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Analysis of the behavior of an experimental absorption heat transformer for water purification for different mass flux rates in the generator

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HIGHLIGHTS

► Exergetic performance of an absorption heat transformer for purifying water to different mass flux rates in the generator.
► The irreversibilities are increasing when the mass flow rate in the generator is major.
► The mass flow rates in the generator plays a decisive role in the whole system efficiency.

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ABSTRACT

In the present study, first and second laws of thermodynamics have been used to analyse the performance of an experimental absorption heat transformer for water purification. Irreversibilities, coefficients of performance (COP) and exergy coefficients of performance (ECOP) were determined as function of the mass flow of hot water supplied to the generator and as function of the overall thermal specific energy consumption (OSTEC) parameter defined in this paper. The results showed that the system irreversibilities increase meanwhile the coefficients of performance and the exergy coefficient of performance decrease with an increment of the mass flow of hot water supplied to the generator. Also it was shown that the system performance is better when the production of purified water increases due to the increment of the heat recycled to the generator and evaporator.

1. Introduction

Nowadays, many countries are investing considerable amounts of money in the development of equipment that facilitates the recovery and efficient use of energy. Some of the most interesting devices for energy savings, which consume negligible amount of primary energy, are absorption heat transformers. Absorption heat transformers are some of the most promising devices for upgrading industrial waste heat to higher temperature levels to be recycled in industrial applications.

Absorption heat transformers have been studied theoretically and experimentally with different water/lithium, water/carrol™, TFE-E181, *n*-heptane–DMF solutions [1–4], applying the first and second law of thermodynamics under specific operating conditions. Rivera and Cerezo [5] published an experimental study of the use of additives in the performance of a single-stage absorption heat transformer operating with water/lithium bromide, demonstrating that the coefficients of performance with additives are higher up to 40% than without additive. Zhao et al. [6] theoretically studied the performance of a double-absorption heat transformer using TFE-E181 as working fluids. The results showed that the new solution cycle has not only wider operating range of absorber temperatures but also a higher coefficient of performance than those obtained with the water/lithium bromide mixture. Sozen [7] studied the irreversibilities in a single-stage heat transformer used to increase a solar pond's temperature. The results showed that the absorber and the generator need to be improved thermally in order to increase the system efficiency. Wu and Chen [8] analyzed the thermo-economic and thermodynamic optimum performance of an absorption heat transformer affected by multi-irreversibilities. The results indicate that the maximum dimensionless thermo-economic objective-function, coefficient of performance and specific heat pumping load decrease as the internal irreversibility increases. Fartaj [9] compared the energy, exergy and entropy

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balance methods for the analysis of a double- stage absorption heat transformer cycle. The results obtained show the influence of irreversibilities of individual components on deterioration of the effectiveness and the coefficient of performance of the system. Sozen and Arcacklioglu [10] proposed the artificial neural networks technique to determine the exergy losses for each one of the main components of an ejector- absorption heat transformer. The results showed good accuracy between the training data and the output results. Martínez and Rivera [11] analyzed the theoretical performance of a double-absorption heat transformer reporting values of the exergy coefficients of performance and the irreversibilities for the complete system and the main components. Several strategies have been reported to improve the performance by using inverse neural network [12,13].

On the other hand, theoretical and experimental studies on heat transformers have been reported by several applications. Ma et al. [14] reported the first industrial scale heat transformer by recovering waste heat from a synthetic rubber plant which was used to heat water from 95 to 110 °C with heat flow of 5000 kW, obtaining a mean coefficient of performance (COP) of 0.470. Huicochea et al. [15] reported for the first time results about the feasibility to obtain purified water by using a heat transformer. The maximum COP and gross temperature lift (GTL) were of 0.230 and 25.9 °C respectively.

Siqueiros and Romero [16,17] demonstrated through thermodynamic models, that one way to increase the performance of a heat transformer is by the integration of a water purification system. The water purification system makes it possible to recycle a certain quantity of heat into the heat source (generator and evaporator, simultaneously). The new configuration makes it possible to reach theoretical COP increases of up to 121% for some specific conditions. Horuz and Kurt [18] demonstrated that about 50% of the waste heat can be utilized to obtain hot water and vapor by using single-stage and double-adsorption systems. By applying different modifications, the COP can be increased by 14.1%, the absorber heat transfer by 158.5% and the hot process water produced by 3.59% compared to the basic absorption heat transformer system.

Sekar and Saravanan [4] tested an absorption heat transformer coupled with a seawater distillation system of 5 kg/h distilled water capacity. The maximum heat delivery temperatures were up to 100 °C, while temperature lifts up to 20 °C. For this system, the COP of 0.300–0.380 was obtained with the maximum distillate flow rate of 4.1 kg/h and a recovery ratio of 0.170–0.230.

In the present study, an experimental evaluation of an absorption heat transformer coupled to a water purification system was done, considering three mass flows of hot water supplied to the generator, while the other mass flows supplied to the other components were maintained constant. This analysis was done with 14 experimental tests giving continuity to the work reported by Rivera et al. [19], where the authors demonstrated a way to enhance the system performance applying changes in the absorber and evaporator temperatures, of independent way.

2. Description of the system

2.1. Absorption heat transformer cycle

Fig. 1 shows a schematic diagram of an absorption heat transformer by using the temperature against pressure levels. An absorption heat transformer consists of an evaporator, a condenser, a generator, an absorber and an economizer. A quantity of waste heat Q_{GE} is added at a medium temperature T_{GE} (between 81.5 °C and 92.2 °C) to the generator to vaporise part of the working fluid from the weak salt solution containing a low concentration of absorbent. The vaporised working fluid flows to the condenser

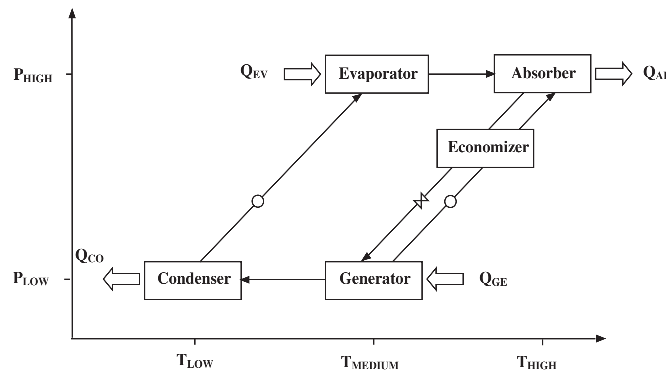

Fig. 1. Schematic diagram of an absorption heat transformer.

delivering an amount of heat Q_{CO} at a reduced temperature T_{CO} (between 23.1 °C and 28.5 °C). The liquid leaving the condenser is pumped to the evaporator in the higher pressure zone. The working fluid is then evaporated by using a quantity of waste heat Q_{EV} which is added to the evaporator at an intermediate temperature T_{EV} (between 77.3 °C and 84.3 °C). Next, the vaporised working fluid flows to the absorber where it is absorbed in a strong salt solution containing a high concentration of absorbent from the generator delivering heat Q_{AB} at a high temperature T_{AB} (between 96.0 °C and 100.8 °C). Finally, the weak salt solution returns to the generator to preheat the strong salt solution in the economizer before repeating the cycle again. The system operates at two pressure levels: the high pressure level and the low pressure level. The evaporator, the economizer and the absorber operate at the high pressure level in a range from 190.4 mmHg to 269.9 mmHg, meanwhile the generator and the condenser operate at the lower pressure level between 59.5 mmHg and 80.7 mmHg.

2.2. The water purification system with the absorption heat transformer

A schematic diagram of a water purification system integrated to an absorption heat transformer is shown in Fig. 2. The water purification system removes the useful heat obtained in the absorber of the absorption heat transformer. Under specific

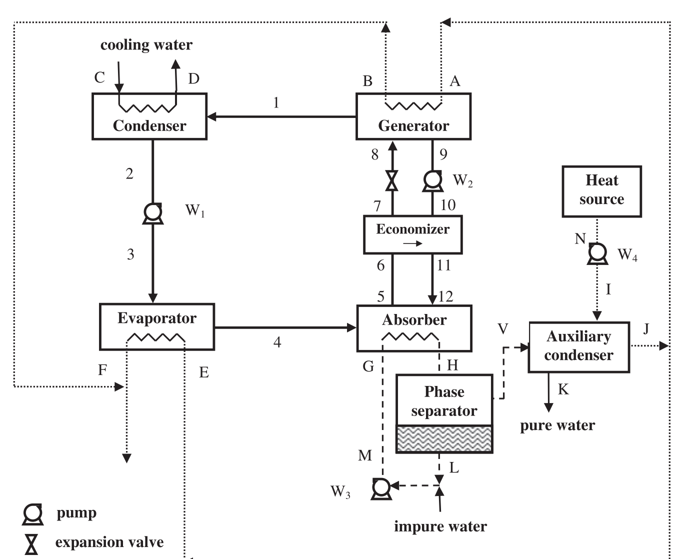

Fig. 2. Schematic diagram of an absorption heat transformer used for water purification.