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Simulation and Optimization of Solar Adsorption cooling System

N.Saravanan
Research Scholar Department of Mechanical Engineering
Annamalai University, Annamalai Nagar-608 002

Dr.R.Rathnasamy
Professor, Department of Mechanical Engineering
Annamalai University, Annamalai Nagar-608 002

Abstract

Refrigeration systems are transforming into an indispensable part of our life with rapid increase in global warming. Solar-powered adsorption refrigeration system is real and exciting alterative in future and finds more suitable in off-grid areas. This paper describes a new thermodynamic analysis of adsorption refrigeration studies by developing the new mathematical model to analyze the effect of operating parameters such as mass concentration ratio, temperature, pressure ratio and refrigerating effect on the performance and it was observed that the impact of mass concentration ratio on performance of the system is highly significant than the other parameters considered for simulation. Each operating conditions has a unique optimum value for maximum and minimum mass concentration ratio and the system operate more efficient while choosing maximum and minimum mass concentration ratio of zeolite-water pair.

Keywords: *Solar, Adsorption Refrigeration, Simulation, Optimization, mass Concentration ratio.*

1. Introduction

Energy acquired by cooling system constitutes a significant role in the world. Since, International Institute of Refrigeration (IIR) has estimated that approximately 15% of electricity is used for cooling process of various kinds. Nowadays innovative cooling systems are under development since the traditional cooling system consumes high grade electrical energy and also responsible for ozone depleting carbon emissions and global warming. In preservation of vaccine and food in remote areas, renewable energy can be an exciting possibility. Due to the above mentioned reasons, the researchers show very much interest to make use of renewable energy and reduce carbon emissions in cooling system. Cooling systems operated by renewable energy is a real and exciting possibility in future. Solar operated cooling system drives water as refrigerant can be a better alternative to traditional cooling system. Indian climate has an attractive potential for solar energy applications.

The objective of this work is to investigate mathematically, the adsorption capacity of the adsorbate on adsorbent at various temperature and pressures for adsorption / desorption processes and to predict the suitable parameters for the system.

The technical feasibility of solar refrigeration system has been investigated in many areas. Work operated vapor compression refrigerators powered by solar photovoltaic cells are available, but it is too expensive. Solar adsorption refrigeration is the only best possible way for preservation of food and vaccine in remote areas.

The zeolite-water cooling system is preferred as it is more cost effective and eco friendly. In Nagercoil,Kanyakumari District,TamilNadu,India (8.1700° N, 77.4300° E) the total average solar radiation is about 737kW/m^{2}hr which is high enough to meet the demand.

Anyanwu et. al [1] carried out a thermodynamic design procedure was applied to system with AC / methanol , AC / Ammonia and Zeolite /water as adsorbent /adsorbate pairs and fount that the results are maximum solar COP as 0.3 , 0.19 and 0.16 for Zeolite/water , AC/ammonia, AC/methanol respectively while using conventional flat plate solar collector was used.

A study of Anyanwu and Ogueke [2] (2005) suggested that the Zeolite - water is the best pair for air conditioning applications, while AC/ammonia was best suitable for low temperature applications like Food preservation and freezing. The study also described that the most important parameters for operation are adsorption and condensation temperatures are more impact than the evaporator temperature on system performance.

Douss and Meunier[3] (1989) proposed a cascading adsorption cycle. The cycle employed two different working pairs Zeolite / water and AC/methanol , three adsorbers , two condensers and two evaporators. As result the higher COP value was obtained by the utilization of adsorption heat caused from Zeolite/water cycle for drive AC/methanol cycle.

Liu and Leong [4] (2006) improved the new cascading adsorption cycle based on the proposed cycle of Douss. Zeolite/water pair was used at high temperature source around 170° C.

The Needful Provision Inc (NPI)[5] (2006) developed a simplified solar adsorption refrigerator with Zeolite / water is used. This refrigerator is equipped with flat plate collector, PVC pipe vacuum hand pump, condenser and 4 Cu.ft capacity evaporator and produced 5 lbs of ice/day per cubic Ft of storage space.

Tcherenev[6] (1983) of Zeo power company in his work natural zeolite to produce refrigeration. Refrigerator produced 0.9 kW of cooling per square meter of collector area and had a COP of 0.15.

Tchernev et.al[7] (1998), Poyelle et.al (1999), Zhang L.Z. et.al (2000) and Lu Yz Wang RZ et.al (2004) have used zeolite/ water pair for air conditioning system with a heat source temperature between 200° C and 300° C and achieved a COP of 0.38 to 1.6, and SCP as 25.7 to 144 W/kg.

Siegfried et.al [8] (1998) carried out experiment on Zeolite / water pair, with water was cooled to 0° C and Zeolite was placed in the vacuum tube solar collector which was heated to a temperature of 180° C by sunlight. The results obtained that at 150° C heating temperature there was a cooling energy of 250 kJ/ kg of Zeolite and storage volume of 125 liters could be cooled down by solar power gained from 3 m^2 collector area. Based on experimental data obtained by a 0.125 m^3 cooling chamber , a solar collector of 3 m^2 and parabolic reflection to focus the whole incident radiation. The resulting cooling energy density was 350 kJ/kg of Zeolite with increase in COP of 8%.

A mobile adsorber was developed by Miguel et.al [9] (2003) with Zeolite / water for food storage of capacity 44 liters which is regenerated out of the refrigeration cycle and no condenser was applied.

The thermodynamic design and procedure for solar adsorption using Zeolite-water, AC/Methanol, AC/Ammonia are reviewed by Anyanwu (2004) [1]. They concluded that Zeolite-water was the best pair for air conditioning applications The maximum possible COP was 0.3, for Zeolite water, a conventional flat plate solar collector was used. AC-Ammonia is preferred for ice making deep freezing ,food preservation and Vaccine storage.

In the consonance with the above the central focus of this work is to investigate the zeolite-water pair system thermodynamically and analyze the effect of operating parameters on the performance of the system.

From the above summarized investigation it is found that Zeolite water pair is more significant and high temperature can be achieved for Food and Vaccine preservation.

2. Abbreviation and Acronyms

T_1	Temperature at point 1 (K)
T_2	Temperature at point 2 (K)
T_3	Temperature at point 3 (K)
T_4	Temperature at point 4 (K)
P	Pressure (mbar)
Q_{12}	Heat rate of isosteric heating process (kJ)
Q_{23}	Heat rate of isobaric desorption process (kJ)
Q_{34}	Heat rate of isosteric cooling process (kJ)
Q_{41}	Heat rate of isobaric adsorption process (kJ)
M_{min}	Mass ratio minimum
M_{max}	Mass ratio maximum
C_p	Specific heat (kJ/kgK)
m	Mass flow rate (kg/s)
ΔH_s	Heat of adsorption/desorption (kJ/kg adsorbate)
ΔH_v	Heat of vaporization (kJ/kg adsorbate)
a_0-a_3, b_0-b_3	Constants of isotherm formulas
α_1, α_2	Constants for the saturation vapor pressure

2.1. Subscripts

evap	Evaporator
cond	Condenser
w	Water
z	Zeolite
sat	Saturation
bed	Adsorption bed
ads	Adsorbent

3. Thermodynamic Model

Ideal adsorption refrigeration cycle is an intermittent cycle that can be operated by low grade energy such as solar energy or waste heat. Adsorbent bed act as thermal compressor in this refrigeration cycle. A refrigerant receiver is placed between condenser and expansion device. Governing equations are framed by the use of existing models. Present investigation is focused to prove the importance of mass concentration ratio of adsorbate/adsorbent on the COP of the system. Schematic diagram of an ideal adsorption refrigeration cycle is shown in Fig 1.

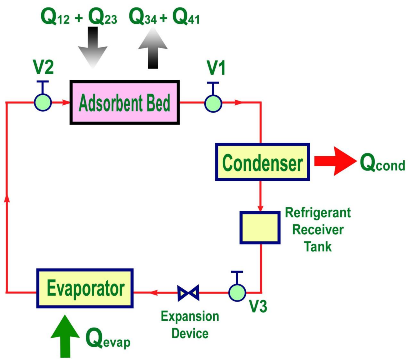

Fig. 1. Ideal adsorption refrigeration cycle

Assumptions to be made to derive the equations

1. Adsorbent bed is packed of uniform sized particles and packing density is constant.
2. Refrigerant in gaseous state behaves ideal.
3. Considered as one dimensional flow.
4. Density and Specific heat of adsorbent and adsorbate are constant.
5. All isosteric and isobaric processes are ideal.
6. Heat absorbed by bed material, valves, condenser, and evaporator is neglected.
7. Uniform temperature is maintained in evaporator and condenser.

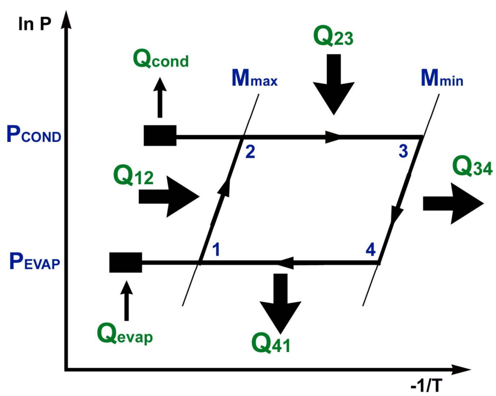

Fig. 2. Clapeyron Diagram

From the clapeyron Diagram the four processes are explained below:

In isosteric heating **(1-2),** V_1 and V_2 are closed and adsorbent bed is exposed to solar irradiance, temperature of adsorbent bed is increases from T_1 toT_2 and Pressure from P_{evap} to P_{cond}. Heat absorbed by this process is given by equation (1).

In isobaric desorption **(2-3),** V_1 is kept open refrigerant flows into condenser and stored in refrigerant receiver tank. Pressure remains constant while temperature increases from T_2 to T_3 and Mass concentration decreases. Heat absorbed by the bed in process 2-3 is given by equation (2).

In isosteric cooling **(3-4),** V_1 and V_2 are closed and adsorption bed is cooled to T_4. Heat rejection in (3-4) is given by equation (3).

In isobaric adsorption **(4-1)** V_2 is opened and refrigerant from the evaporator is adsorbed in the adsorbed bed. Heat rejected in 4-1 is given by equation (4).

$$Q_{12} = [\, m\,(C_{p,z} + M_{max}\, C_{p,w}) + m_{bed}\, C_{p,bed}\,](T_2 - T_1) \qquad ..(1)$$

$$Q_{23} = [\, m\,(C_{p,z} + M_{min}\, C_{p,w}) + m_{bed}\, C_{p,bed}\,](T_3 - T_2) + m\, \Delta H_s\,(M_{min} - M_{max}) \qquad ...(2)$$

$$Q_{34} = [\, m\,(C_{p,z} + M_{min}\, C_{p,w}) + m_{bed}\, C_{p,bed}\,](T_4 - T_3) \qquad ..(3)$$

$$Q_{41} = [\, m\,(C_{p,z} + M_{max}\, C_{p,w}) + m_{bed}\, C_{p,bed}\,](T_1 - T_4) + m\, \Delta H_s\,(M_{max} - M_{min}) \qquad ..(4)$$

$$Q_{evap} = m\, \Delta M\, \Delta H_v + m\, \Delta M\, C_{p,w}\,(T_{evap} - T_{cond}) \qquad ..(5)$$

$$Q_{cond} = m\, \Delta M\, \Delta H_v \qquad ..(6)$$

The coefficient of performance of the basic adsorption refrigeration cycle is given as

$$COP_{ref} = Q_{evap} / (Q_{12} + Q_{23}) \qquad ..(7)$$

In the formulas (1) to (4) heat absorbed and rejected by bed material is neglected and rewritten as (8) to (11).

$$Q_{12} = [\, m\,(C_{p,z} + M_{max}\, C_{p,w})\,](T_2 - T_1) \qquad ..(8)$$

$$Q_{23} = [\, m\,(C_{p,z} + M_{min}\, C_{p,w})\,](T_3 - T_2) + m\, \Delta H_s\,(M_{min} - M_{max}) \qquad ..(9)$$

$$Q_{34} = [\, m\,(C_{p,z} + M_{min}\, C_{p,w})\,](T_4 - T_3) \qquad ..(10)$$

$$Q_{41} = [\, m\,(C_{p,z} + M_{max}\, C_{p,w})\,](T_1 - T_4) + m\, \Delta H_s\,(M_{max} - M_{min}) \qquad ..(11)$$

TABLE I
PROPERTIES OF ZEOLITE & WATER [10]

Property	Values
Boiling Pointof water	373 K
Heat of Vapourizationof water	2258 kJ/kg
Max Adsorption capacity on Zeolite	0.3
Latent Heat of vapourization of water	2361 kJ/kg
Specific Heat capacity	4.2 kJ/kg K
Density of water	1000 kg/m^3
Density of Zeolite	700 kg/m^3
Heat of adsorption / desorption	3400 kJ/kg

3.1. Adsorption Isotherms

Adsorption isoter lines are used to evaluate the mass concentration of adsorbate on the surface of the adsorbent for different vapor pressure and temperatures.

$$Ln(P \times 1000) = a(M) + [\, b(M) / T_b\,] \qquad ..(12)$$

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where

$$a(M) = a_0 + a_1 M + a_2 M^2 + a_3 M^3 \quad .. (13)$$

$$b(M) = b_0 + b_1 M + b_2 M^2 + b_3 M^3 \quad .. (14)$$

In the above equation pressure is in mbar, Temperature in Kelvin. The coefficients can be taken from Table II

TABLE II
COEFFICIENTS OF ADSORPTION ISOTHERM [11]

a_0	13.4244
a_1	110.854
a_2	-731.76
a_3	1644.8
b_0	-7373.78
b_1	6722.92
b_2	5624.47
b_3	-3486.7

3.2.Saturation Pressure of Water [11]

Saturated pressure in the evaporator and condenser was evaluated using the equation.

$$P_{sat} = [\exp[\alpha_1 - (\alpha_2 / T)]] / 1000 \quad ...(15)$$

where $\alpha_1 = 20.5896$
$\alpha_2 = 5098.26$

3.3.Proposed Algorithm used to solve this model

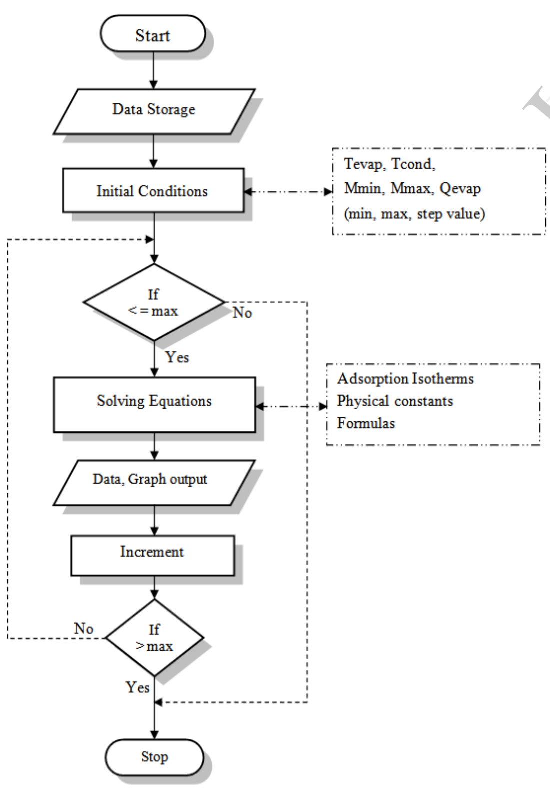

Fig. 3. Algorithm used to solve the model

4. RESULTS AND DISCUSSION

In the Simulation five input parameters are varied one by one and its effects in the COP of the system is studied. The minimum and maximum adsorption capacity of water on zeolite is taken as 0.05 and 0.25 respectively with a evaporator capacity 0.250kJ/s and the surrounding temperature is 298 K and evaporator temperature to be maintained is 278 K .

Variation in the COP of the system when evaporator temperature is varied gradually from 275K to 285K . The performance of the system is linearly increasing with increase in evaporator temperature. The heat requirement and amount of working pairs required decreases. It was observed that the higher performance are obtained if the evaporator temperature should be maintained within the required operational limit and for the further studies a temperature of 278K is chosen as evaporator temperature and high as possible to get higher performance. For the further analysis

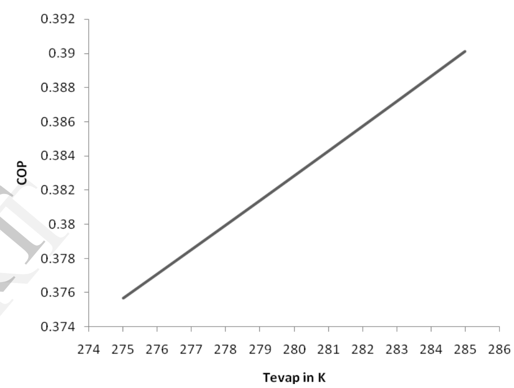

Fig. 4. Effect of COP on Evaporator Temperature

Variation in the COP of the system when condenser temperature is increased from 298K to 308K.

The performance of system decreases with increasing the ambient temperature. The linear counter relation between each other. The heat requirement and quantity working pairs required increases with increase in ambient temperature. The COP of system can be increased by decreasing the ambient temperature and this reduces the solar collector harvesting area. A temperature of 298K is taken as condenser for further analysis.

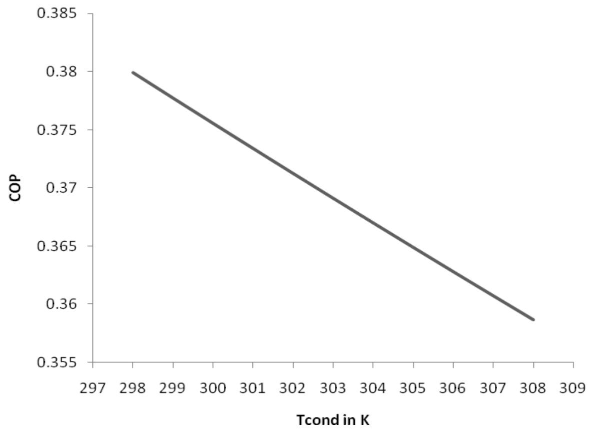

Fig. 5. Condenser Temperature Vs COP

The variation of performance of the system with the maximum and minimum mass concentration ratio is shown in figure.6 .It was observed that the both maximum and minimum mass concentration ratio affect the COP of the system.

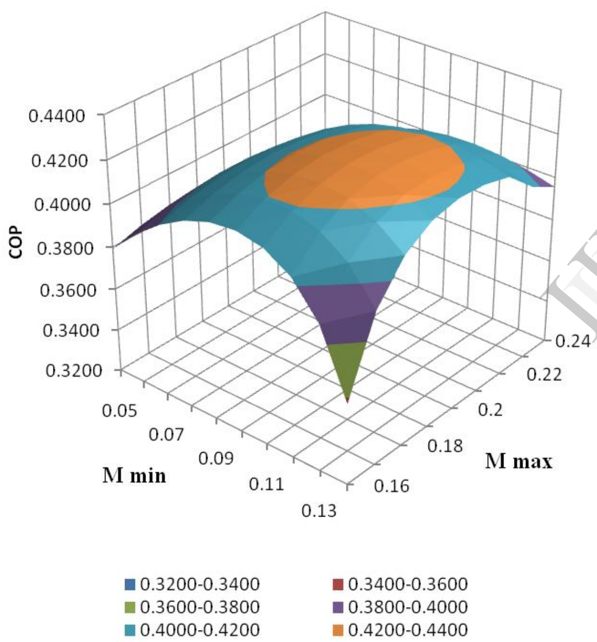

Figure. 6. Mmin Vs COP

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The effect of COP of the system on minimum mass concentration ratio (0.05 to 0.15) is shown in Figure. 7

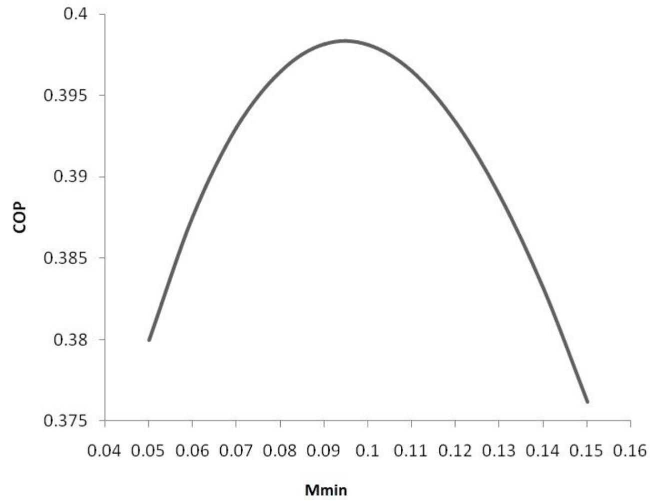

Fig. 7. Mmin Vs COP

Minimum isosteric curve in the clapeyron diagram shifted to left and length of isobaric desorption period decreases.This is done by a valve between the condenser and adsorption bed is opened in short interval of time for increasing value of Mmin. When the opening of the valve between the condenser and the adsorption bed is delayed value of Mmin decreases. Adsorption pairs required is constantly increases. The maximum COP is obtained at minimum mass concentration ratio of 0.0947 .

Dependence of COP of the system on maximum mass concentration ratio when increased from 0.15 to 0.25 is shown in figure.8

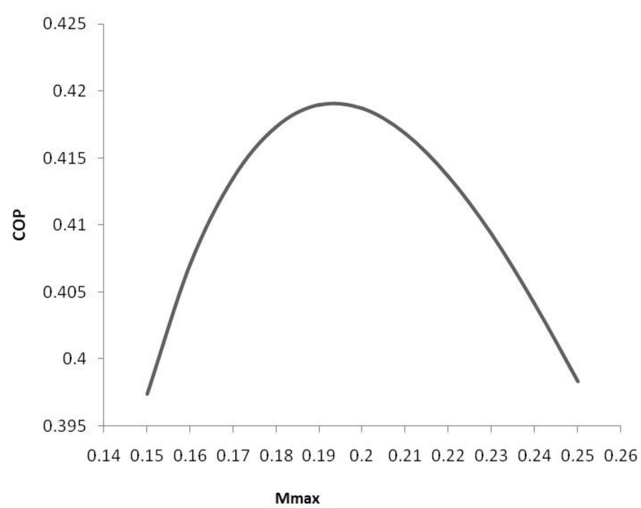

Figure. 8. Mmax Vs COP

Maximum isosetric curve in the Clapeyron diagram shifted to right and length of isobaric desorption period increases. Mmax can be increased by closing the valve between bed and evaporator earlier. The maximum COP is obtained at maximum mass concentration ratio of 0.1395

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The COP is of the system remain unchanged with evaporator capacity. In realistic, when the cooling demand increased COP of the system decreases. A multi bed system reduces the operating time and the values of mass concentration ratios can be kept in better accuracy.

Global irradiance and mean air temperature obtained in the city of **Nagercoil**, Kanyakumari District, Tamilnadu (8.1700° N, 77.4300° E) in the year 2012 is shown in Figures 9 and 10 respectively [12].

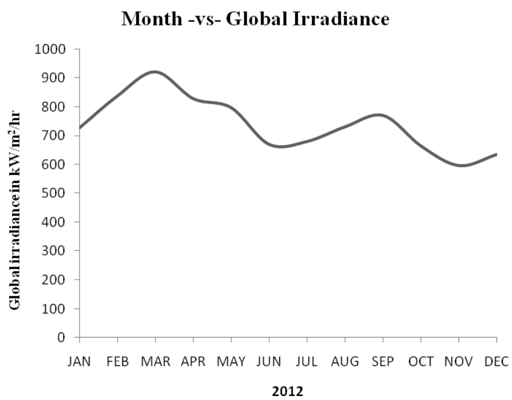

Fig. 9. Month Vs Global Irradiance

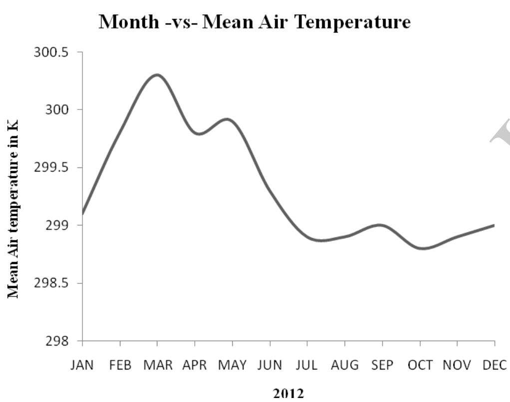

Fig. 10. Month Vs Mean Air temperature

The Coefficient of performance of the system and solar collector harvesting area required is evaluated by simultaneously varying Global irradiance and Mean air temperature in respective month. Solar harvesting area depends on the solar irradiance and COP of the system depends on mean air temperature or condenser temperature.

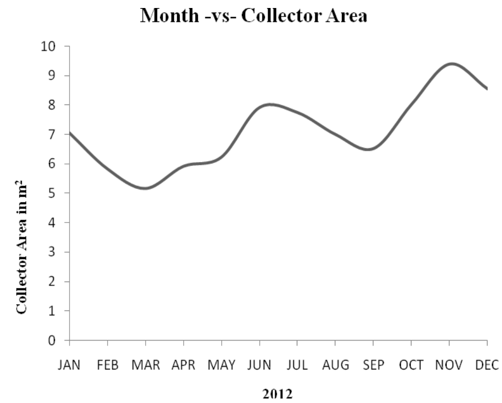

Fig. 11. Month –vs- Collector Area

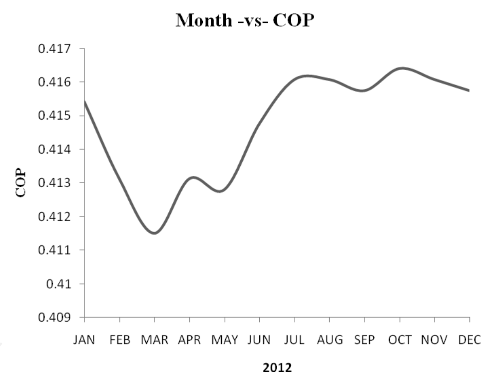

Fig. 12. Month –vs- COP

5. CONCLUSION

The mathematical model of solar adsorption refrigeration system using zeolite-water pair is generated and a brief thermodynamics analysis of the system is carried out. The following conclusions can be drawn based on the study.

- As expected Mass concentration ratio is found to be a main factor in determining the performance of the system. The performance of the system can be maximized by optimizing the maximum and minimum mass concentration ratios.
- The mass requirement of adsorbate and adsorbent pair and collector harvesting area system gets increased However, the performance of the system is the main feature to be maximized.
- The evaporator and condenser temperatures do not affect the performance of the system much as compared to other parameters.
- Evaporator capacity of the system has no effect on the performance of the system.
- Effects of solar irradiance and mean air temperature on the system are studied.
- Minimum solar irradiance and maximum collector area is to be considered for designing the system.

This work can be considered as a first step starting point of our research on mass concentration ratios of the adsorption cooling system. Adsorption cooling system could be a reliable and economical solution to meet increasing cooling demand partially.

6.Authors and Affiliations

N.Saravanan, (23-11-1965) Bachelor of Engineering in ManonmaniamSundaranar University Tirunelveli,1996,Master of Technology (Energy) Pondichery University,1999, Research Scholar (External) /Department of Mechanical Engineering Faculty of Engineering and Technology, Annamalai University , Annamalai Nagar-608 002,Tamilnadu, India.

His research field is Solar refrigeration system..He is a life member of Indian Society for Technical Education. He has more than 17 Years teaching Experience.

Prof.Dr.R.Rathnasamy, (15-05-1959) Bachelor of Engineering in Madras University,India,1981,Master of Technology Indian Institute Of Technology Chennai,1983, PhD in Faculty of Engineering and Technology, Indian Institute of Science ,Bangalore, India. Professor in Department of Mechanical Engineering. Annamalai University, Annamalai Nagar-608 002, Tamilnadu, India.

His research field is Experimental investigation on fluid flow and heat transfer in micro channels.. He has more than 26 Years teaching Experience.

REFERENCES

[1] Anyanwu E.E., Review of solid adsorption refrigeration II: An overview of the principles and theory: Energy Conversion and Management, Vol. 45, 2004, 1279-1295.

[2] Anyanwu E.E., N.V.Ogueke Thermodynamic design procedure for solid adsorption solar refrigerator, Renewable energy – 30 (2005) 81-96.

[3] N.Douss , F.Meunier " Experimental study of cascading adsorption cycles" Chemical Engineering Science , 44 pp 225-235 (1989).

[4]Y.Liu, K.C.Leong " Numerical study of a noval cascading adsorption cycle" International journal of refrigeration , 29 pp 250-25(2006).

[5] David A. Nuttle, Inventor, Solar Cooking & Heating, website link www.needfulprovision.org/main/solaroven.php

[6] Tehevner D. I:(1983) Use of natural zeolites in solar refrigeration : ASSETS Abstracts of selected solar energy technology pp 21-23.

[7] Khairul Habib, Saha et al. Performance evaluation of combined adsorption refrigeration cycles. International Journal of Refrigeration 34 (2011) 129-137.

[8] Siegfried. K and Detlef B:Experiment on Solar adsorption refrigeration, using Zeolite water. http://www.containedenergy.com/html/ zeolite_cooling.html

[9] Miguel .R et al Evaluation of solar adsorption refrigerator. http://fc.uni.edu.pe/mhorn/ISES2003%20(solar%20refrigeration).pdf

[10] Demir Hasan, Mobedi Moghtada, Ülkü Semra, 2007. A Review on Adsorption Heat Pump: Problems and Solutions. Renewable and Sustainable Energy Reviews (2007). Department of Chemical Engineering, Ġzmir Institute of Technology. Turkey.

[11] San Jung-Yan, Lin Wei-Min. 2007. Comparison Among Three Adsorption Pairs for Using as the Working Substances in a Multi-Bed Adsorption Heat Pump. Applied Thermal Engineering 28 (2008) 988- 997. Mechanical Engineering department, National Chung Hsing University. ROC.

[12] www.weatheranalytics.com