



Parametric study of solar adsorption cooling machine under the climatic conditions of Algeria

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Abstract:

A parametric and comparative study was carried out for the simulation of the performance of the adsorption solar refrigeration system and under the climatic conditions of the region of Tlemcen (35.0 ° N / -1.5 ° E, 247m), Algeria. The performance considered in this study was the coefficient of performance COP of the system. The system considered is a solar adsorption cooling machine in its basic configuration. For this, a mathematical model representing the evolution of the solar irradiation and the ambient temperatures was developed and the Dubinin-Astakhov equation was adopted to describe the adsorption rate. We have analysed the influence of the working pair type in parallel with the solar collector area, the adsorption concentration rate, the operating temperatures including the evaporating and the condensing temperatures. The working pairs tested were the AC/methanol and the AC/R134a refrigerant. The temperatures and the solar irradiation profiles were obtained during one day for the four months studied December, April, July and October to analyse the effect of the climatic conditions and mainly the daily solar irradiation on the system performance. The results shows that the COP's reached by the AC/methanol is higher than those reached by the AC/R134a. it was obtained also that the COP was sensitive the solar collector area and the adsorption rate. it decrease with increase in the solar collector area and increase with the increase in the adsorption rate. The COP was also slightly affected by the operating parameters: the evaporating and the condensing temperatures. The climatic conditions have proved that the COP is more suitable during the month of December and October than the April and July.

Key words: Solar cooling, adsorption refrigeration, methanol, R134a, COP.

Nomenclature		indices	
A	solar collector area, m ²	cd	condensation
AC	activated carbon	ev	evaporation
COP	coefficient of performance	max	maximum
Cp	specific heat, kj/kg.k	min	minimum
D	D-A equation parameter		
I	solar intensity, W/m ²		
I _{c,max}	maximal Solar intensity, W/m ²		
G	Solar global irradiance, W		
L	latent heat, kj/kg	α	collector absorptivity
M _a	adsorbate mass, kg	γ	collector reflectivity
n	exponential constant	η	solar collector efficiency
P	pressure, bar		
P _s	saturated pressure, bar		
Q _f	cooling production, W		
T	temperature, °c		

t	time, s
X	concentration ratio, kg.kg ⁻¹

1. INTRODUCTION

The world has witnessed significant economic change for over a century; industrial development, the increase in the automobile fleet and the proliferation of domestic equipment have caused significant growth in energy demand. Solar (solar photovoltaic, solar thermal), hydropower, wind, biomass and geothermal energy are inexhaustible flows compared to "stock energies" from fossil fuel deposits in the process of becoming rare: oil, coal, natural gas [1].

Due to the growth in the energy demand and the increasing concern about climate change in the world, renewable energies and mainly solar energy was considered as an alternative solution. In this context, cold production was known to be achieved by vapour compression cycles which use electricity generated by fossil fuels and uses refrigerants causing environmental problems due to CFC's and HCFC's. Thus, many researches have been taken into account to develop cooling technologies which respond to the environmental and energetic factors. Recently, solar adsorption cooling technology was the subject of numerous studies [2,3].

Solar adsorption cooling is considered the second main technology of solar cooling after absorption technology and was found very appropriate in remote areas and for food and medicines storage applications. While this technology is considered as an alternative to the ecological problems, some factors appear to be drawbacks for solar adsorption cooling like the low performance and high cost of the machine component. Thus, the research activities have focused on solving the technical and economical problems [4].

Numerous studies were carried out to evaluate the system performance [5] of solar adsorption technology in order to hold the appropriate improvements of the technical factors [6] and for the optimization of the system performance [7].

N. Douss and F. MEUNIER tested and simulated the effect of the operating parameters and the type of the working pairs on the solar adsorption machine. They found that the COP was very sensitive to the evaporating and adsorbing temperatures and that the AC/methanol working pair had higher values of COP [8]. A numerical study for solar adsorption cooling system was carried out by Leite et al. The effect of a single cover and a TIM on the performance was studied. It was found that the TIM proved to be 40% more efficient than the single cover [9]. A numerical study was developed to determine the effect of the design parameters on the performance of a solar adsorption refrigerator using flat plate collector and silica gel-water pair. The main parameters in this study were the mass of silica-gel, the number of metallic fins in the silica-gel bed, the orientation of the solar collector [10]. Shu Xu analyzed the effect of the thermal conductivity of adsorbent, the flow rate and the inlet temperature of the heat transfer fluid [11]. Kumar et al studied the influence of collector area and cycle time on the performance of a single-stage, two-bed silica gel / water adsorption chiller. They found that both daily average and cyclic average COP increase with increase in solar collector area and the same thing for the cycle time [12]. Cherrad et al developed a numerical model to study the influence of heating time of the adsorber/collector on

the performance of a solar adsorption refrigerator. The results shows that the shorter heating time corresponds to higher efficiencies of adsorber/collector and the maximum COP reached was 0.11 [13]. Chekirou et al studied the effect of solar collector area and its configuration, solar total irradiation on system's performance. They concluded that both the COP and cooling capacity decrease when solar collector area increases while the utilization of TIM for collector insulation shows best results then the double and single glazed configurations [14]. [15] Discussed the effect of switching and cycle time on the chiller performance for tow bed silica gel adsorption chiller. The results showed that a maximal COP of 0.56 can be attend by a chosen 450s a cycle time. Moreover, an 11% increase in COP can be achieved by a 0.4% reducing in maximal cooling capacity. Tubreoumya et al analyzed the influence of the adsorbate/adsorbent working pairs, the solar flux, and the ambient temperature on the adsorption and desorption process of a silica gel -water adsorption solar refrigeration system [16]. [17] Modelled and discussed the effect of the collector surface area and the operating temperatures of an adsorption cooling system powered by solar energy with activated carbon-methanol. The results showed that both coefficients of performance decrease with the increase of solar collector area, and strongly depends on the operating temperatures considered. Li and Ji designed, analyzed and optimized a large-diameter aluminum-alloy finned-tube adsorbent bed collector for enhancing the heat transfer and reducing the uneven temperature distribution in the collector/adsorber. The adsorbent bed efficiency was improved between 31.64% and 42.7%, the maximum COP was 0.122 and maximum daily ice making can

achieve 6.5 kg [18]. The choice of the adsorbent / adsorbate pairs appeared essential and decisive on the performance of the system.

From literature above, it can be found that a good improvement of technical problem of solar adsorption cooling systems can be brought. Hence, high cooling capacity, coefficient of performance and adsorption chiller temperature can be achieved by a good analyzing of the influence of all type of parameters theoretically, then approve it experimentally in manufactures [19].

This work aims to provide a parametric and comparative study of the solar adsorption cooling system in Algeria by testing the influence of thermodynamic, geometric and meteorological parameters on the system performance. The model described in this study takes into account the climatic data of the region of Tlemcen in Algeria during the day of the four months: December, April, July and October. The influence of: the thermodynamic operating parameters given by the evaporating and condensing temperatures, the solar collector area, the adsorption concentration rate and the climatic data for the chosen working pair adsorbent/adsorbat on the system performance were discussed.

2. SYSTEM DESCRIPTION AND WORKING PRINCIPLE

The studied system is a solar adsorption refrigerator in its simplest form, the schematic diagram of which is shown in fig. 1. 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. [19]

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

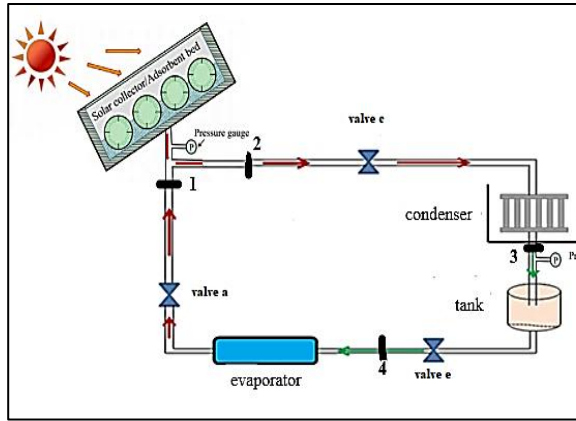


Figure 1. Schematic diagram of the solar adsorption refrigeration system

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} that 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 T_c . 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 T_c .

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 [19].

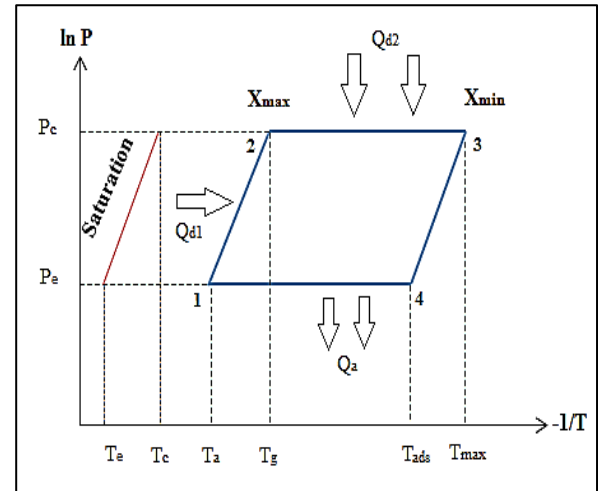


Figure 2. Theoretical cycle of the adsorption solar refrigeration system (Clapeyron diagram).

3.SOLAR INTENSITY AND AMBIENT TEMPERATURE

In order to simulate the system, the ambient temperature and the solar intensity were modelled and simulated during one day of the months: april, july, october and december in the region of tlemcen ((35.0 °N / -1.5 °E, 247m), Algeria).

Transient solar irradiance evolution and the total solar irradiance [20] received by the solar collector from sunset to sunrise is given by Eq. (1) and Eq. (2).

$$I(t) = I_{c.max} \sin\left(\frac{\pi(t-t_{sunrise})}{(t-t_{sunset})}\right)$$

$$(1) \quad G(t) = A\alpha\eta \int_{sunrise}^{sunset} I(t)dt$$

(2)

Where A is the collector surface area, α is the collector absorptivity, η is the collector efficiency and γ is the collector reflectivity [21].

The ambient temperature is calculated by the following equation [20]:

$$T_{amb}(t) = \frac{T_{amb.max} + T_{amb.min}}{2} + \frac{T_{amb.max} - T_{amb.min}}{2} \sin\left(\frac{\pi(t-t_{sunrise})}{(t-t_{sunset})}\right)$$

(3)

Where $T_{amb.max}$ and $T_{amb.min}$ are the maximal and minimal ambient temperatures. $T_{amb.max}$, $T_{amb.min}$ and $I_{c.max}$ were obtained from Meteonorm.

Figure 2. (a) and (b) Shows the hourly evolution of the ambient temperature and the solar irradiation during one day of December, April, July and October.

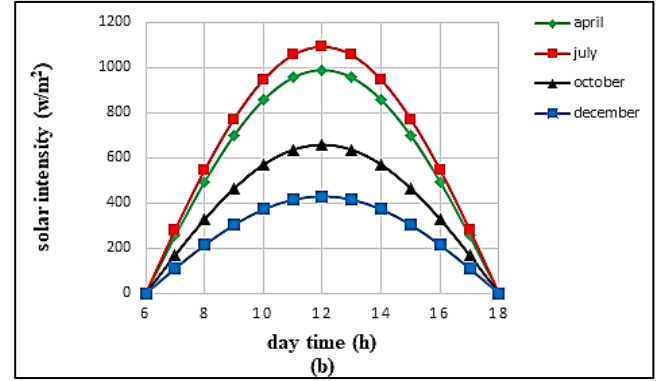
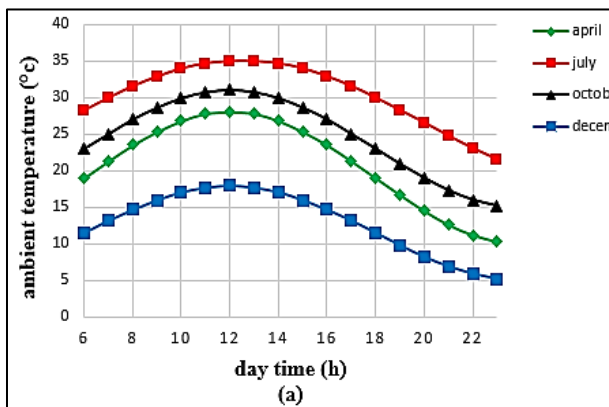


Fig 3. Hourly evolution of solar radiation and ambient temperature.

4. PERFORMANCE ANALYSIS

The system considered in this study is a solar adsorption cooling machine as shown in figure (1) and the performance studied is the coefficient of performance COP that can be calculated as the following:

$$COP = \frac{Q_f}{G(t)}$$

(4)

Where, Q_f is the cooling production, it is defined by the adsorbate latent heat of evaporation minus the sensible heat to cool the adsorbate from the condensation temperature to the evaporation temperature, and it is given by [22]:

$$Q_f = M_a \Delta X [l(T_e) - \int_{T_e}^{T_c} Cp(T) dT]$$

(5)

Where, M_a is the adsorbate mass, ΔX is the instantaneous uptake calculated by the Dubinin-Astakhov D-A equation [23].

$$X = X_0 \exp \left[-D \left(T \ln \frac{P_s(T)}{P} \right)^n \right]$$

(6)

Where, X_0 is the maximum uptake capacity, D and n are the D-A equation parameters, $P_s(T)$ is the saturated pressure of the adsorbate.

5. RESULTS AND DISCUSSION

A parametric and comparative study was carried out based on a numerical model. In order to evaluate the system performance, an equilibrium model described by the Dubinin-Astakhov D-A equation was chosen. The model is based on the thermodynamic equilibrium and given by a set of simplified mathematical equations. The model was justified in fact that the cooling production is given in function of the D-A parameters and that the heat and mass transfer of the solar collector is not taken into account. so this model is sufficient to solve the problem, and we are not need to define the solar collector type and to use a model of high order.

The metrological data have been presented in fig. 2 during one day of the four months: April, July, October and December.

The previous studies shows that the operating parameters of the solar adsorption systems were been very important and affecting the system performance. Thus, the choice of the variation range of the parameters like pressure, temperatures and the adsorbed concentration rate is necessary for the optimization of the system performance. Other parameters like the solar collector area and the working pair adsorbent/adsorbate type were found essential for the optimization of the system performance.

The estimates of the saturated vapour pressure, the specific heat and the latent heat of the selected working pairs are given by Weast [24], Bejan and Kraus [25].

The parameter values and the operating conditions are cited in table 1.

Table 1. Parameter values and operating conditions used in the model.

Symbol	Parameter	Value
A	Surface collector area	1 m^2
α	Collector absorptivity	0.95
η	Collector efficiency	0.935
γ	Reflectivity of the collector	0.7
$t_{sunrise}$	Sunrise time	6h
t_{sunset}	Sunset time	18h
T_e	Evaporating temperature	5°C
T_c	condensing temperature	25
M_a	adsorbate mass	29 kg

5.1. Validation

The model is validated with the results of [13] for the adsorption cooling system powered by solar energy. The system uses the activated carbon AC-35/methanol as a working pair. The fig.8 compares the effect of solar collector area on the COP obtained by [13] for a single glazed cover with the present simulation. A good agreement between the present simulations with the results compared with validates the numerical model adopted for this study.

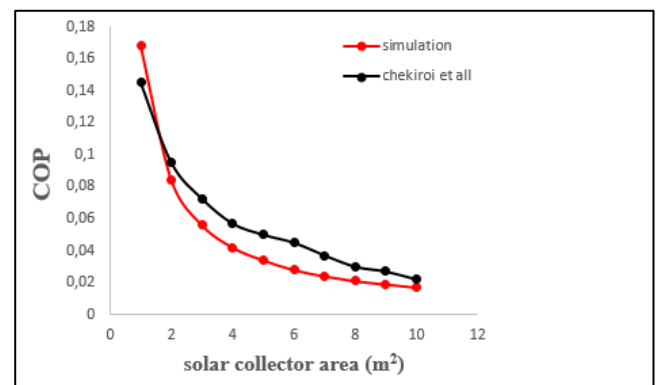


Figure .4. Comparison of simulated and obtained results by [13].

5.2. Effect of solar collector area

Fig.4 represents the evolution of the system performance with the solar collector area for tow working pairs AC/methanol and AC/R134a in the four months.as can be shown from the figure, the system performance considered is the coefficient of performance COP which decreases with the increase of the solar collector area for both working pair types used in this study.it can be noticed that the obtained results differs from a working pair to another and from month to another. For the first working pair AC/methanol the COP's can reach a higher values in the range of 0.65 in the month of December then the second working pair AC/R134a which can be around 0.25.

The climatic conditions seems to be affecting the COP and can be seen clearly from the figures for the same working pair, the month of December can reach the higher values of the COP then the other months April, October and July.

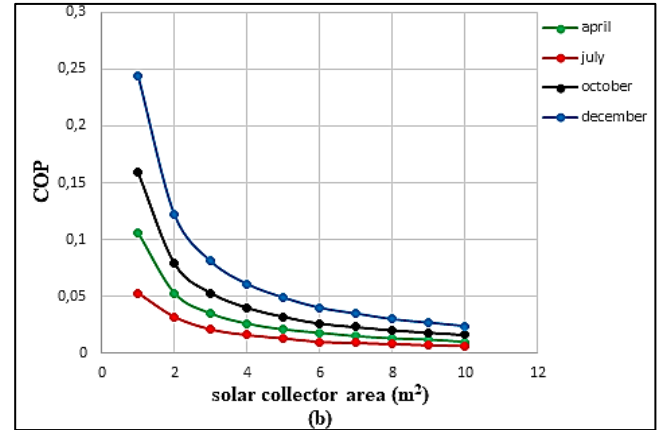
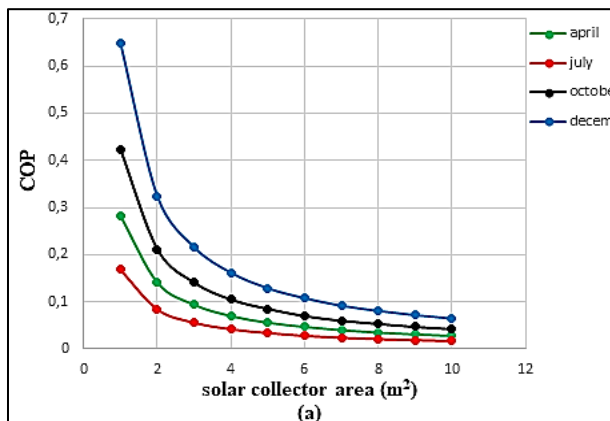


Figure 5. Effect of solar collector area and the working pairs type on system's performance.(a) AC / methanol, (b) AC / R134a.

5.3. Effect of the concentration ratio

The effect of the adsorbed phase concentration rate on the COP is shown in the figure 5.from the figure we can notice that the COP increase with the increase in the concentration rate for the tow working pairs. this is due in fact that the increasing in the rate of absorption of the adsorbent will increase the rate of the adsorbed mass of the adsorbate to fix on the microporous of the adsorbent, which means more adsorbed mass and more cooling production.it was noticed also that the COP's reached by the AC/methanol is higher than those reached by the AC/R134a working pair. This is a result of being that the rate of absorption of AC to methanol is higher than the absorption of R134a refrigerant. Thus, the choice of the working pair type can affect the system performance and even the adsorbate type, which shows in this study that the methanol is more profitable than the R134a refrigerant.

The system performance is affected also by the climatic data, which can be seen from the figure. The COP is higher in the month of December, decrease in April, October,

and has the lower values in the month of July.

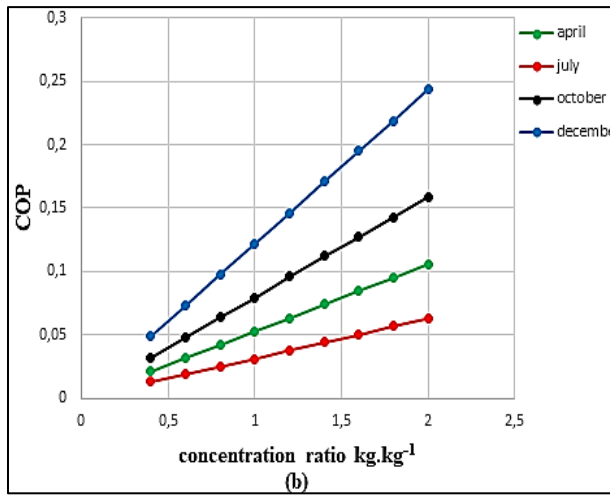
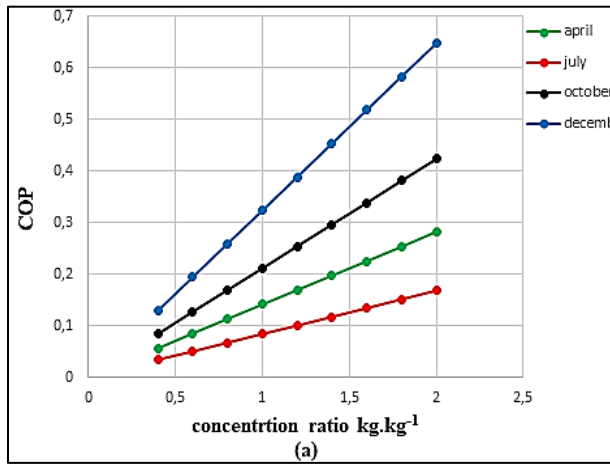


Figure 6. Effect of concentration rate and the working pair type on the COP.(a) AC / methanol, (b) AC / R134a.

5.4. Effect of evaporating temperatures

The evolution of the system performance with the evaporating temperatures is shown in figure 6.the results shows that the COP increase with the increase of the evaporating temperatures for the two types of the working pairs AC/methanol and AC/R134a. This is because the increase in the evaporation temperature leads to the increase in the latent heat of evaporation of the adsorbate $l(T_e)$. The sensible heat of evaporation remains much lower than the latent heat, which is why it has a neglected effect on performance. Thus, the

evaporating temperature positively affects the cooling production and then the COP of the system.

It was also noticed that the COP achieved by the AC/methanol is higher than the COP values of the AC/R134a.the results shows also that the system performance increase in winter and decrease in summer. For the first working pair the highest value of the COP was found to be 0.54 in December and 0.14 in July as a lower value. While for the second case the COP calculated, was 0.20 in December and 0.05 in July.

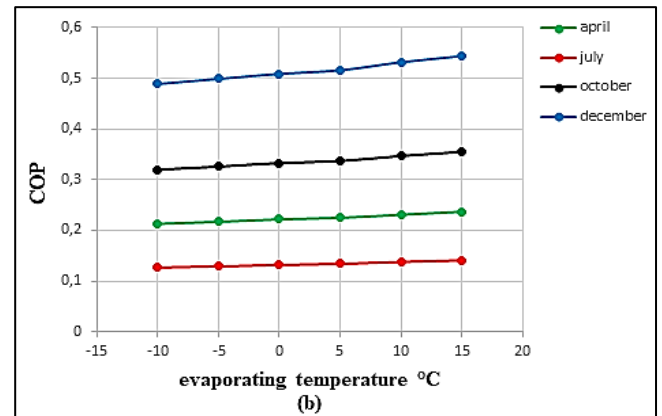
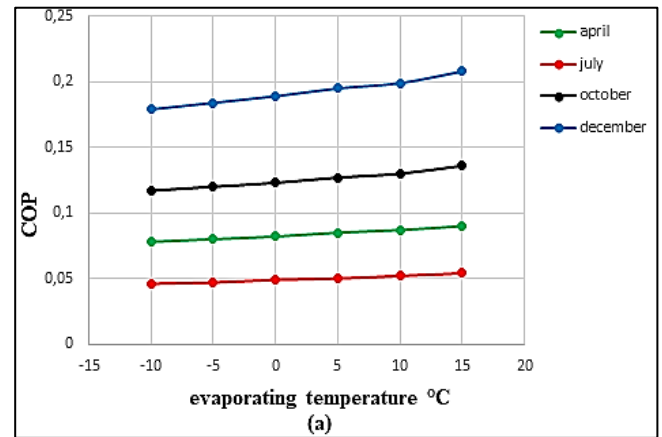


Figure 7. Effect of the evaporating temperatures and working pairs on COP. (a) AC / methanol, (b) AC / R134a.

5.5. Effect of the condensing temperatures

The variation of the COP of the system with the condensing temperatures is shown

in figure 6. the results shows that the COP decrease with the increase in the condensing temperatures. It was also noticed that in the case of the AC / methanol pair, the COPs achieved were higher in the range of 0.53, than those of the AC / R134a pair, which can reach to 0.20. The performance of the system was apparently affected by the climatic conditions of the region. In July, the COP was found to be lower than the COP calculated in December. For the same working pair, the COP calculated in december was found to be around 0.53 while it was in the range of 0.14 in july for the AC / methanol. For the AC / R134a working pair the COP was found to be 0.20 in December and 0.05 in July

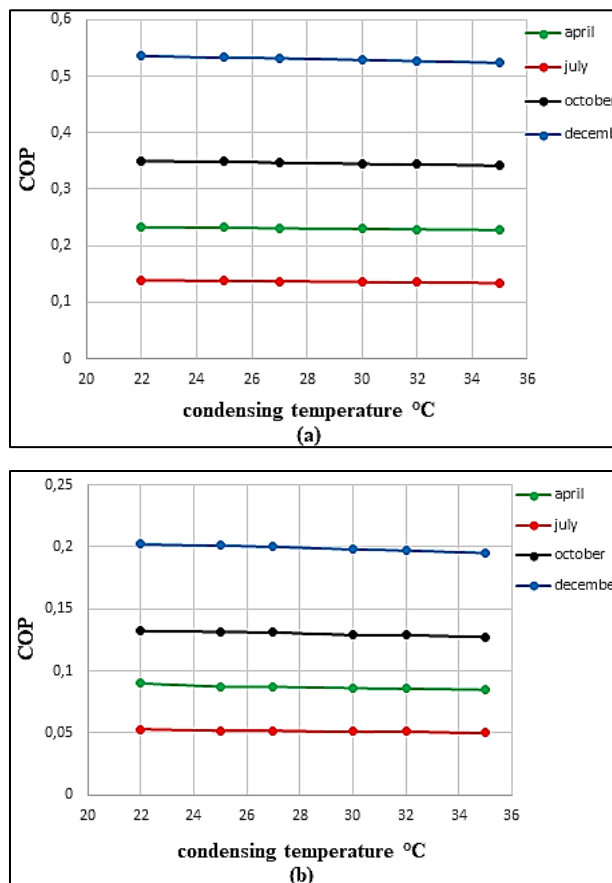


Figure 8. Effect of condensing temperatures and the working pair type on system performance. (a) AC / methanol, (b) AC / R134a.

6. CONCLUSION

A comparative and parametric study based on a theoretical model of a solar adsorption refrigeration system was carried out. The effect of the of the solar collector area and the concentration rate of the adsorbed phase, the condensation and evaporation temperatures as well as the type of adsorbent / adsorbate working pairs and the climatic conditions during the months of: December, April, July and October on the coefficient of performance were discussed. It was found that the coefficient of performance of the system varied greatly with the surface of the solar collector and the concentration ratio of the adsorbed phase for the two working pairs studied. The COP was also found to be sensitive to the climatic conditions studied during the four months. There was deference in the behaviour of each of the AC / methanol and AC / R134a working pairs.

The sizing of the collector area and choice of some operating parameters like the condensing and evaporating temperatures and the working pairs are key parameters for successful operation of a solar adsorption cooling system.

It should be noted that the high cost and low performance are the main drawbacks of the solar adsorption refrigeration systems and the increasing the performance of such a system increases the cost of the machine. Consequently, the research is still active to remove the technical problems and to reduce the economical issues of the solar adsorption cooling systems.

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