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Absorption heat transformers: Sensitivity study to answer existing discrepancies

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A B S T R A C T

This work aims at bringing an analysis upon the heterogeneity and the accuracy of results expressed by authors studying absorption heat transformers (AHTs). Existing work is based on specific operating conditions for specific applications, which shows that detailed thermodynamic and sensitivity studies for a wide range of operating conditions are lacking. Hence, this work shows the impact of wide ranges of operating temperature values upon exergy destruction, COP and performance variations. Main results show a maximum in performance for a given working pair as a function of temperatures and refrigerant content in the fluids at the generator, absorber and evaporator. Exergy destruction in generators and absorbers is confirmed, however, it is for the first time shown that there is a counterbalancing effect between these two components of the AHT. This effect explains why conclusions of works published on AHT seem to lead to contradictory pathways towards optimization.

1. Introduction

Future uncertainty regarding sources of energy supply, the cost of energy, and the need for reduction in carbon emissions means that reducing fuel requirements and increase on energy efficiency are compulsory actions for many companies. Currently, vast quantities of low level heat sources are available on a daily basis. These are typically waste heat obtained from industrial processes and those supplied from solar and geothermal sources. The low temperature of these heat sources renders them frequently useless in most of industrial processes. In order to allow recycling and reuse of this energy, its temperature must be increased using a heat pump. In general, heat pumps may be divided into two main categories, namely vapor compression heat pumps and absorption heat transformers [1].

Vapor compression heat pumps are simple in design and can achieve large gross temperature lifts (GTLs). However, their main disadvantage is that they require significant quantities of valuable high quality exergy: electricity. Meanwhile, absorption heat transformers (AHTs) are an alternative kind of heat pump which reduces this exergy need as they require negligible quantities of electricity. Such systems use a working pair of fluids consisting of a refrigerant and an absorbent to achieve the heat pumping action [2]. The potential of heat recovery by means of AHTs represents 50% of energy available in solar sources, geothermal sources, exhaust gases, cooling water, heated products and from surfaces of hot equipments [3]. The remaining unrecovered energy is discharged to a low temperature sink (to the atmosphere) [4]. It has been demonstrated that considerable energy savings and a reduction in fuel requirements may be achieved if AHTs are installed in suitable facilities [5]. For these reasons, heat transformers have been called 'future technology for energy utilization in the 21st century' by the IEA [6].

The main reason why heat transformers are not widely being used in industry is that they are still an expensive and relatively unknown system. Literature therefore needs to move away from treating AHTs as theoretical static objects, and begin to address component improvements which will facilitate industrial application. This paper therefore attempts to study the Single stage AHTs (SAHTs) performance variation when the heat source temperature varies and to explain why discrepancies are found in conclusions expressed in previous research works.

2. AHT operating principle

AHTs are tri-thermal machines capable of absorbing heat available at a medium temperature level, converting it into useful heat at higher temperature, and some heat rejected to the

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atmosphere at room temperature. AHTs use a pair of working fluids consisting of a refrigerant (most volatile) and an absorbent. According to Fig. 1, the red color shows the streams where the pure refrigerant circulates, the blue color shows the streams where circulates an absorbent-refrigerant solution with high (rich) absorbent concentration and the green color shows the streams where a solution circulates with a low (poor) absorbent concentration.

A SAHT consists of a generator, a condenser, an evaporator, an absorber, an internal heat exchanger, an expansion valve and two pumps (Fig. 1). Two components of the SAHTs, the evaporator and the condenser, operate in the same way as in a conventional compression heat pump system. In an AHT, however, compression of the refrigerant is accomplished using a liquid coolant-absorbing solution and a heat source that replaces the power consumption of an electric compressor operating in the conventional Heat Pump (HP). The generator and the condenser are at the low pressure level of the SAHT, while the absorber and the evaporator are at the high pressure level. The refrigerant vapor at low-pressure comes out from the generator **(1)**. Then, it passes through the condenser where it condenses and releases energy to the atmosphere. The refrigerant in liquid phase and at low pressu**re (2) e**nters the isentropic pump that allows the passage from low pressure to high pressure **(3)**. This high pressure level implies that the evaporation temperature of the refrigerant is higher than the temperature at the condenser. It is possible to evaporate the refrigerant in the evaporator by supplying energy from a heat source (hot source). At the outlet of the evaporator **(4)**, the refrigerant is in saturated vapor conditions.

The temperature of the evaporator thus sets the high pressure of the absorption machine. The high-pressure vapor from the evaporator ***(4)*** is absorbed by the liquid mixture of the working pair coming from the generator. The refrigerant-absorbent solution therefore passes from the absorbent-rich state ***(10)*** to the lean state ***(5)***. It is important to note that this absorption is exothermic and it delivers the useful heat at higher temperatures than those of the available heat source. This useful heat is transferred to a heat transfer fluid (e.g. water for steam production). The refrigerant-absorbent solution ***(6)*** is then brought at low pressure via an expansion valve to the generator ***(7)***. The passage of the solution at low pressure has the effect of decreasing its saturation temperature. The supply of thermal energy (the same source of heat used at

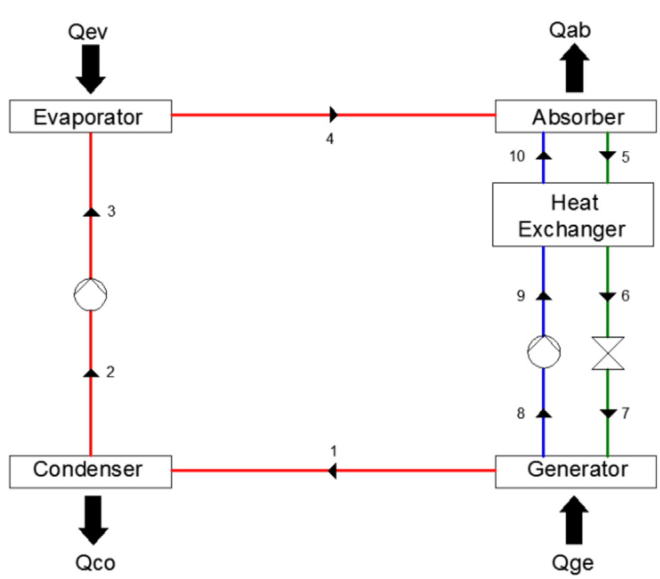

Fig. 1. Configuration of a single stage absorption heat transformer cycle (SAHT).

the evaporator) makes it possible to regenerate the refrigerant vapor from the mixture coming from the absorber. This partial separation of the refrigerant fluid from the refrigerant-absorbent solution is carried out in the generator by vaporization. The absorbent rich solution ***(8)*** will be compressed through a pump ***(9)*** and injected into the absorber ***(10)*** to complete the cycle.

3. Working fluids

The working pair used in an SAHT can significantly influence the initial investment cost of the unit and the maintenance operations required. Therefore, the selection of these fluids is a crucial aspect to consider when determining whether or not a SAHT is practically suitable for installation in a facility. The H_2O-LiBr pair is the working fluid widely used in commercial SAHT machines. This is due to several advantages, such as the high latent heat of the water [4], the high mass and heat transfer capacities, the low toxicity and the fact that no distillation column is necessary in the cycle since LiBr is not volatile and it is easy to obtain pure water vapor [3]. This pair also has several disadvantages, such as operating at pressures below the atmospheric one, the strong corrosivity of salty water, and the risk of crystallization of LiBr. Thus, many efforts have been devoted to finding alternative solutions that have the same thermodynamic properties as H_2O-LiBr while eliminating some of its negative characteristics.

NH_3-H_2O working fluid is also widely used in SAHT and shows lower corrosivity levels than H_2O-LiBr. Kurem and Horuz [7] compared the use of NH_3-H_2O and H_2O-LiBr as a working fluid in an SAHT. It has been demonstrated that the H_2O-LiBr system has a slightly higher coefficient of performance (COP) at all conditions tested and requires a higher refrigerant flow rate inside the system. They indicated that in order for the NH_3-H_2O cycle to have the same performance as the H_2O-LiBr pair, a more complex (and therefore more expensive) SAHT architecture is needed. Major improvements needed are expected in the generator that would need to show a temperature glide and to use a rectification column instead of a boiler to separate the traces of water from the ammonia. The use of NH_3-H_2O is particularly unsuitable for high temperature heat recovery applications because of the very high pressures required (a temperature of 100 °C requires a pressure of 100 bar in the cycle) [8].

In this study, the NH_3-H_2O is nevertheless considered as working pair. The thermo-physical properties are calculated by using the Peng-Robinson thermodynamic model available in the Aspen Properties software.

4. SAHT review

Several research papers have been published in recent years. Most of the studies aimed at the evaluation of the cycle performance. A review of some of the most significant studies is presented below:

Barragan et al. [9,10] have demonstrated that with the increase in GTL (gross temperature lift), the rate of circulation of working fluids in the SAHT increases and then the COP decreases. Sözen [11] and Rivera [12] have shown that the exergetic coefficient of performance (ECOP) has similar trends to those of the COP. It increases as the temperature of the evaporator or generator increases before beginning to decrease. The ECOP increases slightly before starting to decrease when the temperature increases with the absorber temperature, and then decreases rapidly once a critical temperature of the absorber is reached.

Rivera et al. [13] presented a detailed analysis for the absorption heat transformer. The results showed that the COP and ECOP values decreased with an increase in the absorber temperature,