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Alternative absorption heat transformer configurations integrated with water desalination system

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HIGHLIGHTS

- Alternative configurations of absorption heat transformer are integrated in desalination system and analyzed in detail.
- Crystallization risk is considered.
- Regarding the quantity of distilled water rate, an optimization is performed.

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ABSTRACT

Alternative configurations of absorption heat transformer (AHT) systems using LiBr/H_2O as the working fluid and integrated with a water purification system are analyzed and optimized thermodynamically. The waste heat from a textile factory is utilized to run the AHT systems and the generated high temperature heat is employed for the purpose of desalination. A computer program is developed in EES (Engineering Equation Solver) to investigate the effects of different parameters on four different configurations of AHT and the desalination system. It is shown that applying different modifications can increase the coefficient of performance (COP) of the AHT and consequently the productivity of the desalination system. The maximum rate of distilled pure water reaches 0.2435 kg/s when waste heat from the condenser is utilized by the evaporator. Finally, the risk of crystallization of LiBr is lowered in the modified configurations.

1. Introduction

Water and energy are two inseparable items that govern our lives and promote civilization. In order to produce potable water from the sea or brackish water several desalination techniques are employed [1]. The most developed and widely practiced desalination method is the distillation process. The distillation of sea or brackish water can be achieved by utilizing a thermal energy source [2]. Large amounts of low-temperature waste heat are released daily from many industrial plants to the atmosphere at temperatures between 60 and 100 °C [3]. Absorption heat transformers (AHTs) can be exploited to utilize this low–grade heat and improve energy efficiency of the plants. The absorption heat transformer (AHT) systems work in a cycle opposite to those of absorption heat pumps (AHPs) in order to increase these low or moderately warm heat sources to more useful levels. A heat transformer is a device, which can deliver heat at a higher temperature than the temperature of the fluid by which it is fed. Absorption heat transformer systems are attractive for using waste heat from industrial processes and renewable energy sources such as solar and geothermal. In addition, they are interesting systems to upgrade low temperature waste heat to be used in a secondary process.

The AHT system mainly consists of a generator, an absorber, a condenser, an evaporator; two pumps, an expansion valve and a heat exchanger (see Fig. 1). In this system heat is transferred to the working fluid (LiBr/H_2O) in the evaporator and the generator from the hot waste water of an industrial application. The system rejects heat from its absorber and condenser. The rejected heat in the absorber is utilized to provide the required energy in the desalination system. The sequence of processes in the LiBr/H_2O absorption heat transformer (AHT) is as follows: the weak LiBr/H_2O solution (with lower concentration of LiBr) from the absorber goes to the generator via the ECO (solution heat exchanger) and the expansion valve respectively. Superheated water vapor comes out of the generator and then enters the condenser where it is condensed to the saturated liquid. Water pressure is then raised to that of the evaporator by the pump. In the evaporator the water is heated by the waste heat to the saturated vapor. This vapor is then absorbed in the absorber by the strong LiBR/H_2O solution coming back from the generator (state 10). The heat of absorption released in

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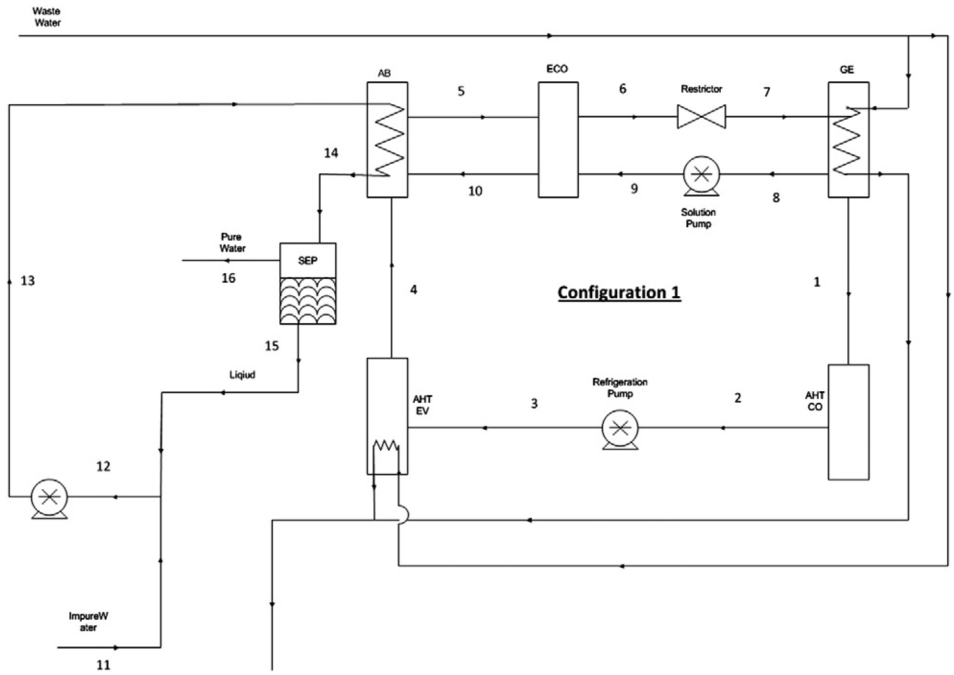

Fig. 1. Schematic diagram of seawater desalination system integrated to a single effect absorption heat transformer (Configuration 1).

the absorber is at a temperature of about 100–140 °C. This upgraded energy now can be used in the water purification system as Fig. 1 suggests.

The water purification system receives its required thermal energy from the absorber of the AHT system. The impure water is heated in the absorber where it is partially evaporated. The two phase flow enters to the separator vessel where it is separated into liquid and vapor. The liquid water mixes with the entering impure water before returning to the suction pump.

These systems have been paid more attention in the last decade and a considerable number of theoretical and experimental works on the engineering aspects of AHTs have been published in the literature [3–10]. Recently, researchers studied the integration of thermal seawater desalination systems with AHT. Using AHT, Bourouis et al. [11] studied the purification of seawater with low temperature heat sources by numerical simulation. They paid more attention on the COP variation of the AHT as the generator and condenser temperatures change. By recycling energy, with and without increasing heat source temperatures, Siqueiros and Romero [12] and Romero et al. [13] reported some improvement in the COP of AHT systems used for water purification.

In another work Romero and Rodriguez-Martinez [14] evaluated the optimal operating condition for different processes which delivers low grade waste heat and requires water purification. A predictive model for an absorption heat transformer integrated in a water purification process, using an artificial neural network, is proposed by Hernandez et al. [15,16]. Gomri [17] studied a solar desalination system at which a single effect heat transformer is used. The system could provide a beach house with drinking water of 500 L per day in July. In another work, Gomri [18] compared the performances of single effect and double effect absorption heat transformer systems when used for seawater desalination and reported that the latter is preferred from the viewpoint of thermodynamics. Rivera et al. [19,20] analyzed the performance of a heat transformer used for water purification, theoretically and experimentally. They showed that the highest irreversibility occurs in the absorber and the condenser while the pump contributes the least irreversibility in the system. In an experimental study, Sekar and Saravanan [21] coupled an AHT with a seawater distillation system of 5 kg/h distilled water capacity. The influence of some operating parameters such as the heat source, condenser, evaporation temperatures, gross temperature lift and feed water flow rate on the COP, absorber heat load and distillate flow rate has been investigated. The feasibilities of utilizing waste heat from a Gas Turbine-Modular Helium Reactor (GT-MHR) and a nuclear power plant were also studied by Zare et al. [22] and Yari [23] respectively.

Recently Horuz and Kurt [3] introduced four different configurations of absorption heat transformers and developed a computer code to study the effects of condenser, evaporator and generator temperatures on COP and absorber heat capacity of single-stage AHT systems.

In the first case, in a basic AHT, the waste hot water is supplied to the generator and the evaporator at the same time. The second system used has such a configuration that the waste hot water initially is directed to the evaporator and then to the generator. In the third system, in addition to the waste hot water configuration in the second system, an absorber heat exchanger is included instead of the solution heat exchanger. Finally, the last system incorporates the second and the third system with the addition of a refrigerant heat exchanger at the evaporator inlet. However, the study did not investigate the effect of parameters such as the flow ratio, weak and strong solution concentrations, heat source and gross temperature quantities. Moreover, it would be interesting to conduct the simulations for more conditions.

The present work aims to redress this shortage and continues Horuz's work in a more detailed study via a methodical comparative investigation. The objective of the present work is to examine in detail the performance of alternative AHT configurations coupled with desalination systems. A thorough and comprehensive thermodynamics analysis and efficiency assessment of the proposed configurations will be performed. In order to identify the effects of some parameters such as; AHT heat source temperature, absorber, generator and evaporator temperatures, flow ratio, concentration of weak and strong solutions on the cycle performance and the quantity of distilled water, a parametric study is carried out and validated with the experimental data. Furthermore the whole cycle is optimized thermodynamically using the Engineering Equation Solver (EES) software [24].

2. Alternative configurations of AHTs integrated with seawater desalination systems

Fig. 2 displays three alternative designs of AHTs integrated with seawater desalinations systems which were described in detail earlier and in [3].