absorption heat transformer
SOAHT	single open absorption heat transformer
SP	Solution pump
TAHT	triple absorption heat transformer
X	concentration

Greek Letters

ε	economizer effectiveness

Subscript

AB/EV1	first absorber-evaporator
AB/EV2	Second absorber evaporator
abs	absorber
con	condenser
ECO	economizer
eva	evaporator
gen	generator
o	ambient temperature
s	strong
u	utilized heat
w	weak

of SAHTs employing $LiBr/H_2O$ as the working pair were compared to each other [8]. They showed that by applying alternative configurations of SAHTs, an enhancement of 14.1% in COP was accessible in comparison to that of basic SAHT. The same configurations of [8] were coupled into desalination system by Parham et al. [13]. They reported that the modified configuration of single stage absorption heat transformers was capable of producing distilled water at a rate of 0.2435 kg/s, which was enough for 2100 residential units. Khamooshi et al. [14] conducted a similar research and coupled six different set ups of TAHTs into water purification system. Later they analyzed and optimized the performance of a triple absorption heat transformer operating with $LiBr/H_2O$ as the working pair, in more detail [15]. They proved that the third heat exchanger within basic TAHT had considerable influence on the performance of the cycle in comparison to those of other heat exchangers. Gomri studied the SAHT and DAHT systems where a desalination system was coupled to it [6]. They found out that first and second law efficiencies of DAHT are higher than that of the SAHT. On the contrary, the water productivity of SAHT is higher than that of DAHT integrated into seawater purification process. Huicochea et al. [16] investigated the performance of a cogeneration cycle consisting of a SAHT integrated to a proton-exchange membrane fuel cell (PEMFC)·They proved the feasibility of the cogeneration cycle while a COP of 0.256 was obtained. An experimental study was conducted by Sekar and Seravanan [17] where a desalination system by the capacity of 5 kg/h was coupled to an AHT. Their study concerned with the dependency of performance of the system on working conditions in terms of heat source temperature and T_{con}. First and second law analysis of DAHT utilizing $LiBr/H_2O$ as the working fluid was proposed by Martinez and Rivera [10]. The results demonstrated that the system could operate with the gross temperature lift of 74 °C. Additionally, they showed that the economizer effectiveness should stand as high as possible.

Different arrangements of TAHTs with various numbers of heat exchangers using water and lithium bromide as working fluid, were proposed and studied by Donnellan et al. [11]. They revealed that the COP can be increased the by 16.4%. Thermodynamic characteristics of the working pairs play an important role on the performance of the refrigeration cycles [18]. A review study work was accomplished by Khamooshi et al. [19] for the ionic liquids carrying the role of the working fluids. The same group published their second review paper wherein; AHTs, from the view point of applications, crystallization risk, working fluids, performance evaluation and economic aspects were considered comprehensively [20].

Table 1 provides a summary of the important characteristics of different types of AHTs coupled into desalination systems available in the literature.

According to the authors' knowledge, a widespread comparison among the three main categories, namely single, double and triple stage of AHTs has never been made. At the first section of the current study a brief description of DAHT and TAHT is presented. The present work aims to investigate and compare performance of three main categories of AHT systems comprising single, double and triple AHTs while coupled into water purification system.

A thorough and inclusive thermodynamic analysis is carried out in order to determine the effects of parameters such as, AHT heat source temperature, absorber, generator, condenser and evaporator temperatures, gross temperature lift, performance ratio and economizer effectiveness on the performances of different set ups and amount of desalinated water. Additionally, selecting best operational conditions based on sensitivity analysis is performed by using the EES software [48].

2. Single, double and triple absorption heat transformers integrated into water desalination systems

On AHT systems, heat from the heat source is fed to evaporator and generator simultaneously. The excluded heat from the absorber provides the required energy for desalination. The operating system of the single absorption heat transformer is explained as follows (Fig. **1**):

The weak solution of $LiBr/H_2O$ from absorber is internally cooled against the rich solution from the generator before it is partially evaporated via throttling in an expansion valve (between 6 and 7 in fig.1). Further evaporation of the water content takes place in the generator, utilizing the heat from the waste heat source. The steam from the generator is condensed and pumped to the operating pressure of the evaporator, where the waste heat is further utilized to generate saturated steam, which is fed to the absorber. The rich solution from the generator is pumped, preheated and injected to the absorber, where it reacts with the saturated steam, releasing heat at elevated temperature of 100–140 °C, which can be employed in desalination system. By taking advantage of this upgraded heat, the impure water is partially evaporated, entering to the separator wherein the liquid phase is separated from the vapor phase. To recover part of the available heat in the liquid phase, it is mixed with the impure water going to the absorber. The extracted