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Absorption heat transformer for solar pond energy temperature upgrading

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Abstract

Solar energy has intermittent heat collection due the atmospheric phenomena, even the clarity index is widely evaluating the approximation for modelling the solar energy always is a function of the time. Solar ponds are a technology for solar energy accumulation, this technology has evaluations for tilt angles and salt concentration temperature variation and has availability with small variation along 24 hours a day. This technology may supply constant heat load to a thermodynamic cycle for temperature upgrade from the solar pond temperature level. Absorption heat transformer is a Type II heat pump to take a heat source part of the thermal energy to increase the temperature of the half heat source, in this case, from a solar pond. This article shows the data for several operating conditions of an absorption heat pump operating whit Carrol © / water solution. The main result is the gross temperature lift from solar pond technology with an AHT operating with condensation into the same solar pond to increase the Coefficient of Performance.

1. Introduction

One of the most important environmental changes being produced is the accumulation of atmospheric carbon dioxide (CO_2). There are other gases with similar effect to that of CO_2. These gases include methane (CH_4), nitrous oxide (N_2O) and various synthetic gases, mainly chlorofluorocarbons (carbon, chlorine, and fluoride compounds). The accumulation of these gases generates the phenomenon called "Global Warning Effects" or "Global Warning Effects", that is, an increase in the average temperature of the Earth's atmosphere and oceans, caused mainly by industrial activity and excessive consumption of fossil fuels. [IEA, 2020]. With regard to the direct impact on humans, it includes the expansion of the area of tropical infectious diseases, flooding of coastal land and cities, more intense storms, the extinction of countless species of plants and animals, crop failures in vulnerable areas, increased droughts, among others.

These findings have led to a global government reaction, focused on tacking and as much as possible solving the crisis. Therefore, it is necessary to develop new technologies that allow the efficient use of available energy resources. These efforts will reduce greenhouse gases produced by industrial activities.

1.1 Heat pumps basic concepts

The technology for energy efficiency proposal for several change climatic authors are the recycled of energy from waste heat, from solar heat and even the soil heat. Of course, that energy needs a thermodynamic cycle to achieve the heat transfer from a source to be useful into the human interaction. One of the thermodynamic cycles for the heat exchanger between the low enthalpy source and the useful process is the heat pumps. This technology has several modes and different classification based on the source and sink.

There is water – water heat pump, water – air heat pump, soil – air heat pump, among the mainly used into the heating and cooling strategic for efficiency energy. But the main process of them has two components that exchange the heat: condenser and evaporator. These operation process unit are well known studied for chemical engineers around the world in the laboratories, universities, and heat device assembly facilities.

Some experimental heat pump devices are focused to diminish the mechanical process energy of the typical compression heat pumps. The compressor device is in the same energy magnitude order compared with the deliver energy process. Heat pumps has a Coefficient of Performance defined as the ratio of delivered heat into the condenser and the compressor mechanical work. This parameter is so useful to compare the technology for heating process and realistic, compared with Carnot temperature efficiency, because the condenser energy and the compression energy are measured for each process. One option for the compressor replacement is a secondary cycle constructed by a vapor generator and an absorber unit. This second cycle has a circulation of an aqueous solution which can operates between two thermodynamic equilibrium pressure.

1.2 Absorption heat transformers basic concepts

Absorption heat pumps may be classified by the physicochemical process: mechanical vapor compression or vapor absorption process. So, the first are known as compression heat pump and the second are named absorption heat pumps. The objective of the heat pump is the same: take energy from lower temperature level in the evaporator and deliver energy at higher temperature level in the condenser. But there is a particular absorption heat pump with a different pressure configuration, with condenser in a lower pressure and temperature levels connected to an evaporator operating at higher pressure and temperature levels, by this configuration with inverse pressure compared with a typical heat pump, those are named inverse heat pump or absorption heat transformers. The figures 1, 2a and 2b show the main components of these three thermal devices.

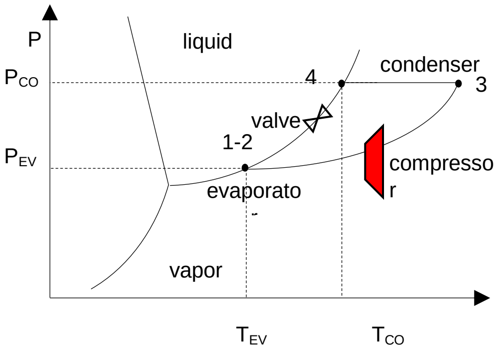
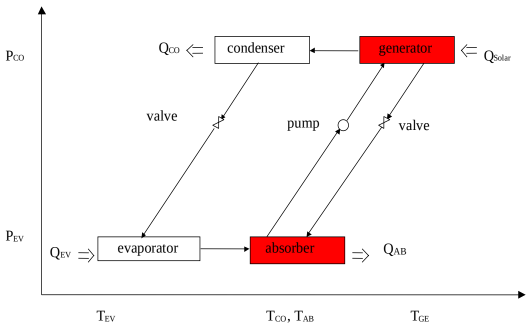


Figure 1. Compression heat pump Schematical Diagram



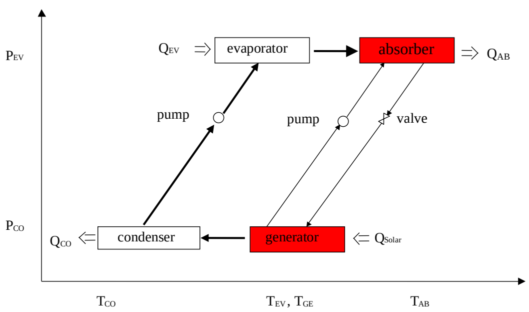


Figure 2a. Absorption heat pump Schematical Diagram. *Figure 2b. Inverse Absorption heat pump (AHT)*

Main usefulness for the absorption heat pump is to use just 5% of the mechanical work for pumping based on the power of the generator process. This means, 95 % of the process is powered by heat exchange process. This ability, compared with compression heat pumps may be useful for process with bigger amounts of thermal energy at low enthalpy level, such as solar collectors. The CIICAp – UAEM had been review it previously [Rivera, 2015].

1.3 Solar ponds concept

Solar ponds are a large device for solar energy collection based on salt gradient and stratification effect depending on salinity and aqueous solution density [Kasaeian, 2018; Ranjan, 2014], even without ideal thermal behaviour [Verma, 2020a; Verma 2020b]. Some experts have been reported the comparison with analytical techniques and modelling based on salinity gradient [Anagnostopoulos, 2020; Sayer, 2016]. Other papers are focus on the pipelines to extract the heat from the bottom of the solar pond with diverse geometry pipe [Khoshvaght-Aliabadi, 2020]. Some previous paper report the highest temperature and heat transfer at noon [Krishnasamy, 2017].

An attractive for this technology is the depth for the construction for solar ponds, [El-Sebaii, 2011] with NaCl aqueous solutions at relative cheap price for large volumes [Kasaeian,2018]. In that operating conditions and small depth size an absorption heat transformer was simulated to operate without exchange thermal energy at outside of the solar pond.

2. Modelling and assumption

2.1 Solar pond

For the modelling of a solar pond, there are some basic assumptions:

1. The solar pond is analysed for three zones; upper convective zone (UCZ), non-convective zone (NCZ) and lower convective zone (LCZ).
2. The temperature variations are considered small enough so that they are negligible for horizontal variations. Temperature and salinity distributions into the solar pond are vertically one dimension.
3. The temperature and density in UCZ and in LCZ are uniform and perfectly mixed.
4. The heat losses from the walls are neglected.
5. The bottom surface is blackened to maximize the radiation absorption. Therefore, the radiation energy reaching the LCZ is completely absorbed by the solution and the solar pond bottom. [Kanan, 2014].

Based on the average data for global irradiance on Mexico, the value for the simulation was fixed for a maximum at 800 W/m^2 and the monthly average irradiation show in the figure 3a. This data is representative for Guaymas, Sonora., with ambient temperature between 10 °C and 35 °C in the year and average wind velocity 10 m/s, with NaCl UCZ salt concentration was 10 kg/m3 and LCZ was 170 kg /m3.

2.2 Absorption heat transformer (AHT)

For the modelling of the absorption heat transformer, the classical assumptions have made:

1. The entire system is under thermodynamic equilibria.
2. The heat loss are negligible compared with the total amount of the thermal loads.
3. There are not pressure drop along the unit operations.
4. Carrol is not evaporated in any place into the absorption heat transformer.
5. Components outlets has saturated conditions for liquid and vapour.
6. Pump work is about 5 % of the entire heat load and it is isentropic.
7. Fluid goes through valve as isenthalpic process. [Valdéz – Morales, 2017]

The absorption heat transformer is operated with Carrol – Water mixture at temperature 5 °C close to the source heat at the bottom of the solar pond, the absorption process is achieved at 105 °C inside the contactor of the vapor and the concentrated aqueous Carrol and the condenser is 5 °C higher than the surroundings temperature conditions.

3. Results

The solar ponds, based on the modelling, increase the temperature as function of time, as shown in figure 3a. The absorption heat transformer is placed into two configurations in the solar pond, the first one assumes condenser is outside of solar pond and the COP is a typical calculation:

$$COP_I = \frac{Q_{AB}}{Q_{GE}+Q_{EV}+W_P} \tag{1}$$

Where Q_{AB} is the energy for useful heat at 105 °C, Q^{GE} is the generator heat at bottom solar pond temperature and Q_{EV} is evaporator heat at same temperature than generator, because they are in the same solar pond depth level. W_P is 5 % of the generator power, calculated in the laboratory conditions [Valdéz – Morales, 2017].

The second configuration assumes the condenser is placed into the solar pond close to the surface, but at temperature level lower than the operation condition, to allow the heat exchange with the solar pond NaCl solution, then the COP is a defined as:

$$COP_{II} = \frac{Q_{AB}}{Q_{GE}+Q_{EV}+Q_{CO}+W_P} \quad (2)$$

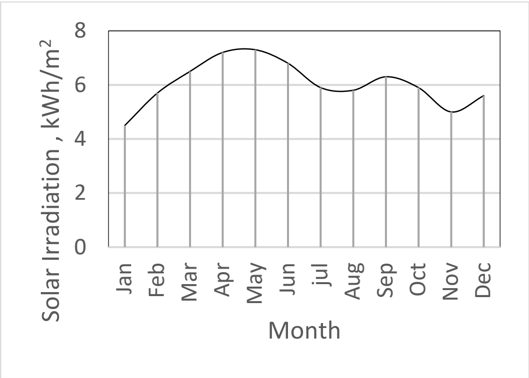


Figure 3a. Solar irradiation for simulation of solar pond for typical year.

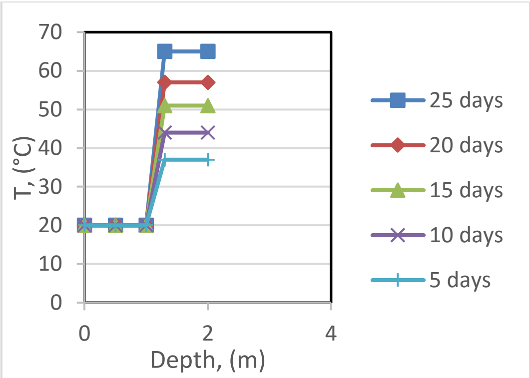


Figure 3b. Solar pond temperature profile as function of time and depth.

Where, similar to equation 1, the Q correspondes to heat load and Q_{CO} is condenser heat returned to the higher part of the solar pond near to the surface. Both conceptual configurations can be seen in figures 4a and 4b, respectively. The black doted line is for Carrol – Water pumped solution and the red line is for water at lower pressure. The simulated data are obtained for heat plate exchangers connected at calculated solar pond model and experimental evaluation of a single stage absorption heat transformer with four components made with 316L SS.

The first configuration leads to typical COP lower than 0.5 values. It is dimensionless and the values are in agree with previous papers from our laboratory evaluations [Valdéz – Morales, 2017] the lower COP is 0.35 dimensionless for ambient temperature close to 19 °C. The COP is increased for higher solar ponds temperatures to heat exchange into generator and evaporator in the LCZ, see figures 5a and 5b.

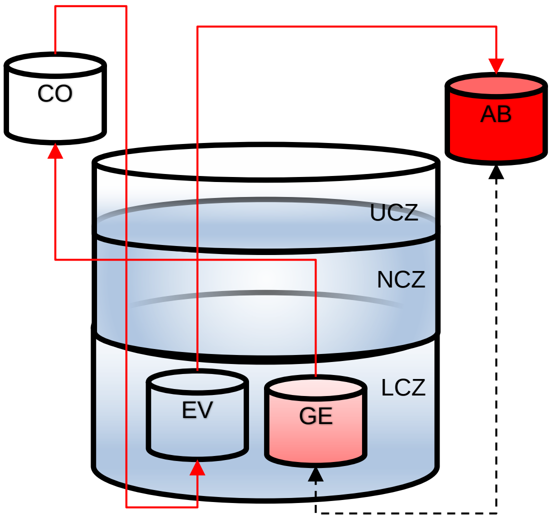


Figure 4a. Solar pond and AHT 1st configuration.

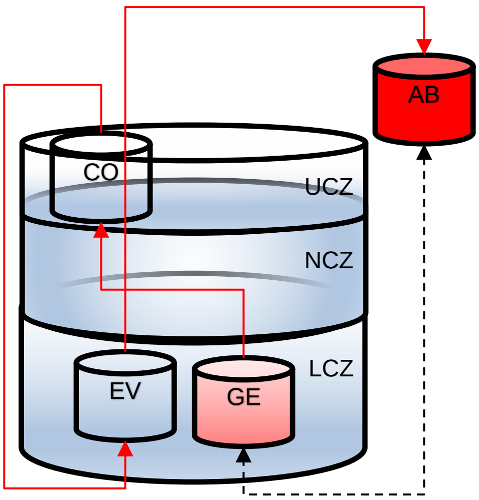
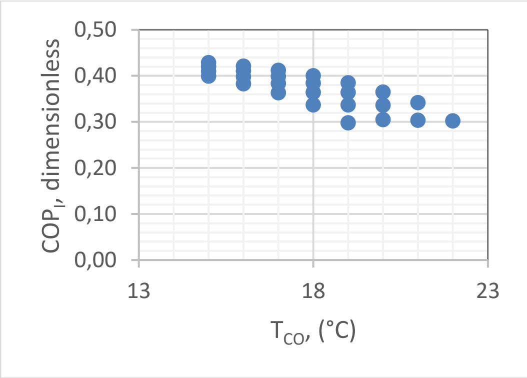


Figure 4b. Solar pond and AHT 2nd configuration.



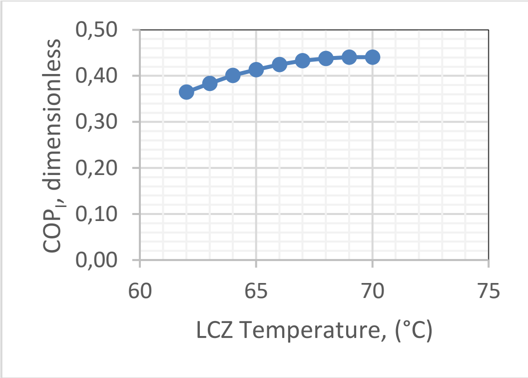
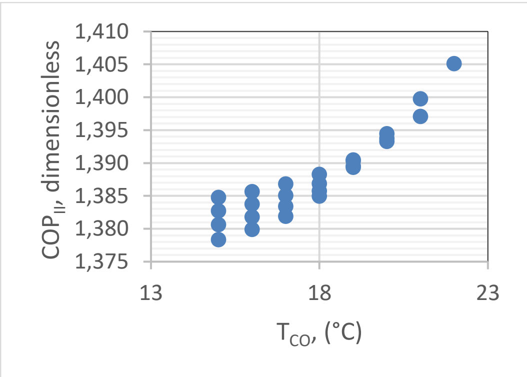


Figure 5a. COPI as function of AHT's T_{CO}. *Figure 5b. COP_I as function solar pond LCZ.*

For the second configuration, the COP is increased for the condenser recycled heat load to the solar pond, this is really useful because, based on the solar pond modelling, the extraction of heat from the LCZ has a limit as function of the solar irradiance and the convective process, the power exchanged heat must be calculated for solar power variation, the excessive exchange to the absorption heat transformer diminish the temperature in the LCZ, so the addition of energy at lower temperature represents the evaporation process of the AHT.

The second configuration has great advantage compared with first configuration: the COP value indicates the usefulness to recycle condenser heat to the upper zone of the solar pond with values higher than 1 and they are similar to absorption solar systems [Solano – Olivares, 2019]. The increase of the temperature in the UCZ leads to a higher efficiency process instead deliver the condenser heat at the surroundings of the solar pond, so the increase in the ambient temperature implies a better performance of the entire thermodynamic process. With this process it is possible define the minimum COP for the process, for the fixed operating conditions, the COP minimum value exists at 67 °C of the LCZ, as can be observed on Figure 6b.



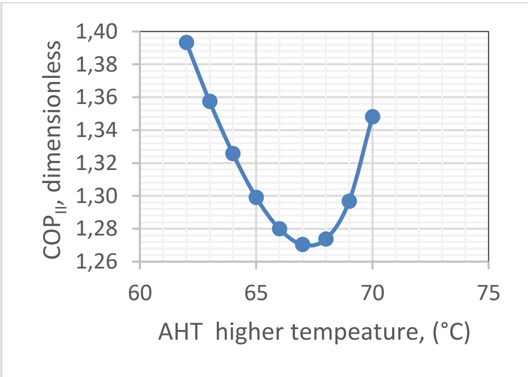


Figure 6a. COP_{II} as function of AHT's T_{CO}. *Figure 6b. COP_{II} as function solar pond LCZ*

4. Conclusions

A modelling for absorption heat transformer inside a solar pond was shown. For a variable solar irradiance and constant NaCl concentration solar pond a thermodynamic evaluation temperature for an absorption heat transformer was calculated. The simulation of the solar pond indicates there is two convective zones: upper and lower for installation of the AHT components. A first configuration with a condenser process depending on the ambient temperature and generator – evaporator temperature directly immersed into the lower convective zone show a 0.35 dimensionless coefficient of performance. A second configuration was evaluated with a new defined coefficient of performance, the proposal considers the condenser process into the upper convective zone with a temperature closer than the ambient temperature. This proposal concludes the COP_{II} is higher than COP_I and the definition is closer than the solar absorption systems.

The integration of the absorption heat transformer allows 105 °C absorption process than is not possible to achieve for a solar pond event 25 days without heat extraction with ambient temperature at 20 °C and daily solar average irradiance of 5 kWh/m^2, as Mexico conditions has.

Acknowledgments

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