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Experimental study of an absorption heat transformer with heat recycling to the generator

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ABSTRACT

An experimental study of an absorption heat transformer-water purification system with a single effect evaporation was carried out. The distillation process is able to recover heat for the generator; therefore, the initial operating conditions change to improve the performance of the absorption equipment. The working solution was LiBr–H_2O in a concentration range from 54.9% to 55.8%. On the other hand, an absorber of graphite disks was used to diminish the leaks caused by the working solution corrosion. The best performance of the absorber happened for a mass flux of a working solution of 0.014 kg/s, obtaining a heat transfer up to 635 W. The coefficient of performance was improved because the absorption process was done with a higher mass flux of refrigerant, strong working solution, and temperature, obtaining more useful heat. The maximum heat recovered from the distillation process was of 541 W with a flow of distilled water of 888 mL/h and coefficient of performance of 0.391, searching a useful heat of 1157 W, a strong working solution concentration of 55.5% and a temperature increment of 0.92 °C.

1. Introduction

The accelerated growth of the global population has increased the demand of fresh water for domestic and industrial usage. Desalination of groundwater and seawater is a promising solution to the problem of global water shortage. It is widely known that 98% of earth's water is in the oceans, which represents an inexhaustible reservoir of water according to Ramilo et al. [1]. Currently, several technologies are used to desalinate sea and brackish water. These technologies are basically divided into two general categories: thermal and membrane processes. Systems based on the distillation process are designed to purify water with elevated concentration levels of dissolved and suspended solids. In the Middle East, water is obtained from the distillation of sea water by multistage flash distillation, which has proved to be one of the best options. There are also other systems that use this principle of simple distillation, such as: solar distiller, multiple effect distillation boiling, vapor compression system, and absorption heat pumps [2,3]. Low quality residual energy as a result of its low temperature of many industrial processes is difficult to recover and to utilize again in another process. The absorption heat transformers (AHT) are a technology that allow to save energy and money saving in different industrial sectors. They can provide thermal energy for certain processes starting from residual energy, operating with waste heat to medium temperature and getting a quantity of useful heat at a higher temperature to be used in another process with a negligible amount of primary energy.

There are studies of AHT for different applications. Ma et al. [4] reported the test results of the first industrial scale heat transformer with lithium bromide–water by recovering waste heat from a synthetic rubber plant. The recovered heat was used to heat the water from 95 to 110 °C with a heat flow of 5000 kW, obtaining a coefficient of performance (COP) of 0.470 with 25 °C of gross temperature lift (GTL). Aphornratana and Sriveerakul [5] described an experimental research of a single effect absorption using aqueous lithium–bromide as a working fluid. A 2 kW cooling capacity experimental refrigerator was tested with various operating temperatures. It was found that the solution circulation ratio (SCR) has a strong effect on the system performance. The measured SCR was 2–5 times higher than the theoretical prediction because of the low heat transfer in the absorber. Huicochea et al. [6] presented the experimental results of the integration of a portable water purification system and an AHT, where the low quality waste heat is simulated, and water–lithium bromide was used as the working solution. The system worked well with waste heat temperatures in the range of 68–78 °C. The maximum COP, GTL and the distillate flow rate were of 0.23, 25.9 °C and 418 mL/h

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Nomenclature

COP	coefficient of performance, dimensionless
Cp	heat capacity, kJ/kg °C
G	volumetric flow, mL/h
h	specific enthalpy, kJ/kg
m	mass flow rate, kg/s
P	pressure, kPa
Q	heat flow, W
T	temperature, °C
X	solution concentration, % weight

Subscripts

AB	absorber
ACO	auxiliary condenser
CO	condenser
DE	distilled water
E	external
EV	evaporator
GE	generator
I	internal
IN	input
RE	recycled
OUT	output
S	sensible
SC	concentrated solution
V	vaporization

Greek symbol

η	fraction of transferred heat (dimensionless)

respectively. Costa et al. [7] reported a preliminary feasibility study of the implementation of three absorption heat pump configurations in a Kraft pulping process: (i) integration of a double lift heat transformer into the heat recovery circuit of the wood chips digesters to produce low pressure steam, (ii) a double effect chiller installed in the bleaching chemicals making plant to chill cooling water and to produce middle pressure steam and, (iii) a heat pump installed on the steam extraction line of a turbine which, combined with the addition of a condensing unit, increases substantially the power output. The net present value is, in all cases, positive, which indicates that the equipment is viable using the assumed cost and efficiency data in this study. Absorption heat pumps are increasingly attractive options for energy upgrading and conversion in a context of increasing energy costs. Sekar and Saravanan [8] carried out an experimental research on an AHT coupled with a seawater distillation system. The results of the operation of the equipment shows a maximum COP of 0.38, a GTL up to 20 °C and a maximum distillated water of 4.1 kg/h.

There are several reports regarding theoretical and experimental studies on AHT to increase performance. Sozen and Serdar [9] presented a mathematical model to simulate the performance of an AHT operating the water–ammonia and using a special ejector located at the absorber inlet. This ejector presented two main functions: helps pressure recovery from evaporator and upgrades the mixing and pre absorption process improving the enthalpy and exergy performance coefficient up to 14% and 30% respectively. Hernández et al. [10] proposed a predictive model for a water purification process integrated with an AHT with and without energy recycling, using an artificial neural network to obtain on-line predictions of the COP. This model takes into account the input and output temperatures of each one of the four components (absorber, generator, evaporator, and condenser), as well as two pressure parameters of the heat transformer and concentrations of the working solution. Escobar et al. [11,12] proposed thermodynamic models with algorithms by bash (information acquisition) and Octave (information training) to obtain direct and indirect COP estimations about an AHT, in order to optimize and to know the system operation situation in each set measured by using the output temperatures for each one of the four components. The result allows to reduce production and investments costs. Siqueiros and Romero [13] proposed a system to increase the COP of an AHT used in a water purification system. This was done by recycling the steam latent heat from the purification process to increase the original heat source temperature (generator and evaporator simultaneously). The new configuration allows to reach a theoretical coefficient of performance up to 121%. Huicochea and Siqueiros [14] worked to improve the efficiency of energy usage of an AHT by recycling a fraction of the absorber's useful heat to only one of the components of the heat source (either in the generator or in the evaporator). The best COP was searched when the heat of the water purification system was applied to the generator, obtaining a COP increment of 110.3%. Rivera et al. [15] theoretically analyzed the performance of an experimental AHT for water purification by using the first and second law of thermodynamics. The absorber and the auxiliary condenser were the components with the highest irreversibilities, representing a 35% and 25% respectively of total irreversibilities. The bibliographic review done shows that there is no experimental work applying the latent heat of a water purification to the generator of an AHT in order to improve the performance. It is very important to mention that this work is a continuation of a reported paper on the improved efficiency of energy use of an AHT using a water purification system. This work compared theoretically the performance when the latent heat of purification system is applied in three different scenarios: generator, evaporator or both [14]. In the present study, the experimental results of a water purification system coupled to an AHT to recycle only heat in the generator are showed.

2. Description of the systems

2.1. Cycle of the absorption heat transformer

Fig. 1 shows a schematic diagram of an absorption heat transformer in a plot of pressure against temperature. A quantity of waste heat (Q_{GE}) is added at an intermediate temperature (T_{GE}) to the generator for vaporizing a part of the refrigerant fluid from the working solution. The vaporized refrigerant fluid flows to the condenser delivering an amount of heat (Q_{CO}) at a low temperature (T_{CO}). The liquid leaving the condenser is pumped to the evaporator to the higher pressure zone. The refrigerant 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}). Then, the vaporized refrigerant fluid flows to the absorber where it is absorbed into a strong working solution coming from the generator, to obtain heat in the absorber (Q_{AB}) to a high temperature (T_{AB}). Finally, the weak working solution returns to the generator for preheating the strong working solution to pass through the economizer before repeating the cycle again.

2.2. Water purification system with an absorption heat transformer

The coupling between the water purification system and the AHT has many advantages: uses waste heat, recycles a part of heat