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Simulation of an Air-Cooled LiBr/H_2O Absorption Chiller under South Algerian Climate Conditions

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Abstract

In the last few years, thermal comfort researches in the residential sector are increasingly focusing on air-conditioning by absorption chillers. In this paper, we present a simulation study of an air-cooled absorption system in South-west Algeria. The main objective is to study the feasibility of an absorption refrigeration installation at an arid zone. The studied system is composed of a thermally driven simple effect air-cooled lithium bromide/water absorption chiller with an adiabatic absorber. It was simulated under the climate condition of a typical summer day of July 22th in Bechar city. The result has proved that the system is able to reach a maximum COP values of 0,7759, 0,7893 and 0,7995 for an evaporator temperature equal to 8, 10 and 12°C respectively without a crystallization problem. The system can provide a cooling power between 5 to 11kW.

Keywords: Air-cooled absorption, lithium bromide, EES modelling, arid zone

INTRODUCTION

Nowadays, the increasing interest in protecting the environment and saving energy had favoured the use of absorption chillers as they provide opportunities for energy saving and whose requirements in electricity are much lower and driven by thermal energy and environmental friendly working fluids.

Although absorption systems are a good alternative, they still have some important drawbacks such as a high cost and low efficiency compared to the vapour compression systems, which still dominate all market sectors. Consequently, in order to promote the use of absorption systems, current efforts are focused to improve their characteristics and performance. Lamp and Ziegler [1] reported the European efforts that have been carried on air conditioning applications and highlighted the most outstanding ideas and experiences. Among the different absorption refrigeration techniques, LiBr-H2O absorption chillers are the most developed and commercialized product, although their crucial crystallization problem [2, 3].

There are two main drawbacks in water-cooled systems: the risk of legionnaire's disease [4] and the difficulty of configuring the cooling tower in residential areas [5, 6]. however, air-cooled absorption chillers can be built as a single unit, which saves both water and space in the residential application.

The interest on absorption refrigeration systems operated with low-temperature solar heat has considerably increased in the last years. The motivation for an air-cooled option is the use of the air, free coolant. A number of studies concerning air-cooled absorption chillers have been reported in recent years, but most of them were conducted through simulation. Liao [7] focused on the crystallization issues in a 63kW single-effect LiBr-H2O air-cooled absorption chillers. As the most critical problem of Lithium bromide occurs on the absorber, Izquierdo et al. [3] focused on the development of a solar air-cooled LiBr-H_2O absorption system using low grade heat taking into account the limit of crystallization using a double-stage LiBr–H2O air-cooled absorption cycle. Operating conditions of the double-stage absorption machine, integrated in the solar plant without crystallisation problems for condensation temperatures up to 53°C, were obtained. Results have shown that about 80°C of generation temperature is required in the absorption machine when condensation temperature reach 50°C, obtaining a COP equal to 0.38 in the theoretical cycle. Marcos et al. [8] carried out an experimental study in the aim to determine the boiling heat transfer coefficients in the high temperature desorber of an air-cooled double effect LiBr/H_2O absorption prototype. Castro et al. [9] constructed a prototype of an 2kW air-cooled LiBr/water machine to be used as a test facility for validating numerical results. In their study, different models of the most critical heat exchangers (absorber, generator, condenser and evaporator) have been developed and validated. Kim and Infante Ferreira [8] reviewed the different available technologies to deliver refrigeration from solar energy and proposed the development of air-cooled machines as an important subject in the future since there was only one air-cooled machine for solar cooling in the market. A wet cooling tower is unfavourable in most of the small applications where regular maintenance work is impossible or in the arid regions where water is scarce. Izquierdo et al. [10] conducted trials to determine the performance of the only commercial (Rotartica 045v) 4.5kW air-cooled, single effect LiBr/H2O absorption chiller for residential use. The Rotartica is an indirect fired single effect system based on rotary absorption technology. All the machine components are installed inside a rotary drum which rotates to improve the heat transfer by means of the generation of a turbulent flow in the LiBr solution. The experimental study was carried in Madrid between 1st and 20th of August 2005. González-Gil [2] evaluated experimentally a new direct air-cooled single-double effect LiBr-water absorption prototype paying attention to the absorber description. The design of this prototype permits to use only a fan to cool both the absorber and the condenser at the same time. Another aspect worth mentioning is that the evaporator and the absorber are assembled together in the same chamber, in such a way that the vapour generated. Palacio [11] reported the experimental campaign carried out in summer 2010 in Madrid to test the single effect mode of the above-described prototype. A new method for COP optimization in water and air-cooled single and double effect LiBr-water absorption machine was proposed by Marcos [12] This method determines the effect of condensation temperatures and the solution concentration variation on COP, clearly defining the crystallization limit which is especially important in the design of air-cooled chillers. All the crystallisation control strategies for water/LiBr absorption heat pumps were reported by Wang [13].

R. Lizarte and al. [14] reviewed of trials introducing an innovative, directly air-cooled absorber-condenser, low power, single effect LiBr/H2O prototype absorption chiller driven by solar-powered facility using vacuum flat-plate solar collectors. This study formed part of a larger project whose goal was to use solar power as a source of heat in air-cooled absorption chillers in residential buildings. The aim was to air condition a 40m^2 room located in Madrid. Later on, an experimental comparison have been carried on between the above-mentioned prototype and the Rotartica045v [15]. Two main differences were: 1- directly air-cooled system where the absorption and condensation heats are transferred to the outside by forced convection. 2- The use of an adiabatic flat-fan sheets absorber. Both were 4.5kW, 1 m^3, and single effect LiBr/H_2O absorption chillers. The two chillers were analysed from the standpoint of their external fluids. The trials were conducted at outdoor dry bulb temperatures ranging from 28 to 37ºC. Izquierdo et al. [16] developed a new flat-sheet adiabatic absorber directly cooled by air which proved to be able to operate in very high outdoor temperatures. This absorber was installed in a prototype with 7 kW of nominal cooling capacity, which was able to chill water between 7°C and 18°C in extreme outdoor temperatures about 45°C. The experiments were performed during three characteristics summer days in Madrid obtaining a mean daily COP of about 1.05 without mentioning any crystallization problem. Moreover, the nominal ratio of cooling volume was about 6.0kW/m^3 while for the only commercialized absorption chiller this ratio was about 4 kW/m^3. However, prior to optimization, this prototype has a cooling cost around 15.9% higher than the electrically powered air conditioners but also an environmental effect 16.7% lower. Zeyu Li et al. [17] developed a parametric model of a solar air cooled double effect LiBr/H2O absorption cooling system. The effect of effectiveness of heat exchanger and pressure drop on total efficiency and the solar fraction was studied and compared. Chen et al. [18] investigated the influence of different operating conditions on the performance of a 6kW air-cooled absorption chillers to produce cold at 15°C for chilled water. Later, due to the need of new concept to improve the efficiency of air-cooled absorption chillers, a novel air-cooled single effect LiBr-H2O absorption chiller with adiabatic flash evaporator and adiabatic absorber was fabricated and tested [19]. The key point was that the secondary heat exchanging between refrigerant water and chilled water was avoided by introducing the adiabatic flash process.

This study is carried out to study the feasibility of an air-cooled thermally driven absorption chiller with an adiabatic absorber on the climate condition of an arid zone situated in South-West Algeria.

MATHEMATICAL MODELLING

The studied system is an air-cooled simple effect LiBr/H_2O absorption chillers with an adiabatic absorber. The absorber and condenser are supposed to be built in a single unit and cooled with a fan (Fig.1).

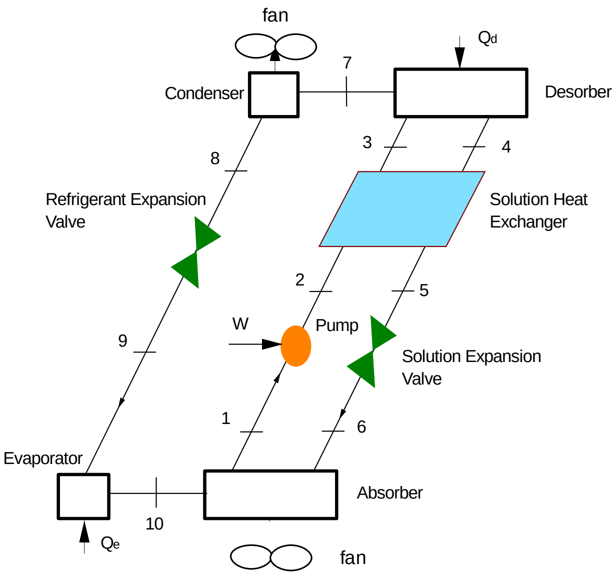

Figure 1. Diagram of the air-cooled LiBr/H2O system

Based on the principles of energy and mass conservation a simple mathematical model has been developed for a steady state simulation an air-cooled single-effect LiBr/H2O absorption chillers; Cycle shown in Fig.1. The following are the performance equations for each of the components considering continuity (mass balance), the first law of thermodynamics (energy balance) and the second law of thermodynamics (entropy generation).

Global mass: $$m_f = m_r - m_p \qquad \text{(II.1)}$$

The fluid mass flow rate:

$$m_f * X_7 = m_r * X_3 – m_p * X_4 \quad (II.2)$$

$$m_f * X_7 = m_r * X_3 – (m_r – m_f) * X_4 \quad (II.3)$$

The coefficient of circulation is defined as:

$$F_f=m_r/m_f= (X_7 -X_4)/(X_3 -X_4) \quad (II.4)$$

The concentration is defined by:

$$X_i = (m_f/m_T) \quad (II.5)$$

Condenser: $Q_c = m_f * (h_7 – h_8)$ (II.6)

Evaporator: $Q_e = m_f * (h_{10} – h_9)$ (II.7)

Generator: $Q_g = m_f * h_7– m_r * h_3 + m_p * h_4$ (II.8)

Absorber: $Q_{abs} = m_r* h_1– m_f * h_{10}– m_p * h_6$ (II.9)

The valve 1: $h_5 = h_6$ (II.10)

The valve 2: $h_8 = h_9$ (II.11)

The pump: $W_p = m_r * (h_1 – h_2)$ (II.12)

Heat exchanger:

$$E = (T_4 -T_5)/(T_4 - T_2) = (T_3 -T_2)/(T_4 -T_2) \quad (II.13)$$

The coefficient of performance:

$$COP = Q_e/(Q_g+ Wp) \quad (II.14)$$

OPERATING CONDITIONS

The whole absorption cycle is modelled using engineering equation solver (EES). The entire problem of system simulation were reduces to a problem of identifying all the components that comprise the particular system and formulating a general mathematical description of each. A numerous simulations are done by using EES to assess the performance of the system. The program is based on heat and mass balances, heat transfer equations and the state equations for the thermodynamic properties of lithium bromide–water. The state equations were evaluated by the thermodynamic properties of water and lithium bromide available in the library of EES. The initial conditions used by the program include the ambient conditions, heat exchanger effectiveness, cooling and chilled water inlet temperature and mass flow rate. With the given parameters, the program calculates at all points of the cycle the values of temperature, enthalpy, pressure, mass flow rate and concentrations for the steady state reached. The program results have been validated with the results obtained by Marcos[12] at an evaporator temperature equal to 10°C and a condensation temperature of 45°C.

In the following, sensitivity analyses and simulations of the different components of the installation are presented in order to improve the efficiency of the system. The behaviour of the complete system is then studied. To find suitable conditions when the cycle is driven by solar energy, a sensitivity analysis was performed for the generator, that is, all the conditions (flow rates, heat coefficients, etc.) used in the simulations are maintained constant except for the generator inlet temperature. The generator provides sensible heat and latent heat of vaporization. The sensible heat raises the inlet solution temperature to the saturation temperature. The latent heat consists of the heat of vaporization of pure water and the latent heat of mixing of the liquid solution.

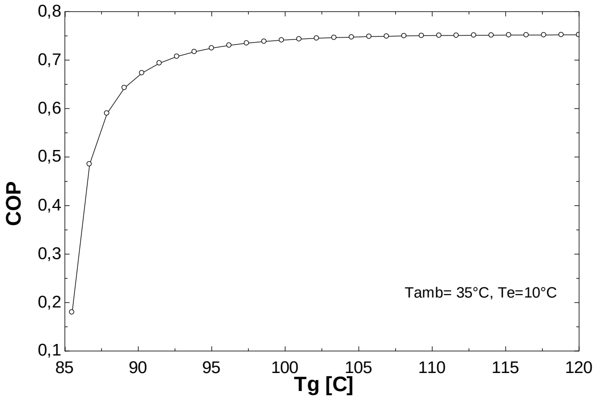

Figure 2: Effect of the inlet generator temperature on the COP

The effect of the inlet generator temperature on the COP value is studied for optimal operating conditions. The simulation inlet temperatures are: the mean daily temperature of 35°C, for the ambient temperature, and 10°C for an optimum evaporator temperature. The influence of the generator inlet temperature on the COP value is presented in Fig.2. The minimum generator inlet temperature needs to be higher than 85°C and the maximum temperature is equal to 105°C. In this case, the crystallization is negligible for an inlet generator temperature less than 100°C and limits is about 9% for a temperature equals to 105°C. An optimum COP value of 0,741 can be obtained at 100°C. Some operational values are mentioned in Table 1.

Table 1 : Absorption chillers operating conditions

Parameter description	Value
Generator temperator	100 °C
Evaporator energy flow	11, 41 kW
Absorber energy flow	14, 81 kW
Condenser energy flow	12,23 kW
Generator energy flow	15,38
COP	0,7416
Crystallization limit	38 %

The influence on the cooling capacity is represented on Fig.3. The rise in the generator inlet temperature increases the cooling capacity of the absorption chillers. For small scale application, a 5kW cooling capacity can be obtained for a generator inlet temperature about 91°C and a value of 11,43kW for 100°C. However, the circulation factor decreases while rising the generator inlet temperature (Fig.4.).

Fig.5 illustrates the relation between the cooling capacity and the desorber capacity for the absorption chillers. It shows that the cooling capacity increase by increasing desorber capacity.

SYSTEM SIMULATION

The air-cooled thermally driven air-cooled absorption chillers is simulated under climate condition of Béchar city, an arid zone situated in South west Algeria (31°36´N, 2°13´W)(Fig.6). Simulations are done using the same conditions as previously taken into consideration the ambient temperature and the solar radiation of a typical summer day on July 22th, 2017 (Fig.7: a-b). The whole cycle in composed of a simple effect air-cooled Lithium bromide absorption machine thermally driven with a waste heat source and a flat plate solar collector.

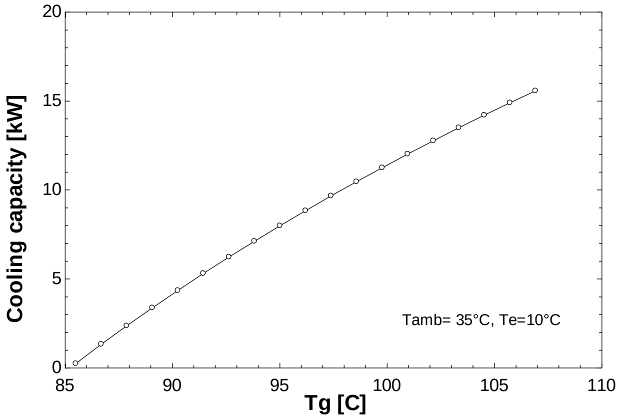

Figure 2. Effect of the inlet generator temperature on the cooling capacity

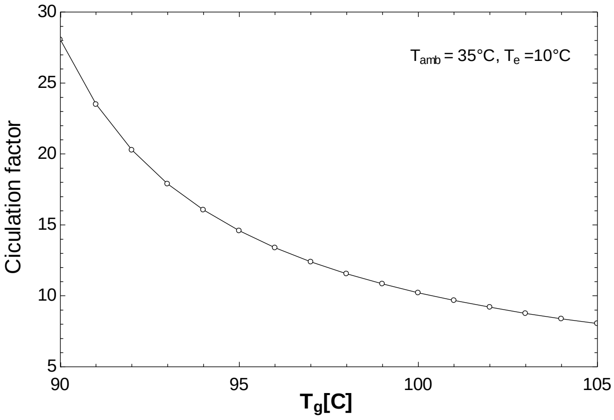

Figure. 4 Effect of the inlet generator temperature on the circulation factor

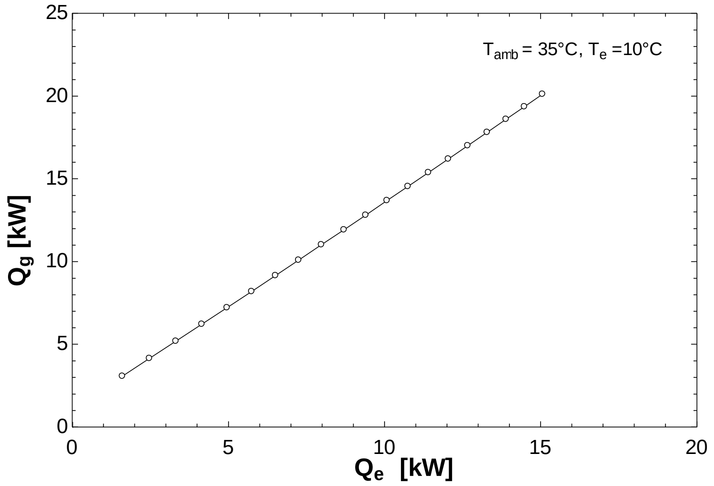

Figure. 5 Effect of the cooling capacity on the desorber capacity

Figure 6. Geographic localisation Bechar city

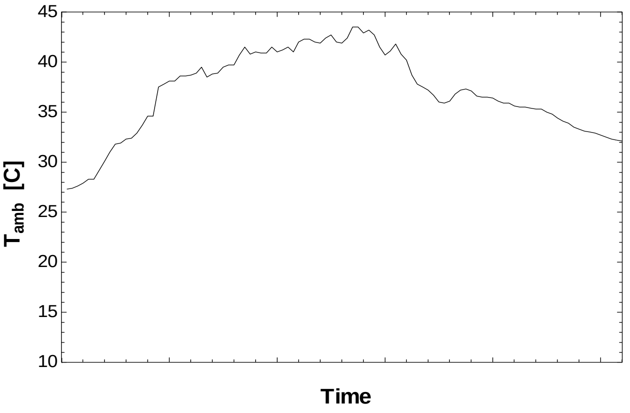

Figure 7.a Daily mean temperature on July 22th

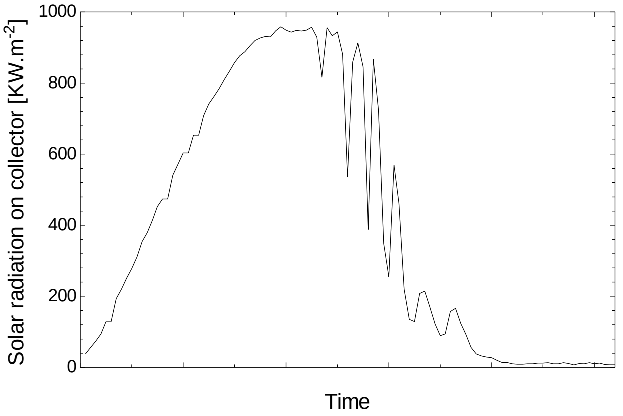

Figure 7.b Daily mean solar radiation on July 22th

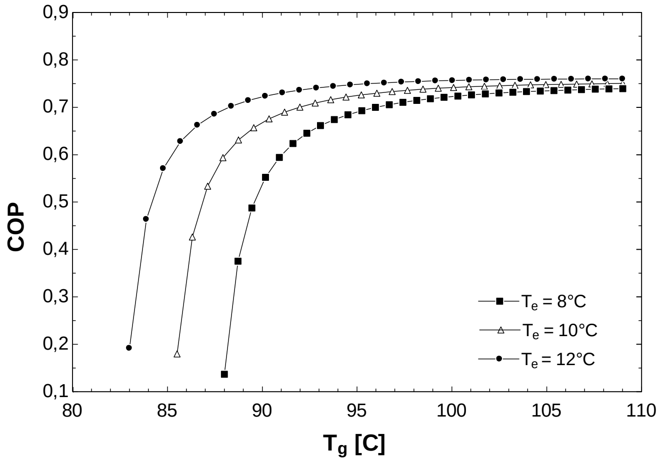

Figure 8. The effect of the inlet generator temperature on the COP

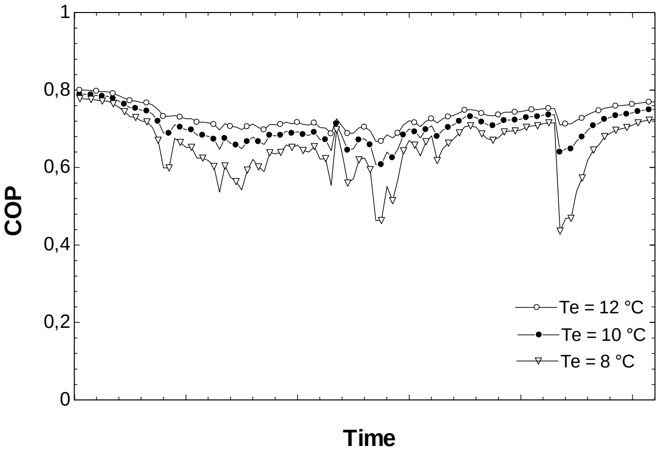

Figure 9. Performance of the system on the day of July 22th

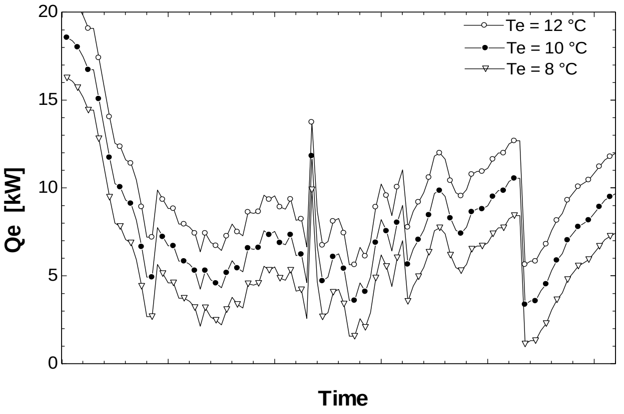

Figure 10. Cooling capacity of the system on July 22th

In operation, a change in any input variable of an absorption machine causes changes in all the other dependant variables. When an input changes, the entire cycle reacts to reach a new equilibrium operating condition. In that purpose, the performance of the whole cycle is studied for three different evaporator temperature (T_e = 8, 10 and 12°C). Fig.8. represents the variation of COP according to the generator temperature for choosing the appropriate temperature of the waste heat source. The system is operated by the flat plate solar collector and a waste heat source while the provided temperature from the solar collector is under 100°C The behaviour of the coefficient of the performance of the cycle during the day of July 22th is shown in Fig.9. It has been shown that the system have the same behaviour for the three different evaporator temperature and has a maximum value of 0,7759 , 0,7893 and 0,7995 for evaporator temperature 8,10 and 12°C respectively without having any crystallization problem. The main system input parameters are mentioned in table 2.

The cooling capacity provided by the system during the day of July 22th is shown in Fig.10. The system works with a need of the auxiliary heat when the available solar radiation isn't enough. The cooling capacity provided by the system is comprised between 5 and 11kW which can cover the cooling load a residential building.

Such a system is suitable for Bechar city. It could help to minimise the energy consumption and reduce the electricity demand specially in summer time.

Table 2: Main system input parameters

Parameter description	Value
Solar collectors	
Optical efficiency	79,1 %
Loss coefficient a_1	4,47 W/m^{2}K
Loss coefficient a_2	0,0069 W/m^{2}K^2
Unitary area	2,295 m^2
Waste heat source temperature	101 °C
Thermal chiller	
Heat exchanger efficiency	70 %
Weak solution flow rate	0,05 m^3/h
Nominal COP	0,6
Nominal cooling power	5 kW

CONCLUSION

Several thermally driven air-conditioning technologies are market available by today which enable the use of solar thermal energy for this application. Among solar cooling technologies the absorption cooling system are the most studied ones. The absorption cycle is a process by which refrigeration effect is produced through the use of two fluids and some quantity of heat input, rather than electrical input as in the more familiar vapour compression cycle. The current work present a research project which aims at assessing the feasibility of thermally-driven absorption cooling technology in South Algeria. The system is modelled EES programs. The influence of generator heat exchanger on cycle performance was tested.

The results have shown that such a system is suitable for air-conditioning application in Bechar. It's can possibility be used for domestic application. The simple effect air-cooled Lithium Bromide have proved to be able to work without crystallization problem. Somehow it has been shown that remarkable advances are still needed, not only in the solar energy side but also in the absorption technology one.

NOMENCLATURE

T: Temperature.
X: Mass fraction.
Q: Thermal energy.
Wp: Pump power.
E: Effeciency of the heat exchanger.
m: Mass flow rate
h: Enthalpy.
P: Pressure.
COP: Coefficient of performance.
HTD: High temperature desorber
PHE: plate heat exchanger

Subscripts

amb : ambient.
a : absorber.
c : condenser.
e : evaporator.
f : fluid.
g : generator.
i : state point.
p : pump.

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