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Research Paper

Irreversibility analysis of the absorption heat transformer coupled to a single effect evaporation process

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HIGHLIGHTS

- Heat transformer coupled to seawater distillation system was studied.
- Second law thermodynamic analysis was made for the proposed system.
- It is advisable to supply the sensible heat to the liquid refrigerant.
- The generator and absorber irreversibility for all configurations were the highest.

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ABSTRACT

An absorption heat transformer integrated to a desalination system based on a thermal distillation process is simulated from the point of view of the first and second laws of the thermodynamics. Three possible configurations were proposed in the literature in order to transfer the sensitive and latent heats from the desalination process to the absorption heat transformer to improve the coefficient of performance. The performance of the systems was analyzed as a function of the evaporator, generator, condenser temperatures and the main heat exchanger effectiveness, as well as the salinity of seawater. From the exergy analysis, it was clear that the highest irreversibility was obtained in the generator and absorber for all the configurations evaluated in this work. It was found that the lowest values of total irreversibility were estimated for the configuration 1 where sensitive heat was transferred from the distillation process to the strong-working solution, which goes to the absorber.

1. Introduction

In the literature, absorption heat transformer (AHT) has been enhanced from the theoretical and experimental point of view. On the issue of water purification, Siqueiros and Romero [1] theoretically evaluated the integration of a water purification system in an AHT, where a fraction of heat obtained by the AHT can be recycled for the generator and evaporator, causing the increase of the heat source temperature. Huicochea and Siqueiros [2] reported the experimental results of a portable water purification system coupled to the AHT. The maximum distilled water was of 684 mL h^{-1} with an absorber heat load of 0.524 kW and the maximum coefficient of operation (COP) was of 0.336 considering the recycled heat configuration. Rivera et al. [3] presented a theoretical thermodynamics analysis using the first and second laws for the AHT-water purification system. The influence of irreversibility was discussed in every component with respect to the deterioration of the COP. The absorber was found as the component that produces more than 30% of the irreversibility of the entire cycle. The maximum absorber temperature and Gross Temperature Lift (GTL) were of 135 °C and 44 °C respectively. By using experimental exergy analysis, Rivera et al. [4] identified the absorber and the condenser as the main components with the highest irreversibility. And after this, some modifications were made in the experimental equipment in order to increase the exergetic coefficient of performance.

On the other hand, absorption cycles have been successfully coupled with renewable and desalination systems. Ratlamwala et al. [5] developed a computational model for a solar desalination based on a quadruple effect absorption system, which used ammonia-water as a working fluid in order to provide freshwater and cooling.

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Energetic and exergetic utilization factors were used to evaluate the effect of solar radiation and salinity of seawater, assuming the conditions of Abu Dhabi. Gomry [6] carried out a thermodynamic analysis using the first and second laws for a seawater desalination system integrated to a solar heat transformer, where the exergy analysis showed the irreversibility of the main component and the exergy efficiency, assuming a reference environmental state as water at 23 °C and atmospheric pressure. According to Gomry [6], the absorber and generator presented similar values of exergy destruction. For the first, the greatest exergy destruction was found with an absorber temperature at 103 °C. Sekar and Saravanan [7] presented an experimental evaluation about an AHT using the water-lithium bromide working solution. The maximum distillate flow rate was of 4.1 kg/h with a COP up to 0.38. The experimental equipment was activated with heat source temperature of roughly 70 °C and a constant heat in the generator of 5 kW, keeping the condenser temperature at 20 °C and 25 °C. The GTL was up to 15 °C and water satisfied the quality of the Bureau of Indian Standards. Parham et al. [8] proposed an energy analysis for alternative configurations of AHT integrated with seawater desalination systems. The thermodynamic model was used to find the optimum quantity of produced distilled water as a function of all components. Khamooshi et al. [9] introduced a theoretical thermodynamic model to evaluate six different configurations of a triple AHT with the water-lithium bromide solution working. The exergetic efficiency, COP and distilled water were calculated in order to compare all configurations by means of the COP. The irreversibility of the all systems was not estimated. Salata and Coppi [10] presented the energetic perspective to reach the process temperature over 100 ºC, through the usage of solar ponds and an AHT for producing desalinated water. This work demonstrated that the whole system needs areas ranging from 1000 to 4000 m^2 in the solar ponds per 1 m^3 of desalinated water produced every day. Demesa et al. [11] developed only one thermodynamic analysis by applying the first law of the thermodynamics for an AHT coupled to a seawater distillation system considering three new configurations, where the sensitive heat from the distillation process was applied in the liquid refrigerant, steam and the strong working-solution inside the AHT. This energy analysis demonstrated that the best scenario was applying the sensitive heat in the first scenario to find the maximum COP, and the configuration where the sensitive heat was used to preheat the strong-working solution before arriving to the absorber, produced the maximum distilled water up to $4.99e^{-4}$ kg/s. However, an exergetic study has not been carried out up to now.

The aim of this research was to determine the exergy destruction in every component under all the configurations, considering the whole system by means of the first and second laws of the thermodynamics. The development of this analysis will be considered to carry out the following stage for the project, which consists of building the experimental equipment. Coefficients of performance, irreversibility and the exergetic efficiency are analyzed as a function of the outlet temperatures in the main system and the main heat exchanger effectiveness. The water-lithium bromide mixture was used as the working solution in the AHT cycle, while the atmospheric pressure conditions are used in the distillation cycle.

2. System description

A single stage AHT of 2 kW and a water distillation system using single effect evaporation are used for this thermodynamic analysis.

2.1. Absorption heat transformer

Figure 1 illustrates the schematic diagram of temperature against pressure of a basic AHT, which is built by means of four main heat exchangers: a generator, evaporator, condenser and an absorber. An absorbent and a refrigerant are used as a working solution in the whole system. The absorbent goes through the generator and the absorber as liquid phase, while the refrigerant goes through all components as liquid or steam phases.

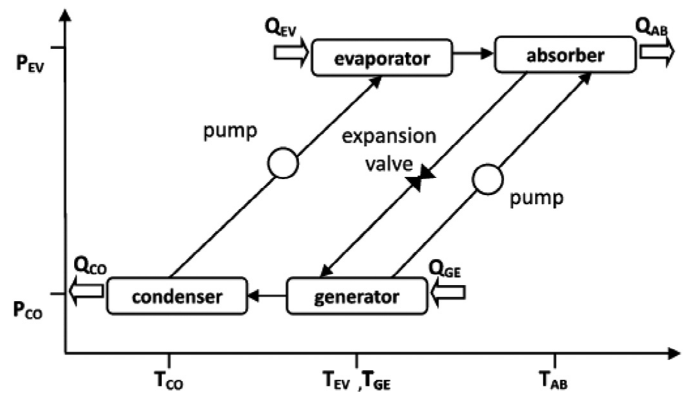

Fig. 1. Schematic diagram of a basic AHT.

External heat is supplied at medium temperature to the generator and evaporator (T_{GE}, T_{EV}). A partial separation of the refrigerant from the working solution takes place when the saturation conditions are reached in the generator. Using external heat extraction at a lower temperature (T_{CO}), the refrigerant temperature is diminished in the condenser and the refrigerant changes to liquid phase. In the evaporator (with an absolute pressure higher than that of the generator and the condenser), the refrigerant is then evaporated and goes into the absorber where it is mixed with the strong solution that comes from the generator. In this process, heat liberation occurs at a high temperature (T_{AB}) and a weak LiBr–water solution is obtained. The weak solution goes back into the generator, while the strong LiBr–water solution goes into the absorber in order to repeat the thermodynamic cycle.

2.2. Water Desalination System (WDS)

A single effect evaporation process is used in WDS, which is integrated by a phase-vessel (VEP), an auxiliary condenser (COA), a pump, a main heat exchanger (MHE) and piping, as indicated in Fig. 2. The seawater inside the phase-vessel is pumped to the absorber in order to seek the saturation conditions. When this happens, the liquid is partially evaporated and comes back to the phase-vessel as a mixture of steam and liquid. The liquid phase is given the sensitive heat to the AHT by means of the main heat exchanger, while the vaporization heat goes to the auxiliary heat exchanger to preheat the seawater before entering the absorber and thus obtaining the distilled water.

The sensitive heat of the water purification system can be recovered inside the AHT because of its high thermal level. There are at least three locations where to recover the heat and thus improve the performance of the AHT. The heat recuperation level is directly in function of the heat exchanger effectiveness, which is well known as the ratio of the heat flux transferred and the maximum possible heat flux.

2.2.1. Configuration 1

An option is to recover the heat by using the strong-working solution piping, which goes to the absorber as shown in Fig. 3a. The exothermic reaction inside the absorber improves when this working solution has a higher specific heat.