Conférence Internationale en Automatique & Traitement de Signal (ATS-2018)
Proceedings of Engineering and Technology – PET
Vol.35pp.108-113

Sensitivity analysis to optimize a solar adsorption cooling system using Moroccan climate data

ABAKOUY Hanane [#1], EL KALKHA Hanae [*2], BOUAJAJ Adel [*3]

Laboratory of innovative technologies, National School of Applied Sciences Tangier, Morocco
[1]hananeabakouy@gmail.com
[*] Department of Industrial and Electrical Engineering,
National School of Applied Sciences Tangier, Morocco
[2]elkalkha_hanae@yahoo.fr
[3]dbouajaj@yahoo.fr

Abstract—

Study of the sensitivity analysis of solar adsorption cooling system is presented in this paper. The aim of this study is to focus on the critical parameters that affect the performance of this system.

The main examined factors are the geometric parameters, climate data and the working pair.

So, the study shows that the parabolic trough collector (PTC) provides the effective temperature compared to that achieved by the flat plate collector. Activated carbon-methanol and activated carbon-ammoniac are the working pair that provide the effective temperature, according to the climate data which is the most important parameter, the coefficient of performance (COPs) increase with high solar radiation and decrease when initial temperature is higher.

Keywords-component; refrigerattion systems, solar energy, adsorbante, adsorbant, parabolic trough collector, flat plate collector, climate data, Morocco.

I. INTRODUCTION

Since the 1848s, a considerable number of researchers are focusing on the study of adsorption cooling machines [1-2]. Scientists have become aware about the traditional refrigerator systems major problems. These machines are dominating electricity consumers [3]. In addition to the problem related to energy shortage and environmental pollution. So, researches on adsorption cooling have gained a renaissance in a strong direction.

Solar adsorption refrigerator system is a process based on the phenomenon of adsorption which occurs when a balance is established between a couple of adsorbate / adsorbent. When solar energy is used as the main energy source, activated carbon, zeolite, and silica gel are the common materials used as an adsorbent. Environmental-friendly materials including ammonia, methanol [4], or water [5] can be a refrigerant. The adsorbent-refrigerant pairs used in this kind of system are considered as zero ozone depletion potential as well as zero global warming potential.

Despite their potential advantages, the existing solar adsorption cooling systems are not yet competitive enough to replace electricity-driven refrigerators because of their low efficiency, intermittent operation, and high initial cost.

So, in this study, we will focus on the critical factors that affect the performances of this system, which will make it possible to highlight the variation of the critical parameters influencing the behavior of this machine, and improve the overall performance of the system.

II. SYSTEM DESCRIPTION

A. Solar adsorption refrigeration machine

The solar adsorption refrigeration machine (figure 1) is constituted by three main elements [6]:

- A reactor (adsorber) enclosed in a solar collector, containing the adsorbent/adsorbate mixture, where the phenomena of adsorption and desorption are produced;
- A condenser, where the refrigerant is liquefied ;
- An evaporator, in which the refrigerant evaporates, producing cold ;

When solar radiation is available, the solar collector captures the solar thermal energy, which is transferred to an adsorber reactor located inside the collector. The heated adsorber reactor releases the refrigerant from its adsorbent in desorption process. The suitability of this configuration has been already assessed by several authors [7], [8-9].

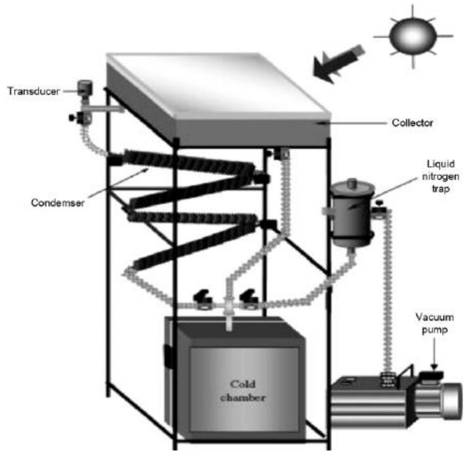

Figure 1: Layout of an experimental solar adsorption refrigeration

ISSN 2356-5608

B. *Adsorption refrigeration cycle description*

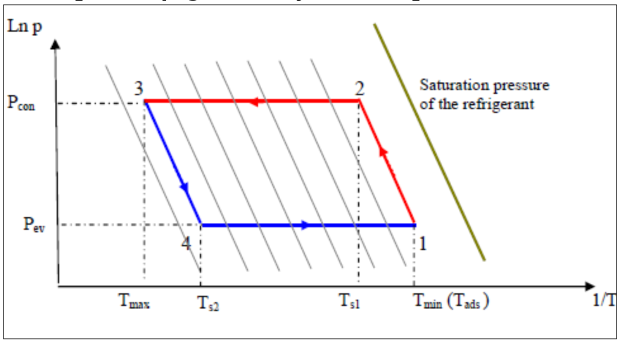

Figure 2: Thermodynamic cycle of adsorption refrigeration machine

An ideal cycle (1-2-3-4) of solar adsorption refrigerating machine is represented on the diagram (Figure 2). The cycle represents the evolution of the mixture adsorbent-adsorbate contained in the adsorber, It consists of two isosteric phases (1-2 and 3-4), where the adsorbed mass remains constant, and two isobaric phases (2-3 and 4-1) where the pressure remains constant [6].

C. *Working pairs*

A number of studies have been carried out both experimentally and theoretically, for the selection of adsorbent-adsorbate materials. In this kind of system the working pair requires the following characteristics:

1. A refrigerant with a large latent heat of evaporation.
2. A working pair with high thermodynamic efficiency.
3. A small heat of desorption under the envisaged operating pressure and temperature conditions.
4. A low thermal capacity of the adsorbent material.

So, the most widely used working pairs are: zeolite – water, activated carbon – methanol, silica gel – water and activated carbon – ammonia.

D. *Solar collectors*

As a part of solar adsorption cooling system, solar collector provides the driving energy for system operation. Flat plate collectors are commonly used in this kind of systems [10-11]. Some attention has also been given to use concentrator collector [12-13]. So in this study we made a comparison of the coefficient of performance of this system using two kind of collector: flat plate collector and parabolic trough collector.

a. flat plate collector

A flat plate solar collector (Figure 3) constitute of an absorbent surface exposed to solar radiation, which exchanges with calorific fluid the calories produced by the absorption of the incident radiation.

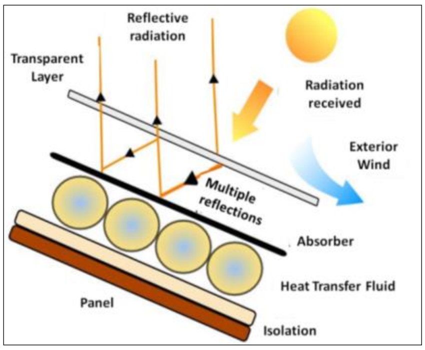

Figure 3: Flat plate collector

b. Parabolic trough solar collector concentrator collector

The parabolic trough collector (Figure 4) consists of a parabolic trough and a linear evacuated tube which is located in the focal line of the parabolic trough. The main idea of PTC is that the reflected radiation over the parabolic trough is directed to the focal point and so all the solar energy is concentrated in the evacuated tube.

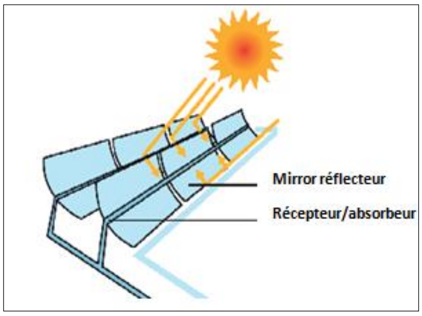

Figure 4: Cylindrical-parabolic collector

III. MODELIZATION

For this modelization, the following assumptions have been adopted [6]:

1) The porous medium properties have a cylindrical symmetry;
2) All the phases are in local thermal all the time, mechanical and chemical balance;
3) The pressure is uniform;
4) The heat transfer is radial and the convection heat transfer owing to the radial mass transfer is neglected;
5) The conduction heat transfer in the medium can be characterized by an equivalent thermal conductivity coefficient.

A. *Equations of heat and mass transfer*

a. The energy conservation equation combined with the masse conservation equation

The transient behavior of the temperatures in the reactive medium is expressed by the energy conservation equation, combined with the mass conservation equation which is written at the position r and at time t by the following equation [14]:

ISSN 2356-5608

$$A(t)\frac{\partial T}{\partial t}=B(t)+\lambda_e\left[\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right] \quad (A.1)$$

Where:

$$A(t)=\left[(1-\varepsilon)\rho_s C_s+\theta\rho_a C_a+(\varepsilon-\theta)\rho_g C_g\right] \quad (A.2)$$

$$B(t)=\left(\frac{p}{\rho_g}\right)\frac{\partial}{\partial t}\left((\varepsilon-\theta)\rho_g\right)+\left(\frac{1}{V_t}\right)\left(\frac{p}{\rho_a}+\Delta H_{ads}\right)\frac{\partial m_a}{\partial t} \quad (A.3)$$

Where:

T absolute temperature (°C)
ε porosity of adsorbent bed
ρ_s density of the solid phase (kg/m^3)
C_s specific heat of solid phase (J/kg K)
θ volume fraction of the adsorbed phase
ρ_a density of the adsorbed phase (kg/m^3)
ρ_g density of the adsorbed phase (kg/m^3)
C_a specific heat of adsorbed phase (J/kg K)
C_g specific heat of gas phase (J/kg K)
p pressure in the reactor (bar)
m_a adsorbed mass in kg of ammonia per kg of activated carbon (kg/kg-CA)
ΔH_{ads} adsorption heat of ammonia on activated carbon (J/kg)
λ_e equivalent thermal conductivity

b. Quantity of cold produced

It's important to know the quantity of cold produced in each cycle, to evaluate the performance of the system. Its expression is:

$$Q_f=\Delta m\left[L(T_{ev})-\int_{T_{ev}}^{T_{cond}} C_{p,l}\,dT\right] \quad (A.4)$$

Where Δm is the cycled mass, given by:

$$\Delta m=m_a\left(T_{ads},P_s(T_{ev})\right)-m_a\left(T_g,P_s(T_{cond})\right) \quad (A.5)$$

Where m_a (T,P), is the adsorbed mass of ammonia at temperature T and pressure P, calculated using the BET model.

$L(T_{ev})$ latent heat at evaporation temperature (J/kg)
T_{cond} condension temperature (°C)
T_{ev}evaporation temperature (°C)
$C_{p,l}$ liquid specific heat (J/kg K)

c. Solar performance Coefficient

The performance evaluation of solar machine is determined from the amount of heat Q_f and Q_s the amount of global irradiation received by the collector surface of the collector, its expression is given by:

$$COP_{sol}=\frac{Q_f}{Q_s} \quad (A.6)$$

Where $$Q_s=S_c\int_{Sunrise}^{Sunset} G(t)\,dt \quad (A.7)$$

And S_c is the collecting area sensor (m^2)

B. *Modeling using a flat plate collector*

The following dynamic equations are given for 1 m^2 of the surface of the planar solar collector [6]:

$$\begin{cases} C_v\frac{dT_v}{dt}=q_v-h_{va}(T_v-T_a)-h_{vs}(T_v-T_s)+h_{pv}(T_p-T_v) & (B.1)\\ C_p\frac{dT_p}{dt}=q_p-h_{pv}(T_p-T_v)-h_{pa}(T_p-T_a)+h_{pm}(T_p-T_m) & (B.2)\end{cases}$$

Where: C_v , C_p are respectively thermal capacity of the glass and the wall (J/K.m2)
h_{va} coefficient of heat exchange (W/K. m^2) between the glass and the atmosphere
h_{vs} coefficient of heat exchange between the glass and the sky
h_{pv} coefficient of heat exchange (W/K. m^2) between the wall and the galss
h_{pa} coefficient of heat exchange (W/K. m^2) between the wall and the atmosphere
h_{pm} coefficient of heat exchange (W/K. m^2) between the wall and the mixture
T_v temperature of the glass (°C)
T_a ambient temperature (°C)
T_p temperature of the wall (°C)
T_m temperature of mixed adsorbent-adsorbate (°C)

$$\begin{cases} q_v=a_v.G; \text{ is the glass absorbed radiations}\\ q_p=a_p.G; \text{ is the wall absorbed radiations}\end{cases}$$

G global irradiation (W/m^2)

a_v and a_p are respectively the glass and the wall absorption coefficients of global radiation

C. *Modeling using a parabolic trough collector*

The equation of the energy balance of the glass tube, surrounding the absorber, is written under the form [16]:

$$\underbrace{\rho_{ve}C_{ve}A_{ve}\frac{\partial T_{ve}}{\partial t}}_{(1)}=\underbrace{\gamma_r\alpha_{ve}\beta\,WI_b(t)}_{(2)}+\underbrace{\pi D_{vi}h_{ab-ve}(T_{ab}-T_{ve})}_{(3)}-\underbrace{\pi D_{vo}h_{ve-amb}(T_{ve}-T_{amb})}_{(4)} \quad (C.1)$$

The different terms of this equation are defined by [15]:

(1) Sensitive energy of the glass tube; where :
ρ_{ve}: Density of the glass tube
C_{ve}: Specific heat capacity of the glass tube
T_{ve}: Temperature of the glass tube

(2) Solar energy absorbed by the glass tube; where:
γ_r: Reflectivity of reflective surface
α_{ve}: Absorptivity of the glass tube

(3) Heat exchanges with the absorber, where
D_{vi}: Inside diameter of the glass tube
h_{ab-ve}: refers to the heat transfer coefficient between the absorber and the glass envelope;

(4) Heat exchanges with atmosphere, where
D_{vo}: Outside diameter of the glass tube

ISSN 2356-5608

T_{amb}: ambient temperature (°C)
h_{ve-amb}: refers to the heat transfer coefficient between the glass envelope and the ambient air;
The equation of energy balance of the absorber (heat pipe) is expressed as follows [15]:

$$\underbrace{\rho_{ab} C_{ab} A_{ab} \frac{\partial T_{ab}}{\partial t}}_{(1)} = \underbrace{\gamma_r \alpha_{ab} \beta\, W I_b(t)}_{(2)} + \underbrace{\pi D_l h_{ab-ve} (T_{ab} - T_{ve})}_{(3)} \underbrace{- \pi D_l h_T (T_{ve} - T_{cal})}_{(4)} \quad (C.2)$$

The different terms of this equation designate respectively [15]:

(1) Sensitive energy of the Sensitive energy, where :

ρ_{ab}: Density of the absorber
C_{ab}: Specific heat capacity of the absorber
T_{ab}: Temperature of the ansorber

(2) Solar energy absorbed by the absorber, where :

α_{ve}: Absorptivity of absorber

(3) heat exchanges with glass, where :

D_l: Outside diameter of the absorber

(4) useful energy, transferred to the heat pipe, where :

h_T: refers to the heat transfer coefficient between the outer surface of the absorber and the vapor-liquid interface.

IV. RESULTS AND DISCUSSION

For this study, the porous medium used is a fixed bed of grains of activated carbon reacting by adsorption with ammonia.
The phases existing in the porous medium are: Solid phase constituted by carbon grains, gaseous phase and adsorbed phase.

A. *Geometric parameters*

We present the results of numerical simulation (Figure 5) [16- 17], obtained using the hourly solar data and climate (ambient temperature and overall solar irradiation) corresponding to a clear typical day of July in Tetouan (Morocco, 35°35' N, 5°23' W), from the climatological database [18] (Figure 5).

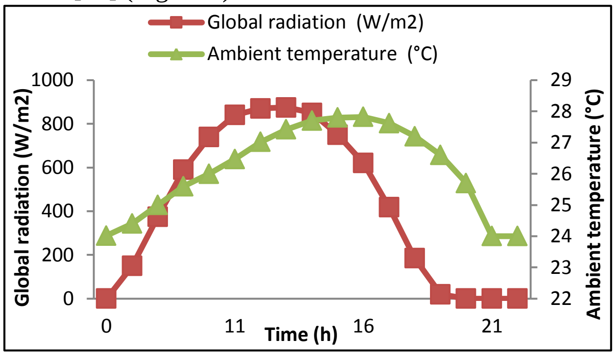

Figure 5: Climate data used in the study for a typical day of July in Tetouan

We present in the figure 6, the COP as a function of the temperature of the working pair [19], we notice that the COPs increase respectively, from 0,06 to 0,15.

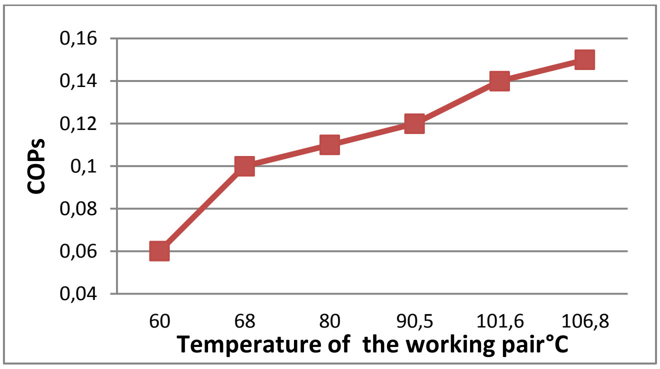

Figure 6: Variation of refrigeration production as a function of the temperature of the working pair [19]

We present in figure 7 the variation of COP as a function of the temperature of the hot source; we notice that the COPs and the refrigeration production increase, respectively, from 0.025 to 0.22 and from 356 to 3030 kJ per day and per 0.8 m^2 of surface area of the concentrator [20].

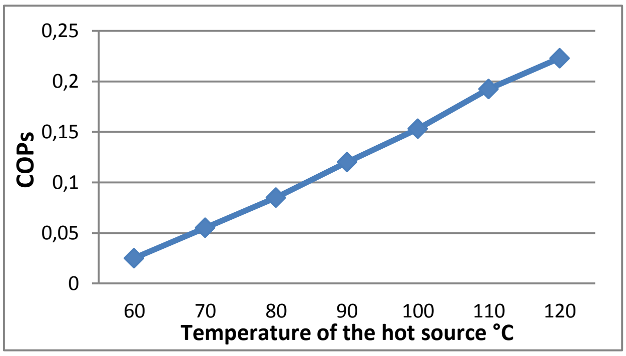

Figure 7: Variation of refrigeration production as a function of the temperature of the hot source [20]

A comparison of the COPs of each collector show us that the parabolic trough solar collector makes it possible to obtain high enough coefficient of performance which is 22% compared with the flat plate collector 15%. So the geometric parameters can be adjusted to increase the energy efficiency of the system. In fact, numerous studies have reported that the parabolic trough solar collector has a high efficiency comparative to other types of collectors [21-22]. It has been tested in various applications, such as steam production [23-24], sea-water desalination [25] and production of hot water [26-27]. The result of this concentration is the high temperature levels in the absorber, because large amounts of energy absorbed in a small region. The use of an evacuated tube increases the thermal efficiency of the collector, because convection losses between the absorber and the cover are eliminated.

ISSN 2356-5608

B. *Climate data*

In this study, we have used the hourly solar data and climate data (ambient temperature and global radiation on inclined surface) corresponding to a clear typical day in three Moroccan cities located in different regions with different climate data Tetouan, Marrakech, Oujda, we have taken into account the climate data obtained in each month May, June, July and September [28].

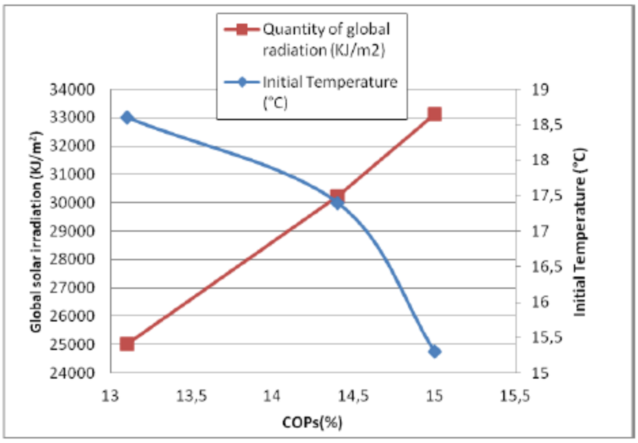

Figure 8: Variation of the COPs as a function of initial temperature and global solar radiation in Tetouan

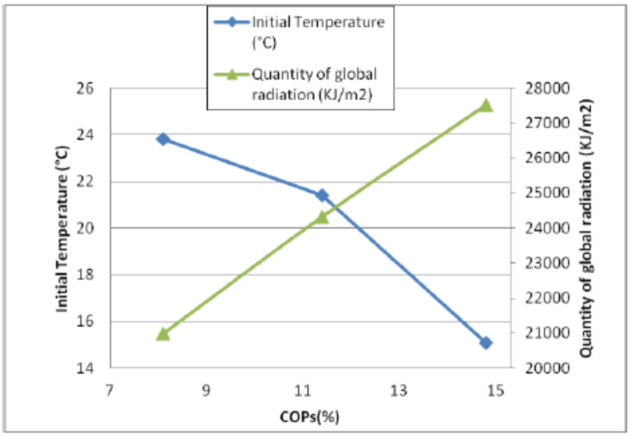

Figure 9: Variation of the COPs as a function of initial temperature and global solar radiation in Oujda

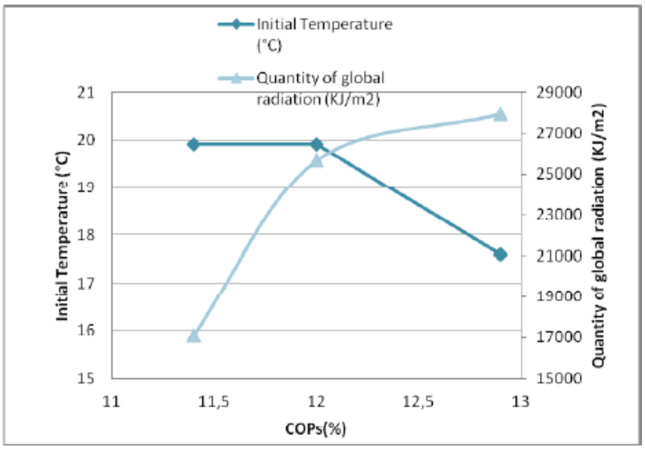

Figure 10: Variation of the COPs as a function of initial temperature and global solar radiation in Marrakech

Figure 8, 9 and 10, show that the coefficient of performance of this system is related to the initial temperature and the global solar radiation of the area of study. The COP increase when global solar radiation increases and decrease when initial temperature increase.

C. *Working pair*

The performance of adsorbent-adsorbate pair is reviewed here based on heat source temperature.

Table 1: Adsorbent –adsorbate pairs used in the solar adsorption refrigeration system

Adsorbent-adsorbate pair	System COP
Zeolite-water [29]	0.1-0.40
Silica gel- Water [30]	0.2-0.3
Activated carbon-Methanol [31]	0.15-0. 23
Activated carbon-Ammonia [32]	0.2-0.7

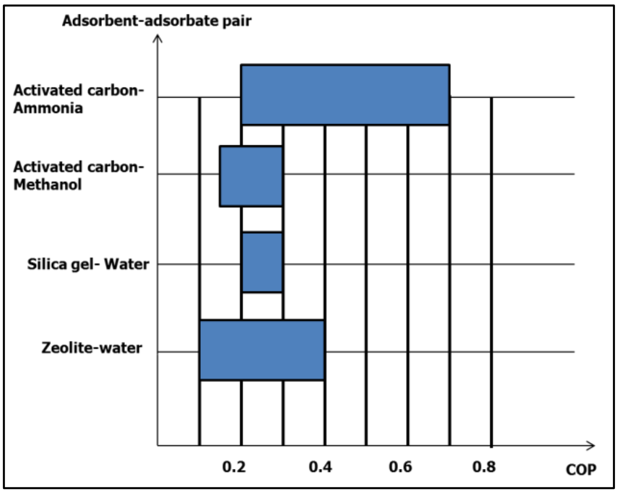

Figure 11: COP reached using different selected adsorbate/adsrbent

The activated carbon-ammonia helps to improve system performance as we can see in Figure 11 and activated carbon-methanol is also a suitable working pair of solar energy because of its relatively low regeneration temperature and low freezing point & no corrosion problem. Moreover, methanol seems to be a good adsorbate, its enthalpy of vaporization is high and its molecule is small enough to be easily adsorbed into micropores. Its working pressure is always lower than the atmospheric one, which means a safety factor in case of leakage. And it can operate at a cooling temperature below 0°C. As a result activated –carbon methanol is the most widely used adsorbent reported in the literature due to its extremely high surface area and micro pore volume.

V. Conclusion

In this paper, we have presented an evaluation of the solar adsorption cooling system with different Moroccan climate data.

- The parabolic trough collector helps to improve the performance of the system compared with the flat plate collector. We can get a higher COP with the parabolic trough solar collector if it's oriented permanently towards the sun and follows its movement.
- The COPs increase with high solar radiation and when the initial temperature is lower.
- The activated carbon-ammoniac helps to get a higher COP.
- The Activated carbon-methanol is widely used due to its extremely high surface area and micro pore volume.

References

[1] Wang, D. ; Zhang, J. ; Yang, Q. ; Li, N. Sumathy, K. Study of adsorption characteristics in silica gel-water adsorption refrigeration. Appl. Energy 2014, 113, 734-741

[2] Lu, Z.; Wang, R.; Xia, Z; Gong, L. Experimental investigation adsorption chillers using micro-porous silica gel-water and compoubd adsorbent-methanol. Energy Convers. Manag. 2013, 65, 430-437

[3] Hassan, H.Z.; Mohamad, A.A. Thermodynamic analysis and theoretical study of a continuous operation solar-powered adsorption refrigeration system. Energy 2013, 61, 167-178

[4] Hassan, H.Z.; Mohamad, A.A.; Bennacer, R. Simulation of an adsorption solar cooling system. Energy 2011, 36, 530-537

[5] Marlinda; Uyun, A.S.; Miyazaki, T.; Ueda, Y.; Akisawa, A. Performance analysis of a double-effect adsorption refrigeration cycle with a silica gel/water working pair. Energies 2010, 3, 1704-1720.

[6] H. El kalkha, A.Ezzarfi, A. Mimet, F. Lemmini, M. Pérez-Garcia, M. Ganaoui, Evaluation of a cold map for a Moroccan climate by a solar adsorption refrigeration machine working with activated carbon-ammonia pair, **2011,** p 3

[7] A. Mimet, Theoretical and experimental study of an active ammonia adsorption refrigeration machine, Doctoral thesis, FPMs, Mons, Belgium, **1991**.

[8] M. Pons and J.J. Guilleminot, Design of an experimental solar-powered, solid-adsorption ice maker. Solar Energy Eng., ASME Trans. 108 (1986) :332-337.

[9] M.Pons and Grenier. Experimental data on a solar-powered ice maker using activated carbon and methanol adsorption pair. J. Solar Energy Eng., ASME Trans. 109 (**1987**): 303-310.

[10] E.E. Anyanwu,; C.I. Ezekwe, Design, construction and test run of a solid adsorption solar refrigerator using activated carbon/methanol, as adsorbent/adsorbate pair. *Energy Convers. Manag.* **2003**, *44*, 2879–2892.

[11] M.Louajari,; A.Mimet,; A.Ouammi, Study of the effect of finned tube adsorber on the performance of solar driven adsorption cooling machine using activated carbon–ammonia pair. *Appl. Energy* **2011**, *88*, 690–698.

[12] M.I.González,; L.R. Rodríguez, Solar powered adsorption refrigerator with CPC collection system: Collector design and experimental test. Energy Convers. Manag. **2007**, 48, 2587–2594.

[13] O.S. Headley; A.F.Kothdiwala,; I.A. McDoom, Charcoal-methanol adsorption refrigerator powered by a compound parabolic concentrating solar collector. Sol. Energy 1994, 53, 191–197.

[14] A. P. F. Leite, M. Daguenet, Performance of a new solid adsorption ice maker with solar energy regeneration, Energy. Convers. Manag., Vol. 41, pp 1625 - 1647, **2000**.

[15] A. El Fadar, Study of a solar refrigeration machine with adsorption of ammonia on activated carbon using a cylindro-parabolic solar concentrator coupled to a heat pipe, p71, (**2009**)

[16] A. El Fadar, A. Mimet, A. Azzabakh, M. Pérez-Garcia, J. Castaing, study of a new solar adsorption refrigerator powered by a parabolic trough collector", Applied Thermal Engineering 29 (**2009**) 1267-1270

[17] A. El Fadar, A. Mimet, M. Pérez-Garcia, study of an adsorption refrigerator powered by a parabolic trough collector and coupled with a heat pipe, Renewable Energy 34 (**2009**) PP. 2271-2279.

[18] Meteotest. Meteonorm version 6.1 – handbook; www.meteonorm. Com, **2008**

[19] H. El kalkha, A.Ezzarfi, A. Mimet, F. Lemmini, M. Pérez-Garcia, M. Ganaoui, Evaluation of a cold map for a Moroccan climate by a solar adsorption refrigeration machine working with activated carbon-ammonia pair, (**2011**) p.9

[20] A. El Fadar, Study of a solar refrigeration machine with adsorption of ammonia on activated carbon using a cylindro-parabolic solar concentrator coupled to a heat pipe, p115, (**2009**)

[21] O. Badran, M. Eck, The application of parabolic trough technology under Jordanian climates, Renewable Energy 31 (**2006**) 791-802

[22] S.P.Bird, M.K.Drost, , Assessement of generic solar thermal concept for large indusrial process heat applications. In "Proceedings of the ASME Solar Energy Division, Fourth Annual Conference, Albuquereque, NM. **1982**,

[23] S. Kalogirou, Parabolic trough collector system for low temperature steam generation: design and performance characteristics, Applied Energy **1996**;55(1): 1-19.

[24] E. Zarza, L. Valenzuela, J. Leon, K. Hennecke, M. Eck, H.Dieter Weyers, M. Eickhof, Direct steam genration in parabolic troughs: Final results and conclusions of th DISS project. Energy 29 (**2004**) 635-644

[25] S. Kalogirou, Use of parabolic trough solar energy collector for sea-water desalination, Applied Energy 60 (**1998**) 65-88.

[26] S. Kalogirou, S. Lloyd, Use of parabolic trough collectors for hot water production in Cyprus, a feasibility study, Renewbale Energy 1992

[27] A. Valan Arasu, T. Sornakumar, Design, manufacture and testing of fiberglass reinforced parabola trough parabolic trough solar collector, solar Energy 81 (**2007**).

[28] H. El kalkha, Evaluation of the performance of a solar refrigeration machine with adsorption of ammonia on activated carbon according to the Moroccan solar irradiation map, (**2011**), pp 120 – 123

[29] Dong Wu, Hua Zhang, Chuan-lin Men, Performance of a modified zeolite 13X-water adsorptive cooling module powered by exhaust waste heat, Internationa Journal of Thermal Sciences. 50 (**2011**) 2042-2049.

[30] Henning, H.M., and H. Glaser. Solar assisted adsorption system for a laboratory of the University Freiburg.

[31] Mahesh, A. Investigation of solar vacuum tubes assisted solid adsorption refrigeration, Ph.D Thesis(**2010**), Madurai Kamaraj University, pp.190.

[32] Critoph R.E, Evaluation of alternative refrigerant-adsorbent pairs for refrigeration cycles, Applied Thermal Engineering. 16(**1996**)891-900.

ISSN 2356-5608