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Experimental assessment of an absorption heat transformer prototype at different temperature levels into generator and into evaporator operating with water/Carrol mixture

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ABSTRACT

Absorption Heat Transformer (*AHT*) is a device to recovery heat waste by a thermodynamic cycle. In this paper, an experimental *AHT* prototype operated with four temperature levels and two pressure levels was analyzed. This prototype was build with commercial Plate Heat Exchangers (*PHE*) and operates with water/Carrol mixture. The heat powers measured were 1.03, 1.48 and 1.51 kW for the generator, 1.19, 1.54 and 1.61 kW for the condenser, 1.21, 1.57 and 1.64 kW for the evaporator, and finally, 0.59, 0.98 and 1.09 kW for the absorber. Experimental Gross Temperature Lift (*GTL*) was 18.0, 17.4 and 16.5 °C and the dimensionless values of Coefficient of Performance (*COP*) calculated for those operating conditions were 0.26, 0.32 and 0.35. Absorber temperatures were 106.8, 105.3, 103.9 °C.

1. Introduction

As the probed reserves of fossil fuels decreases and the Kyoto protocol has urged nations to mitigate the negative effect of green house, the efficient use of energy is an important topic for many industries. A major cause of energy inefficiency is the generation of waste heat and the lack of waste heat utilization, particularly low grade heat. Technologies such as Absorption Heat Transformers (*AHT*) which allow the recycling of waste heat energy are very attractive methods of improving performance in this area. *AHT* is a closed cycle system which upgrades a fraction of the energy contained by an intermediate temperature waste heat stream to a higher temperature to it will be reused. These cycles require a negligible mechanical or electrical work and thus have very low running costs [1–3].

As a very effective technique, the *AHT* can be applied to improve low-grade waste heat with temperatures ranging from 60 to 100 °C. The *AHT* system can effectively recover about 50% of this waste heat and give an opportunity to reuse it in industrial processes [4,5].

Applications of *AHTs* technology include, mainly: Thermal energy revalorization, purification water process and desalination seawater. Horuz and Kurt [6] proposed an *AHT* in a textile company in order to produce hot process water by utilizing the hot water generated by a cogeneration system. The case of study had four different units which each produces 15 ton/h water at 90 ± 2 °C. A theoretical analysis shows that is possible increase the source temperature at 120 °C, and the heat waste revalorization by an *AHT* is around 50%. Rivera et al. [7] carried out a theoretical analysis for *AHT* coupled to a butane and pentane distillation column in order to reduce the heat load supplied to the reboiler; the heat delivered in the condenser, at 82 °C, may be used as heat input in the generator and evaporator of the *AHT* system and revalorizes at high temperature level in the absorber to preheat the stream entering to the reboiler at 155 °C. Authors concluded that with the use *AHT* is possible to save up to 43% of the energy supplied to the reboiler of the distillation for the process conditions. Ma et al. [8] reported an *AHT* for 5000 kW of heat flow in a synthetic rubber plant. It was used to recover the waste heat released from mixture of steam and organic vapor at 98 °C. The heat recovered was used to heat water process from 95 to 110 °C, in order to feeding back to the coagulator as heating source. The *COP* calculated was 0.47, and the gross temperature lift of 25 °C. An economical analysis demonstrated that the

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Nomenclature

Abbreviations

AHT	Absorption Heat Transformer
COP	Coefficient Of Performance, dimensionless
FR	Flow Ratio, dimensionless
GTL	Gross Temperature Lift, °C
PHE	Plate Heat Exchanger

Symbols

h	enthalpy, kJ kg^{-1}
m	mass flow, kg s^{-1}
T	temperature, °C
Q	heat power, kW
x	Carrol solution concentration, %w/w

Subscripts

AB	absorber
CO	condenser
EC	economizer
EV	evaporator
GE	generator
liq	working fluid in liquid phase
max	maximum
mix	water/Carrol mixture
vap	working fluid in vapor phase
WF	working fluid

Greek symbols

η	thermal effectiveness, dimensionless

payback period is approximately 2 years. The use of *AHT* for water purification and desalination seawater process has been widely reported in the literature: Meza et al. [9] reported an experimental *AHT* for water purification process, authors reported that with this device was obtained 888 ml/h of purified water with absorber temperature of 104.9 °C, besides this, in this experimental study, authors reuse the auxiliary condenser heat in order to reduce the generator energy supply. Huicochea et al. [10] describes an experimental *AHT* and reported the absorber temperature from 96.3 to 98.4 °C, it allows a water purification flow from 181 to 418 ml/min. In other experimental report, Huicochea et al. [11] studies the effect of hot water supply to generator on the water distillation process by an exergy analysis, in same *AHT* configuration used by Meza et al. [9], authors concluded that when the mass flow rates of hot water supplied to the generator are lower, the irreversibilities are also lower, increasing the exergy efficiency of the hole system, therefore, the highest distillation water flow values can be achieved. Parham et al. [12] analyzed some configurations of *AHT* integrated in desalination seawater system. Authors proposed that the waste heat from a textile factory supplied thermal energy (at 80–90 °C) to the *AHT* and the useful high temperature heat (at 130 °C) can be employed for the purpose of desalination. In this theoretical study, the maximum rate of distilled pure water reaches 0.2435 kg/s. Gomri [13] carried out a theoretical analysis about *AHT* for desalination seawater process. Author concluded that the production of water is almost constant for a wide range of absorber temperatures when the *AHT* heat load source (in the generator and in the evaporator) is varied from 74 °C to 96 °C, and the maximum fresh water production of the system are in the range of 0.168–0.179 kg/s. Sekar and Saravanan [14] carried out an experimental study about absorption heat transformer coupled distillation system. The results of the operation of this laboratory scale pilot unit showed, absorber temperature up to 100 °C, the *COP* was from 0.30 to 0.38 while the maximum distillate flow rate of 4.1 kg/h. Another application of the *AHTs* is in cogeneration systems: Huicochea et al. [15] studied the potential of a cogeneration system which consisted of a 5 kW proton exchange membrane fuel cell (*PEMFC*) and an *AHT*. The dissipation heat resulting from the operation of the *PEMFC* would be used to feed the absorption heat transformer which is integrated to a water purification system at 80 °C. With this coupled system is possible achieve 1.0×10^{-4} kg/s to 1.89×10^{-4} kg/s of distillation water. Yari [16] proposed the use of *AHT* in a cogeneration cycle where there compression of S-CO_2 in a Brayton cycle that utilized the waste heat from a nuclear power plant. Author concluded that both, the energy and exergy efficiencies of the new S-CO_2 cycle were higher than that of the simple S-CO_2 cycle by 5.5–26%. For the proposed operating conditions, a maximum pure water flow rate of 3.317 kg/s was obtained with the new S-CO_2 cycle. The exergy destruction value of the new cycle was on average 12.6–19.1% lower than that of the conventional cycle (without *AHT* and desalination system). Zare et al. [17] proposed an *AHT* coupled to a gas turbine-modular helium reactor (GT-MHR) to produce power through two Organic Rankine Cycles (ORCs) in order to upgrade the heat waste for distillation processes. Authors concluded that for each 50 °C increase in the gas turbine inlet temperature, the thermal efficiency is increased by around 2.5–4% and the pure water production rate by an *AHT* is decreased by around 6.5%. In another work Yari et al. [18] analyzed a combined cogeneration cycle: the waste heat from an ejector-expansion trans-critical CO_2 refrigeration cycle was utilized for power production and water purification simultaneously. The waste heat utilization was performed by means of a CO_2 supercritical power cycle and a desalination system. In order to run the desalination system, an *AHT* was employed to upgrade the lower temperature waste heat. The results showed that, at the optimum conditions, the energy efficiency ratio of combined cogeneration cycle was about 13–45% higher than the coefficient of performance of the ejector-expansion trans-critical CO_2 cycle (without *AHT* and desalination system). An extends recompilation about *AHTs* were carried out by Parham et al. [19].

Compact heat exchangers are becoming increasingly important elements in many industrial processes. In order to increase the thermal energy transfer efficiency those heat exchangers offer a number of benefits, such as [20]:

- Improved efficiency. For the heat pump, the closer approach temperatures lead to higher *COP*.
- Smaller volume and weight.
- Lower installed cost.
- Multi-stream and multi-pass configurations. Useful for absorption cycles.
- Tighter control of conditions. Low inertia of the system.
- Improved safety. Reduced fluid inventory.

A type of compact heat exchanger is the Plate Heat Exchanger (*PHE*). It has been widely used in the fields of energy transport due to its favorable characteristics, such as high heat transfer coefficient, easy maintenance, compact size and convenience to increase the heat transfer area. The compact design and