Influence of Operating Parameters on the Performance of an Adsorption Solar Refrigeration Machine

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Research Article

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Influence of operating parameters on the performance of an adsorption solar refrigeration machine

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Abstract

Renewable energies including solar energy requirements for refrigeration and air conditioning are increasingly gaining interest due to the refrigerants friendly to the environment. However, it was found that these technologies have some limitations like the low performance and their high cost. This paper proposes a comparative study of a solar adsorption refrigeration machine. The study consists in determining the optimal thermodynamic parameters of operation as well as their influences on the performance of the system. This is based on a thermodynamic model using different types of adsorbent / adsorbate pairs. The main parameters considered in this study are: temperature of generation, evaporation, maximum heating temperature, condensation pressure as well as the type of the pair used: activated carbon / methanol and zeolite / water. Simulations for different thermodynamic parameters show that the COP is very sensitive to the generation and evaporation temperatures as well as the maximum heating temperature, on the other hand it was slightly influenced by the condensation pressure. The results obtained have shown that the AC / methanol pair is more profitable than the zeolite / water pair.

Keywords:

Refrigeration machines, adsorption, solar cooling, AC / methanol, zeolite / water and COP.

Nomenclature		subscripts	
AC	activated carbon	a	adsorption
COP	coefficient of performance	c	condensation
h	specific enthalpy, kJ/kg	ch	adsorber
$\dot{m}$	mass flow rate, kg/s	i	in
P	pressure, bar	d	desorption
Q	heat, kW	e	evaporation
T	temperature, °C	g	generation
X	concentration, kg adsorbate/kg adsorbent	min	minimum
		max	maximum
		o	out
		w	water

1. Introduction

Energy demand and growing global economic development impose challenges regarding energy supply, this is accompanied by the depletion of conventional energy resources: fuel, natural gas, coal ...etc.

On the other hand, renewable energies including solar energy are considered as alternatives and which have been the subject of interest in recent years. The conversion of solar energy into cooling has become one of the major applications, this has several methods of which gas sorption is the dominant one in air conditioning and solar refrigeration [1].

Absorption [2,3,4,5] and adsorption [6,7] are the technologies that have received a great deal of interest due to their refrigeration capacities in comparison with photovoltaic systems [8,9] which are offered for low-capacity air conditioning applications. In this article, the study focuses on the adsorption solar system, this technology has received several attentions because of their silent behaviour and the refrigerants friendly to the environment, especially the use of solar energy since the demand of the cold coincides most of the time with the availability of solar irradiation [10]. However, several factors have been discovered and appear to be disadvantages for this type of refrigeration such as intermittent solar energy, low coefficient of performance compared to those with vapor compression cycle, poor heat transfer performance.

In this context, several research works have been carried out mainly for the optimization of adsorption solar refrigeration systems [11] by studying the effect of operating parameters on performance [12,13,14]. The choice of the adsorbent / adsorbate pairs appeared essential and decisive on the performance of the system [15,16], depending on the climatic conditions and type of collector also type of materials used in the installation and which influences heat and mass transfer and therefore performance, which has been shown by the literature [17,18].

In this paper, thermodynamic results were presented to see the effect of coefficient of performance as a function of the pressure and temperature operating parameters and compared for two pairs chosen AC / methanol and Zeolite / water and that for a solar refrigeration system at conventional adsorption. A thermodynamic model is used to calculate the performance of the system.

2. system description and working principal

The studied system is a solar adsorption refrigerator in its simplest form, the schematic diagram of which is shown in fig. 1. [19] has shown in detail the various components of a solar adsorption refrigeration system as well as the working principle. A solar adsorption refrigerator based on the basic adsorption refrigeration cycle does not require any mechanical or electrical energy, just thermal energy, and it operates intermittently according to the daily cycle. [7]

The basic cycle process of adsorption solar refrigeration systems is as follows:

1-2: Isosteric heating

2-3: Isobaric heating

3-4: Isosteric cooling

4-1: Isobaric cooling

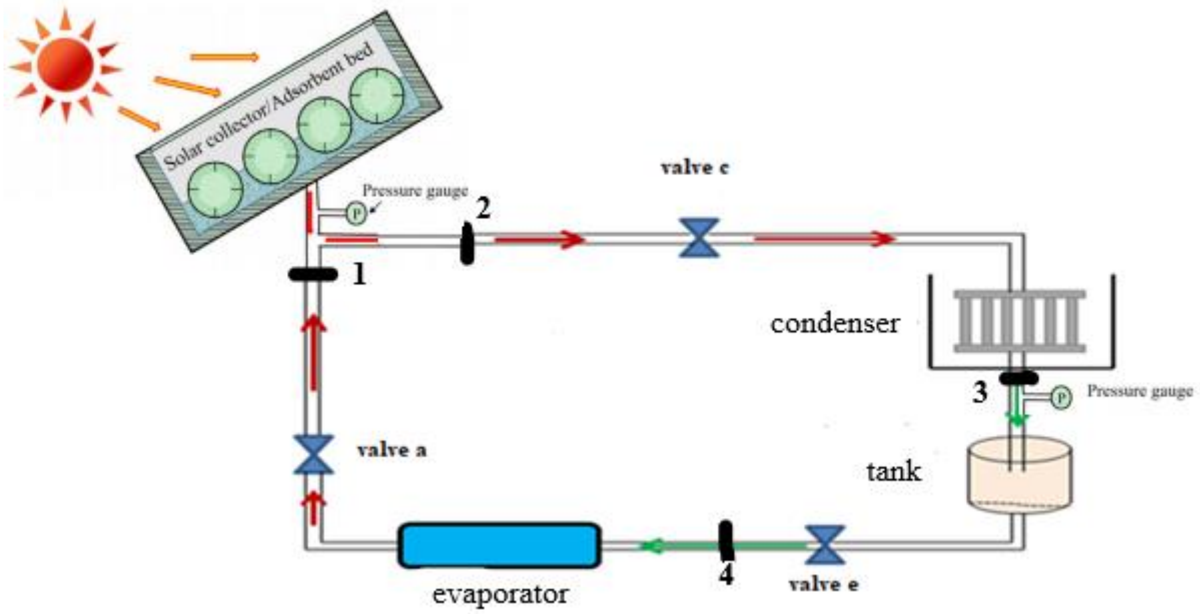

Fig. 1. Schematic diagram of the solar adsorption refrigeration system.

The cycle begins at point 1 (fig.2), when the system is at the adsorption temperature T_a and at a low pressure P_e (evaporation pressure), but the concentration of the refrigerant is maximum X_{max}. The adsorber receives a quantity of thermal heat Q_{d1} which increases the pressure and temperature along the isosteric line 1–2 (at constant concentration). at point 2, the heating continues and by increasing the temperature and desorption begins, the generation of steam occurs receiving a quantity of heat Q_{d2} the pressure remains constant along the isobar line 2–3 while the concentration decreases to X_{min}. the vapor generated is liquefied by the condenser following the isosteric line 3–4 releasing a quantity of heat Q_{cd} at a constant concentration X_{min} and at a condensing temperature Tc. During transformation 4–1, the condensed refrigerant following the isosteric line 3–4 releasing a quantity of heat Q_{cd} at a constant concentration X_{min} and at a condensing temperature Tc. During transformation 4–1, the condensed refrigerant flows into the evaporator and the pressure decreases to the evaporating pressure P_e and the adsorption phase occurs by absorbing a quantity of heat Q_{ev} bringing the vapor back to liquid and producing the effect of cold. The evaporated refrigerant flows to the adsorber to be adsorbed

and accumulated causing its concentration to increase to X_{max} at point 1 and is cooled to the adsorption temperature T_a and the cycle begins again.

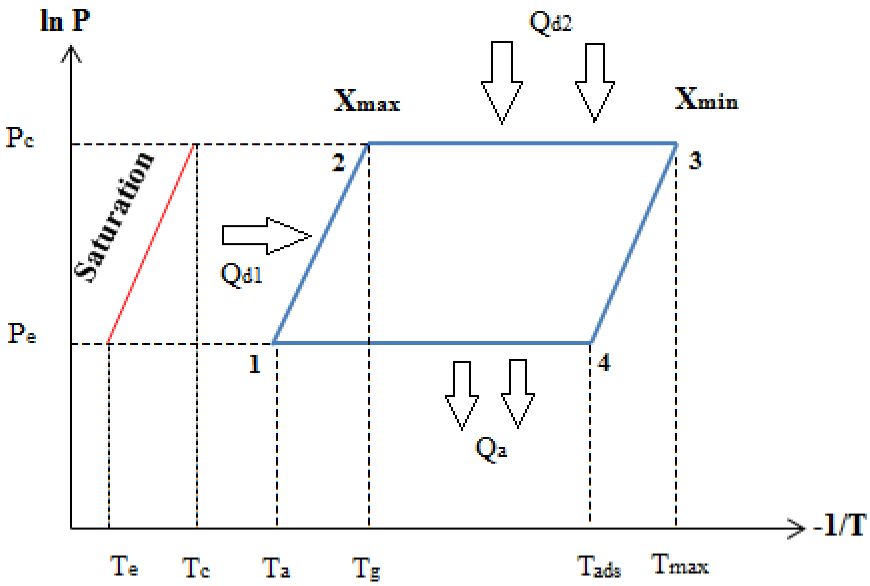

Fig. 2. Theoretical cycle of the adsorption solar refrigeration system (Clapeyron diagram)

3. Thermodynamic study

The refrigeration capacity, the heating capacity and the coefficient of performance are given by [20] in the equations of (1) to (3).

$$Q_e = \dot{m}_{ch} c_w \left(T_{ch,i} - T_{ch,o}\right) \tag{1}$$

$$Q_h = \dot{m}_h c_w \left(T_{h,i} - T_{h,o}\right) \tag{2}$$

$$COP = \frac{\dot{m}_{ch} c_w \left(T_{ch,i} - T_{ch,o}\right)}{\dot{m}_h c_w \left(T_{h,i} - T_{h,o}\right)} \tag{3}$$

For constant physical properties of fluids, the mass enthalpy is defined by:

$$\Delta h = c(\Delta T) \tag{4}$$

The expression of the quantity of heat exchanged in this case by the adsorber, the condenser and the evaporator are expressed as follows:

3.1. Adsorber / condenser

According to the theoretical thermodynamic cycle of adsorption solar refrigeration systems, the generation of vapor from the liquid state of the working fluid occurs in two different phases:

- Isosteric heating: The adsorber receives a quantity of solar energy necessary for heating the adsorbent / adsorbate pair Q_{d1} expressed by:

$$Q_{d1} = \dot{m}_d (h_2 - h_1) \tag{5}$$

- Isobaric heating: in this phase begins the generation of steam (desorption), the required energy Q_{d2} is given by:

$$Q_{d2} = \dot{m}_c (h_3 - h_2) \tag{6}$$

3.2. Evaporator

During the evaporation phase, the refrigerant which is the adsorbate in the case of the adsorption refrigeration system, passes from the liquid state to the vapor state by absorbing a quantity of heat from the medium to be cooled Q_{ev} corresponds to:

$$Q_e = \dot{m}_e(h_1 - h_4) \quad (6)$$

3.3. System performance equation

The expression of the COP will be defined as follows:

$$COP = \frac{Q_e}{Q_g} \quad (8)$$

Within our case Q_g is given by:

$$Q_g = Q_{d1} + Q_{d2} \quad (9)$$

By replacing (1) and (2) in (5):

$$Q_g = \dot{m}_d(h_2 - h_1) + \dot{m}_c(h_3 - h_2) \quad (10)$$

The final expression of the coefficient of performance becomes:

$$COP = \frac{\dot{m}_e(h_1 - h_4)}{\dot{m}_d(h_2 - h_1) + \dot{m}_c(h_3 - h_2)} \quad (11)$$

4. Working constraints

4.1. Hypotheses

In order to have an agreement between the chosen model and the considered unit, certain assumptions were imposed.

- We consider that there is no heat loss to the outside environment
- All the liquid present in the adsorber is evaporated (desorption) as well as the condensate stored in the container is assumed to be completely evaporated (adsorption)
- The flow rate of the fluid in each phase is assumed to be constant
- The opening and closing of each valve are done at the end of each phase.

4.2. Operating parameters

- Condensation and evaporation pressure: literature shows that condensation takes place at a pressure of 145 mbar to 216 mbar, while adsorption takes place at a pressure of 90 mbar to 160 mbar [21] [22].
  Our work consists in varying the pressure value in this interval to see the effect of condensing pressure on the COP and that for the two couples chosen.
- Temperatures: the operating temperatures were chosen such that they are close to those found in the experimental units seen in the literature [10] [12].
  The objective of this study is to investigate the COP variation as a function of operating temperatures and pressure as well as a comparative profitability study between the two pairs chosen: AC / methanol and zeolite / water.

4.3. Data table

The data required for the calculation software are presented in the following table:

Symbol	parameter	value
$\dot{m}_c$	Mass flow rate of condensate	3.7 m^3/h [10]
$\dot{m}_d$	Desorption phase mass flow	1.6 m^3/h [10]
$\dot{m}_e$	Evaporation phase mass flow	2 m^3/h [10]
P_c	Condensing pressure	0.21676 bar [20]
P_e	Evaporation pressure	0.02872 bar [20]
T_a	Adsorption temperature	16 °C [12]
T_e	Evaporating temperature	-5 °C [12]
T_g	Generation temperature	61 °C [12]
T_{max}	Maximum heating temperature	82 °C [12]

Table 1. Calculation data.

5. Results and interpretation

To facilitate the analysis of the effect of varying the operating parameters of different components of the solar adsorption refrigeration system on performance, a thermodynamic model was presented. Numerical analysis consists of obtaining the appropriate configurations and therefore making the improvements to the COP.

The governing equations have been solved by a computer code which takes into consideration the thermodynamic adsorption cycle presented by the pressure and temperature parameters at each point of the diagram (figure 2) and from there the quantities of heat exchanged can be determined and represented as a function of the mass enthalpy at this point. So, the variation of the operating parameters which describes the cycle cause the variation in the quantity of associated heat, hence the importance of the parametric study given the great dependence between the operating parameters and the coefficient of performance given in the model thermodynamics as the ratio between the quantities of associated heat. So, this work consists in showing this dependence positively or negatively. Another factor is taken into consideration, it is the choice of the type of adsorbent / adsorbate pair. This work also aims to see the behaviour of performance under the effect of the chosen pair and to determine the best operating conditions for the pairs. In this case, AC / methanol and zeolite / water were chosen as the adsorbent / adsorbate pair.

In this study, we respectively discuss the effect of: (1) the maximum temperature T_{max} (2) the evaporation temperature T_e (3) the generation temperature T_g (4) the condensing pressure P_c as well as the choice of the couple adsorbent / adsorbate on the COP. Calculation data is shown in Table 1.

5.1. Model validation

The values of the coefficient of performance COP as a function of the maximum temperature reached during the heating of the adsorption bed for the AC / methanol couple and those calculated by douss & meunier are presented in table.2. The figure shows a reasonable agreement between the results although the COP shows a slight difference, which can be a consequence of not taking into account the thermal losses present in each phase and the difference between the operating conditions taken in each model.

T_{max} °C	70	75	80	90	110	130
COP_{model}	0.496	0.417	0.359	0.281	0.195	0.149
$COP_{douss\&meunier}$	0.49	0.5	0.51	0.51	0.49	0.47

Table 2. The COP calculated by the model and by douss & meunier [12].

5.2. Generation temperature effect

The effects of the generation temperature Tg on the coefficient of performance are shown in fig. 3. From the figure, it is noticed that the COP increases with the increase in the generation temperature and that for the two pairs used AC / methanol and zeolite / water. The reason is that the mass of the adsorbate generated is proportional at the generation temperature, in fact, increasing the generation temperature ensures better heat transfer performance at the adsorption bed level, which gives a greater amount of adsorbed mass and subsequently an increase in COP.

In addition, it is found that the change in COP as a function of the generation temperature is clearly different in the two cases of the pair type. The COP varies rapidly with the generation temperature in the case of the AC / methanol pair and reaches a maximum COP of 0,45 at T_g = 80 °C. on the other hand, in the case of the zeolite / water pair, the COP varies slowly and reaches a maximum value of around 0,15.

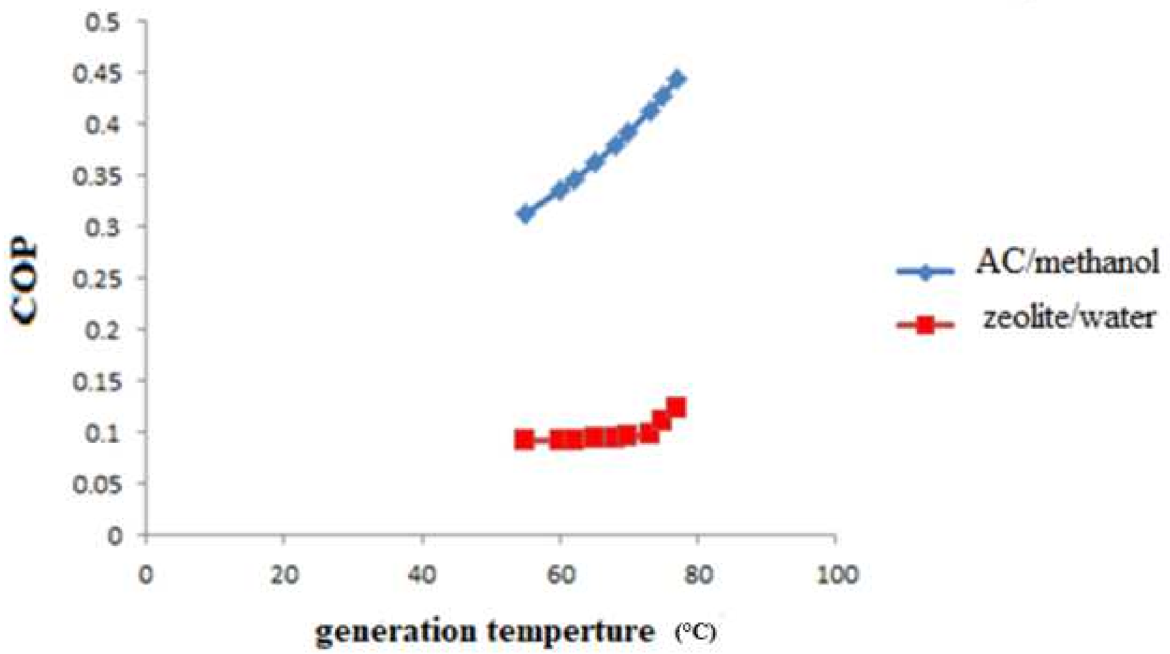

Fig. 3. Effect of the generation temperature T_g and type of the pair on the COP

5.3. Effect of evaporating temperature on the COP

Fig. 4. shows the effect of varying the evaporating temperature T_{ev} on the performance of the system. As can be seen in the figure, the COP decreases as the evaporating temperature increases. In addition, the COP in the case of the AC / methanol pair decreases rapidly in comparison with the zeolite / water pair. In the first case the COP reaches 0.09 at T_{ev} = 10 °C and 0.01 in the second case for the same temperature. The results also show that the AC / methanol pair is more profitable in comparison with the zeolite / water pair. In the first case the COP reaches its maximum value of 0.35 at T_{ev} = -5 °C while in the other case the maximum value of COP is of the order of 0.1 for the same evaporation temperature.

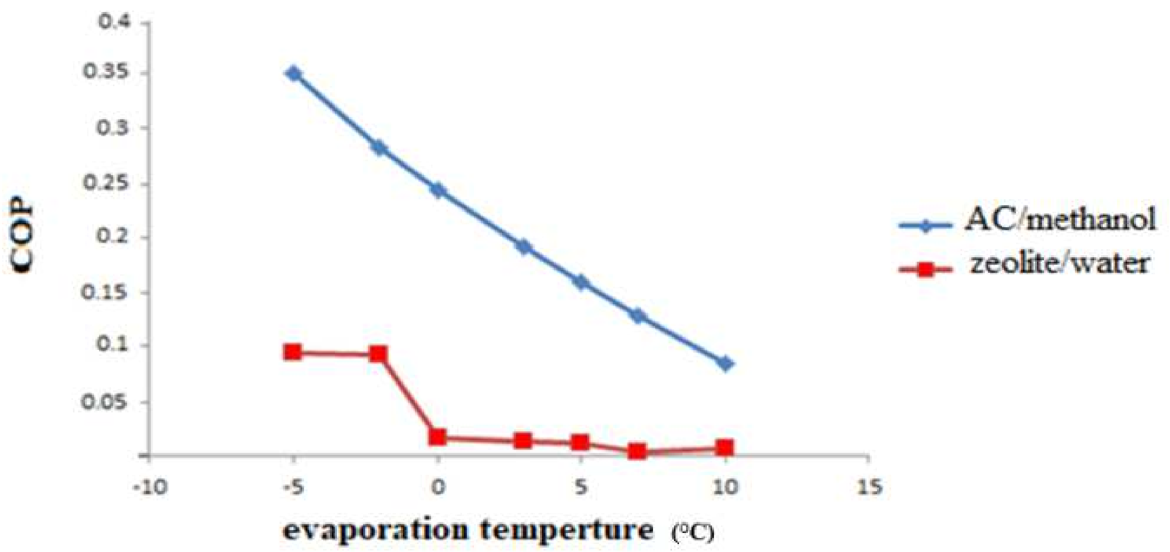

Fig. 4. COP variation as a function of the evaporation temperature T_{ev} and type of the pair.

5.4. Effect of the maximum temperature on the COP

A number of simulations have been carried out by varying the temperature of the maximum adsorption bed during the heating phase. Fig. 5 shows the results for the two types of couples used. The figure suggests that the COP decreases when the maximum heating temperature increase. the figure also shows that the optimum COP reached is 0.49 in the case of the AC / methanol couple for a temperature of 70 °C and 0.093 in the case of the zeolite / water couple. As with high heating temperatures, the COP decreases slower in the second case, reaching lower COPs.

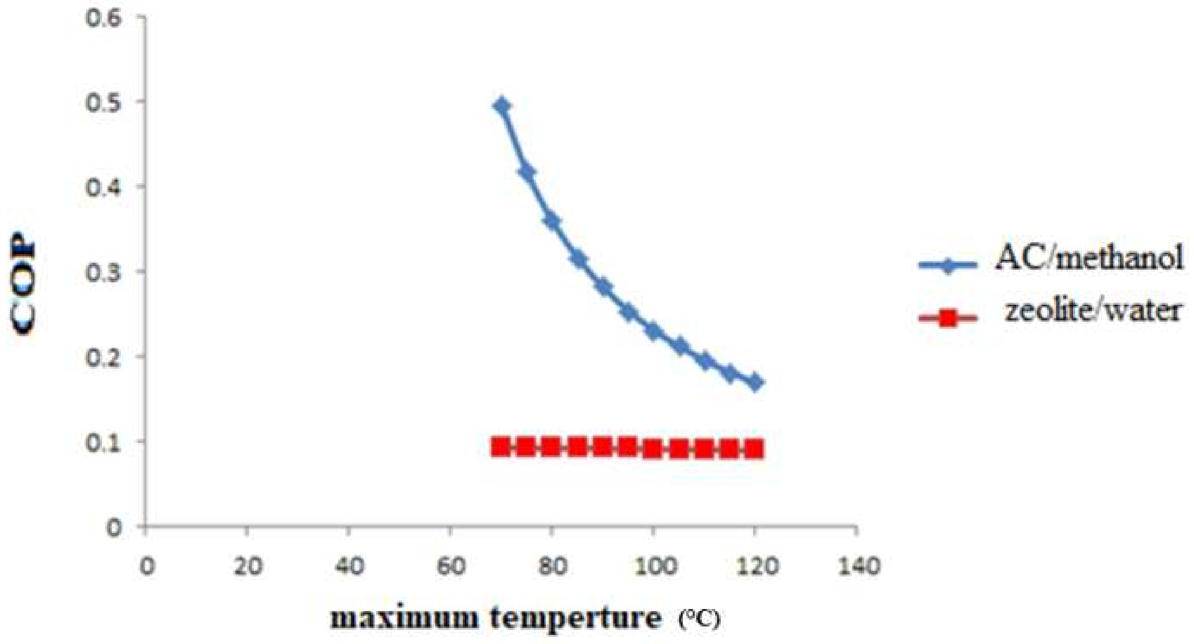

Fig.5.variation of COP with maximum temperature T_g and type of the pair.

5.5. Effect of condensing pressure

Fig. 6 shows the variation in the effect of condensing pressure on the coefficient of performance. The results showed that the COP is slightly affected by the variation of the condensing pressure between 100 mbar and 270 mbar. This corresponds to a maximum COP of 0.346 in the case of the AC / methanol pair and 0.0972 in the case of the zeolite / water pair. Another thing can be seen in the figure is the influence of adsorbent / adsorbate pair type. This is present in this study with the use of the zeolite / water and AC / methanol pair, the latter seems to be the most favourable given the high values of COP given in each simulation under such imposed operating conditions of pressure and temperature and with this type of system and these components illustrated above. In addition, the profitability of the adsorbent / adsorbate couple can be affected by the components of the solar adsorption system used and the operating conditions and the incident solar flux.

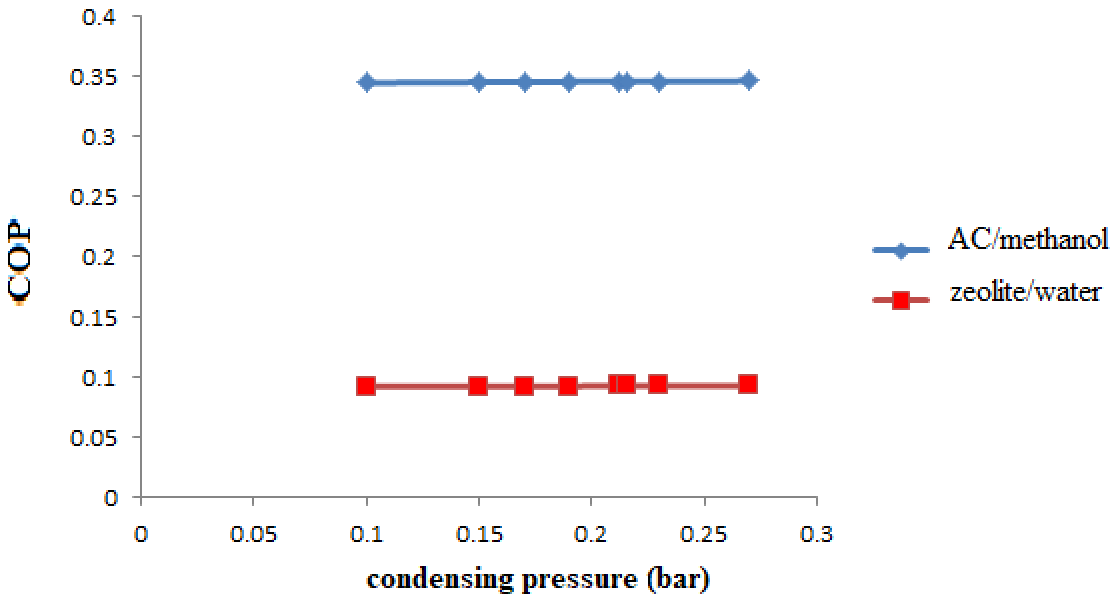

Fig. 6. Effect of condensing pressure P_c and the pair type on the COP.

6. Conclusions

The effects of variations in the operating parameters of a refrigeration system based on AC / methanol and zeolite / water pairs is studied using a thermodynamic equilibrium model describing the amount of heat exchanged in each component of the solar adsorption refrigeration system.

the following conclusions can be drawn:

- The performance of the system in terms of COP varies almost linearly with the generation temperature T_g. The coefficient of performance increases remarkably if T_g is increased.
- The COP decreases with the increase in the evaporating temperature T_e for fixed operating parameters. A similar effect is observed when the maximum heating temperature T_{max} is increased.
- The condensation pressure does not present a determining factor in this study because the COP is slightly affected by its evolution and it is observed that the two pairs used AC / methanol and zeolite / water give the same variation while the effect was different. which appears in a COP of 0.346 in the case of the AC / methanol couple and 0.0972 in the other case.
- This study has shown that a solar adsorption refrigeration machine operating with the AC / methanol pair is more profitable than a machine operating with the zeolite / water pair, which justifies the wide use and commercialization of this pair in this field in the face of other.

This study evaluated the direction of variation of COP as a function of the operating parameters with a comparison between the two pairs used in this adsorption solar refrigeration system and their effects on performance, which leads to an improved system with a COP comparable to values reported in the literature. These results are therefore useful for further research into performance improvements in this area and with this type of systems.

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Figures

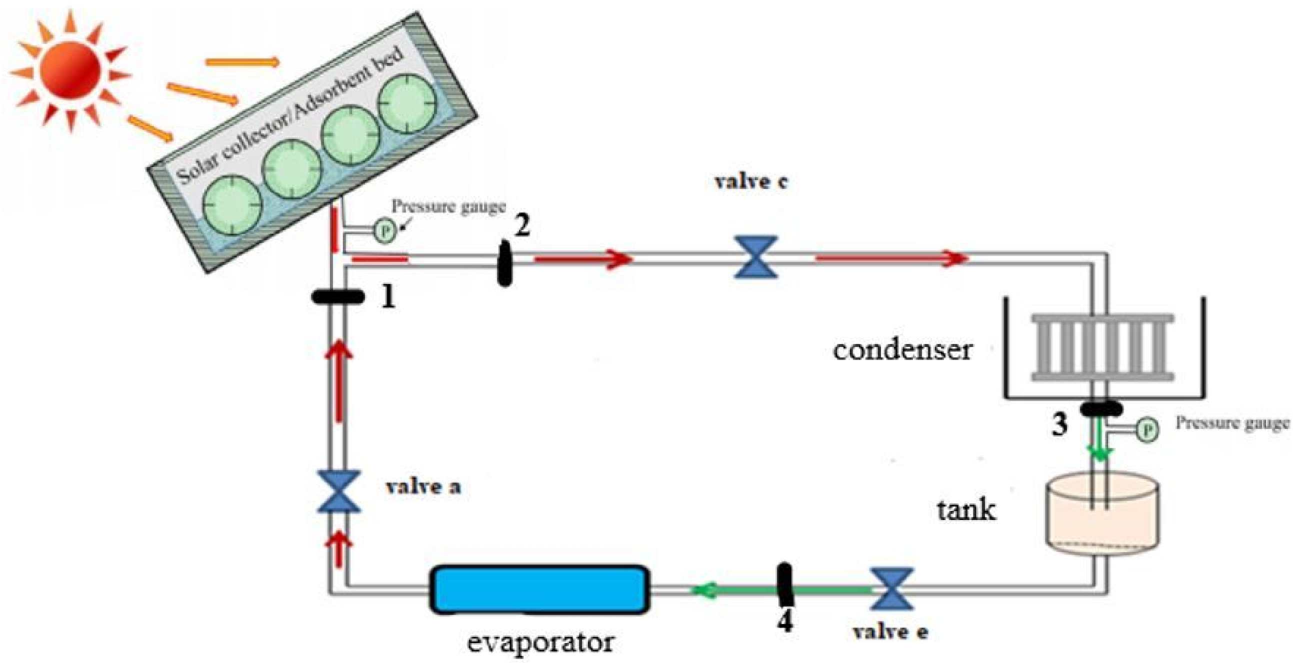

Figure 1

Schematic diagram of the solar adsorption refrigeration system.

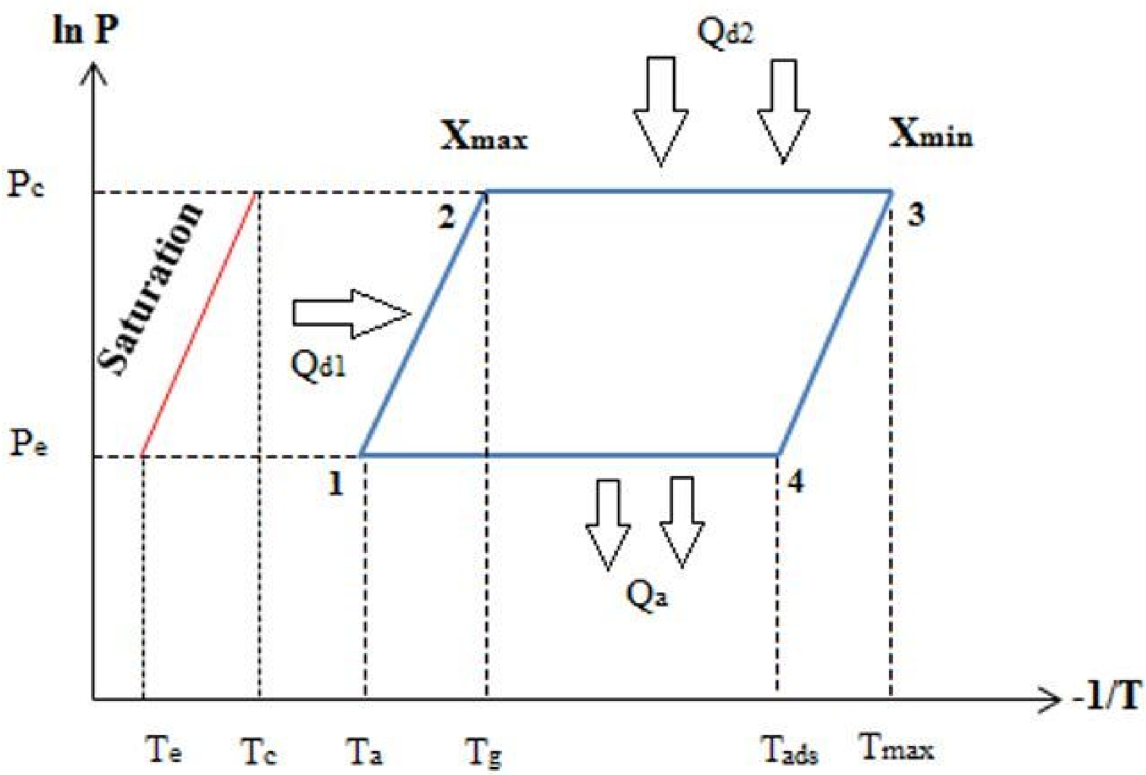

Figure 2

Theoretical cycle of the adsorption solar refrigeration system (Clapeyron diagram)

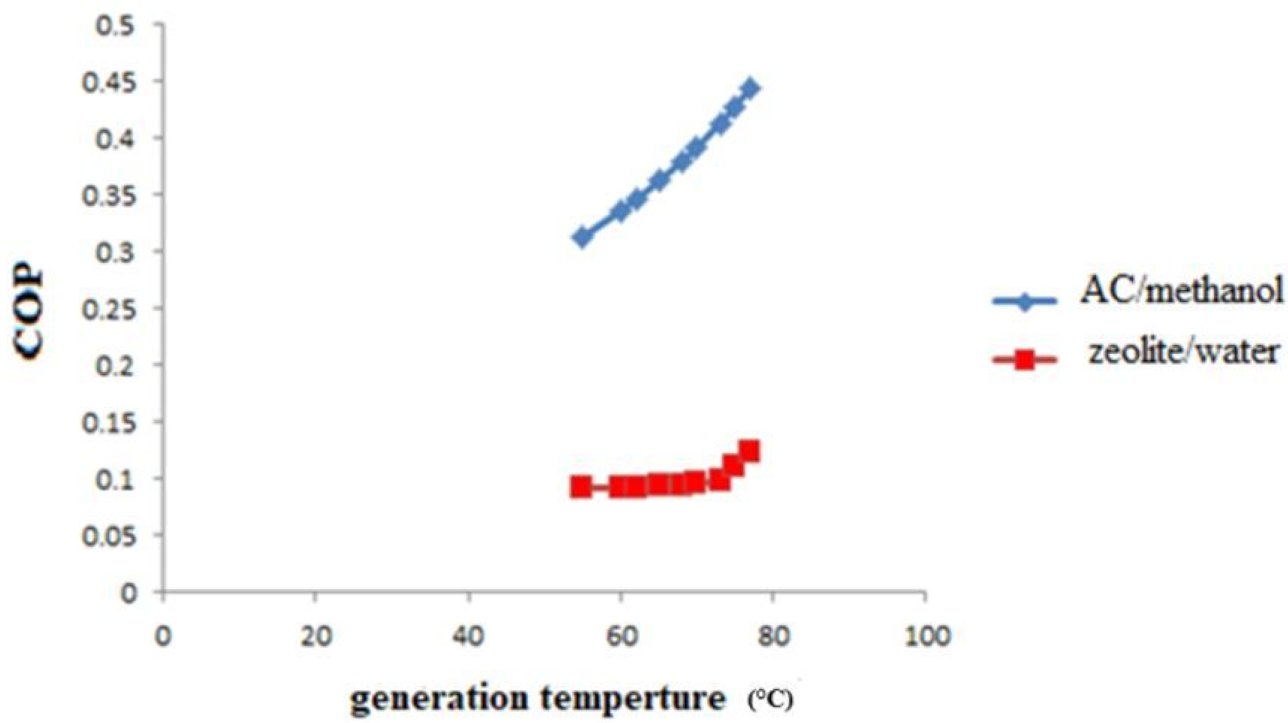

Figure 3

Effect of the generation temperature Tg and type of the pair on the COP

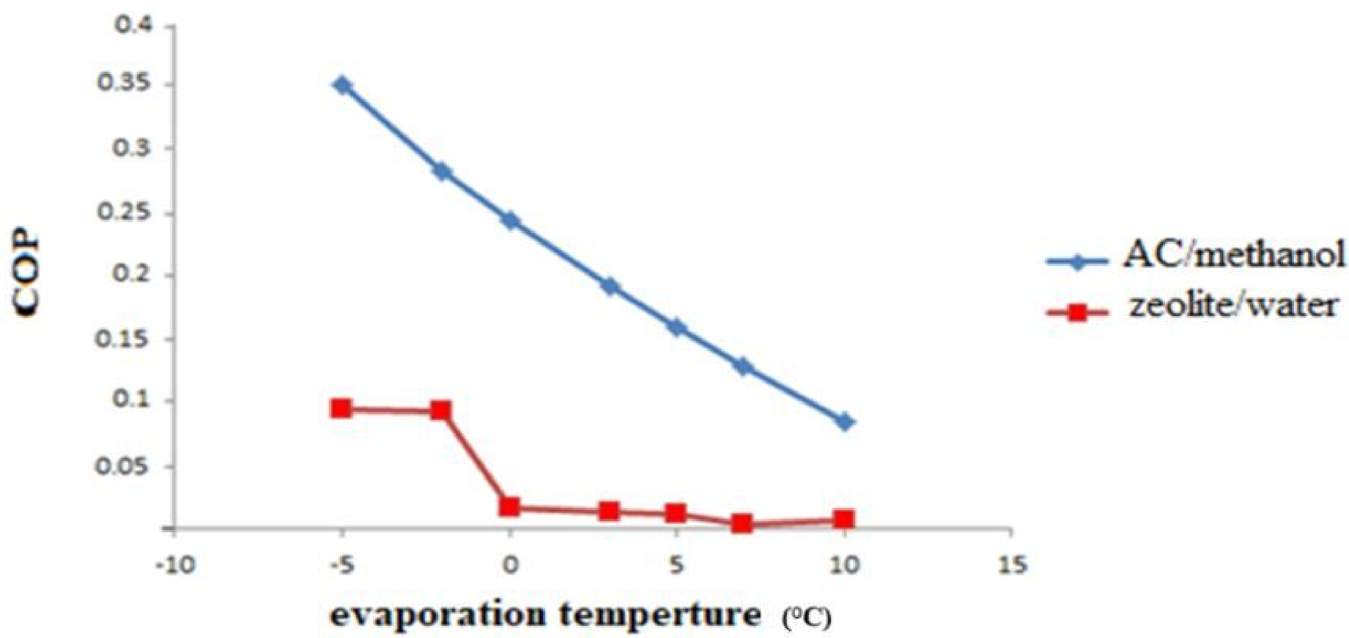

Figure 4

COP variation as a function of the evaporation temperature Tev and type of the pair.

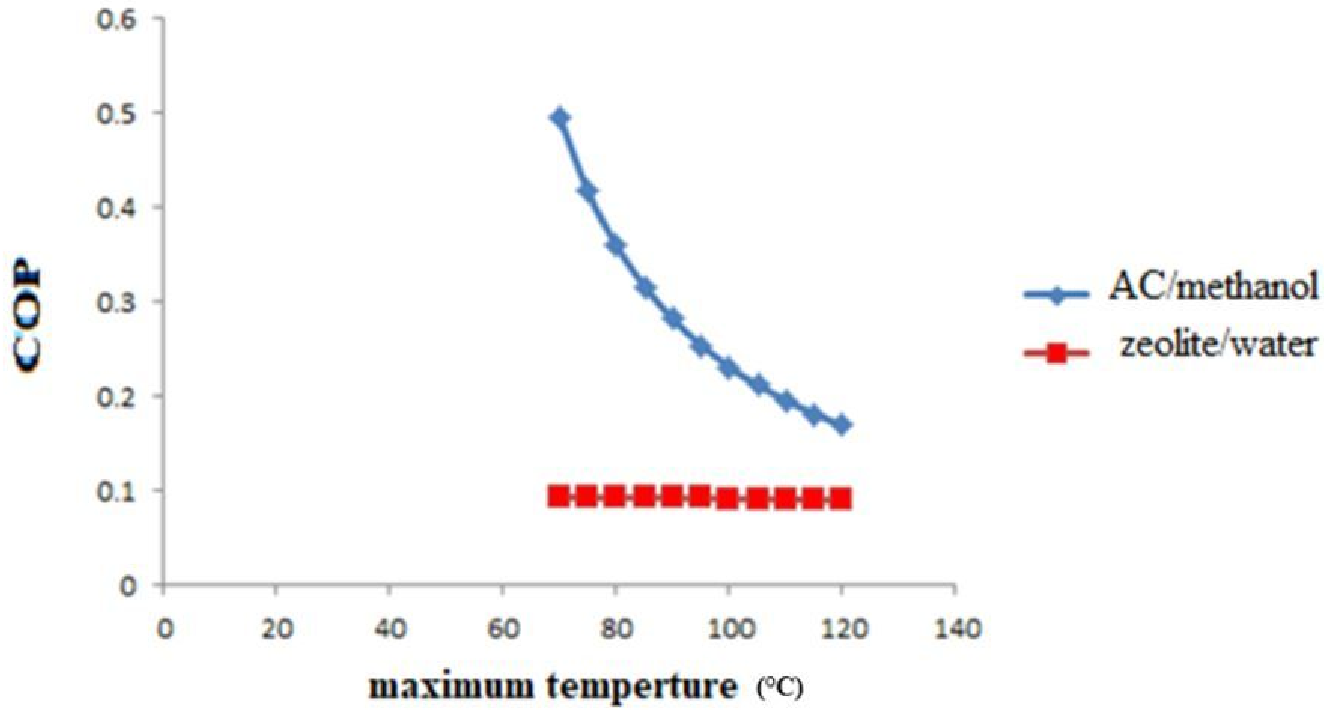

Figure 5

variation of COP with maximum temperature Tg and type of the pair.

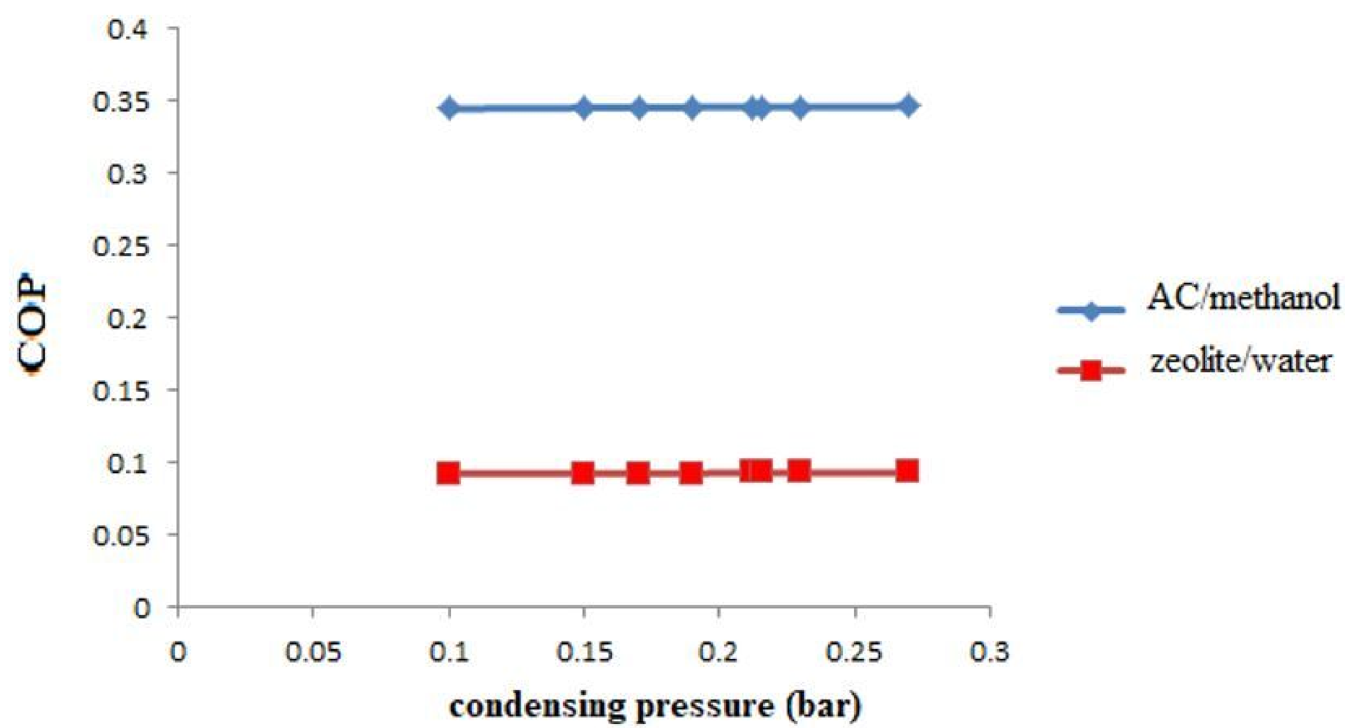

Figure 6

Effect of condensing pressure P_c and the pair type on the COP.