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A NEW TOOL USING SIMULATION AND OPTIMIZATION OF SOLAR ADSORPTION COOLING TECHNIQUE

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ABSTRACT

Cooling systems are transforming into an indispensable part of our life with rapid increase in global warming and ozone layer depletion. Solar-powered adsorption cooling system is real and exciting alternative in future and finds more suitable in remote off-grid areas. In this paper describes a new perspective about adsorption refrigeration studies, a brief thermodynamic study of the system is carried out and effect of operating parameters such as mass concentration ratio, temperature, pressure ratio and refrigerating effect on performance of the system is numerically analyzed. 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 optimized value of maximum and minimum mass concentration ratio. Applying very old classic methods in the new software platform put forth wonderful results. Invention of Adsorption Technique is a very old classical phenomenon Application of Visual Studio Ultimate 2012 version of Dot Net services to various adsorption equations by Providing various variable data input put forth wonderful result to the modern scientific eco friendly Environment The main conclusion are that the performance of the system is very sensitive to the mass concentration ratio of adsorbent and the adsorbate with COP, are optimized based on the capacity. In this system equation are solved with micro level intervals and accurate answers were obtained.

KEYWORDS: Solar, Adsorption Refrigeration, Simulation, Optimization, Concentration Ratio

INTRODUCTION

Energy required by the cooling system constitutes a significant role in the world. Since, International Institute of Refrigeration (IIR) has estimated that approximately 15% to 20% high grade electrical energy is used for cooling process of various applications. 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 off grid areas, renewable energy can be an exciting possibility. All the above attracted several countries to setup target to increase the share of renewable energy utilization 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. 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 the efficiency of the system is very low and the cost is also high. Solar adsorption refrigeration is the only best possible way for preservation of food and vaccine in remote off grid areas. The zeolite-water cooling system is preferred as it is more cost effective and eco friendly. In Nagercoil (8.1700° N, 77.4300° E) the total average solar radiation is about 737 kW/m^2hr 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. The results are maximum solar cop as 0.3, 0.19 and 0.16 for Zeolite/water, AC/ammonia, AC / methanol respectively when a conventional flat plate solar collector was used.

A study of Anyanwu and Ogueke [2] (2005) suggests that Zeolite - water is the best pair for air conditioning applications, while AC/ammonia is better for low temperature application like Food preservation and freezing. The study also showed that the most important parameters for operation are adsorption and condensation temperatures. Evaporator temperature has little effects 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, high COP value was obtained by utilizing 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. Zeolite / water is used. This refrigerator used 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) Lu Yz Wang RZ et.al (2004) they are used zeolite/ water as pair used for air conditioning system at a heat source temperature between 200° C and 300° C got a COP of 0.38 to 1.6, and SCP 25.7 to 144 W/kg.

Siegfried et.al [8] (1998) carried out experiment on Zeolite / water pair, water is cooled to 0° C, Zeolite was placed in the vacuum tube solar collector which was heated to 180° C by sunlight. The results obtained showed 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 m2 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 and a COP of 8%.

A mobile adsorber was developed by Miguel et.al [9] (2003) Zeolite – water pair was used. Capacity of the cold chamber is 44 liters and it's used for food storage 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 showed that Zeolite-water was the best pair for air conditioning applications

The possible maximum COP was 0.3, for Zeolite water, a conventional flat plate solar collector was used. AC-ammonia is preferred for ice making deep freezing and food preservation. From the above summarized investigation it is found that zeolite-water pair is more significant and high temperature can be achieved. The term zeolite originally coined in the 18^{th} century by a Swedish mineralogist, natural zeolite the stones began to dance about as the water evaporated "stones that boils". More than 150 zeolite types have been synthesized and 40 known naturally occurring. Many zeolite lose water fairly continuously over a temperature range of 150 to 400° C.

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)

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}: Minimum Mass Concentration ratio

M_{max}: Maximum Concentration Mass ratio

P: Pressure (mbar)

C_p: Specific heat (kJ/kg K)

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

m: Mass flow rate (kg/s)

Subscripts

Evap: Evaporator

Cond: Condenser

Sat: Saturation

W: Water

Z: Zeolite

Ads: Adsorbent

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 sysyem. Schematic diagram of an ideal adsorption refrigeration cycle is shown in Figure 1.

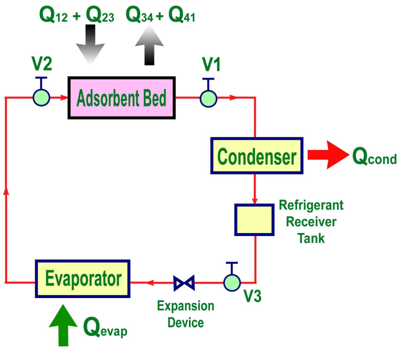

Figure 1: Ideal Adsorption Refrigeration Cycle

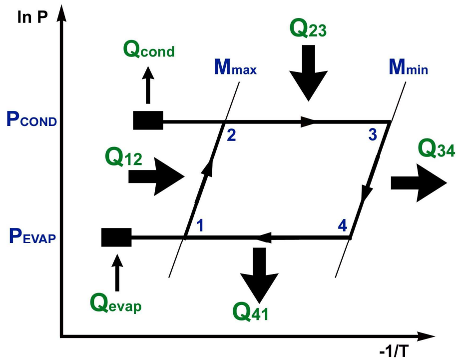

Figure 2: Clapeyron Diagram

Assumptions to be made to derive the equations

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

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).

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

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

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

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

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

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

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

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

Table 1: 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 *Density of Zeolite* *Heat of adsorption / desorption*	1000 kg/m^3 700 kg/m^3 3400 kg

Table 2: 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

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.

$$Ln\ (P \times 1000) = a\ (M) + [b(M) / T_b\ ] \quad (8)$$

Where

$$a\ (M) = a_0 + a_1\ M + a_2\ M^2 + a_3\ M^3 \quad (9)$$

$$b\ (M) = b_0 + b_1\ M + b_2\ M^2 + b_3\ M^3 \quad (10)$$

In the above equation pressure is in bar, Temperature in Kelvin. The coefficients can be taken from Table 2

Saturation Pressure of Water [11]

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

$$P_{\ sat} = [\exp\ [\alpha_1 - (\alpha_2 / T)\ ]\ ] / 1000 \quad (11)$$

Where α_1=20.5896, α_2=5098.26 for zeolite –water pair

Algorithm Used to Solve the Model

Old one to be shedded and new one to be budded is the order of the day. New Scientific inventions, innovations and the mushroom growth of software technique leads the world to the new heights. Applying very old classic methods in the new software platform put forth wonderful results. Invention of Adsorption Technique is a very old classical phenomenon. Application of Visual Studio Ultimate 2012 version of Dot Net services to various adsorption equations by providing various variable data input put forth wonderful result to the modern scientific eco friendly Environment. Visual Studio.Net Services is an Microsoft product which is an integrated set of services and is user friendly.

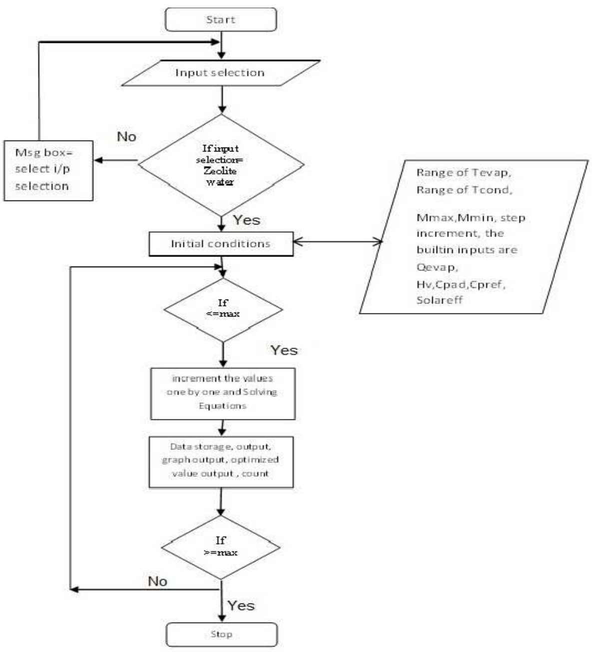

Figure 3: Algorithm Used to Solve the Model

RESULTS AND DISCUSSIONS

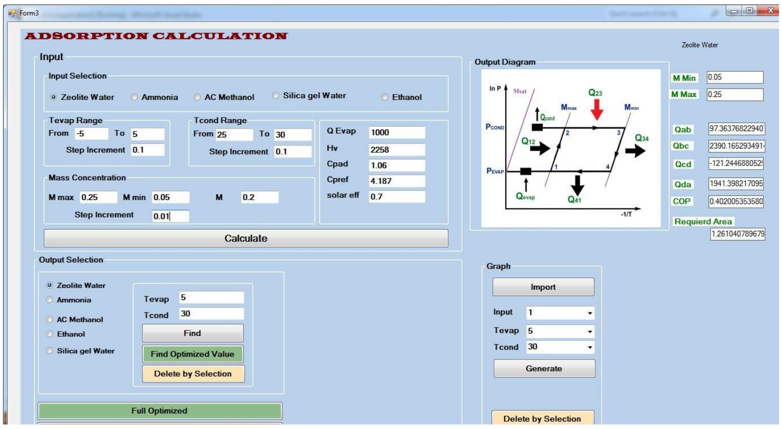

Figure 4: Screen Shot of Adsorption Calculator

A fully automated adsorption refrigeration system with required output can be designed using Visual Basic. Net programme. It is possible to simulate the system performance, when the input parameters are well known. The surrounding temperature may be taken as condenser temperature. If the environmental temperature is varied the system can automatically increases or decreases the mass concentration ratio of the pair. So that the optimum output is produced. This Algorithm is used to solve the governing equation of the basic ideal adsorption refrigeration cycle, and provide a ready reckoner database for the researchers on adsorption refrigeration systems. The temperature of evaporator is from -5 ᵒC to +5 ᵒC, the condenser temperature is from 27 ᵒC to 30 ᵒC with the incremental value of 0.1 ᵒC and the maximum and minimum mass concentration ratio of the zeolite water pair 0.25 to 0.05 with incremental rate of 0.01, nearly 361865 results are produced. No other computer based programme provide such a quantitative results. These results are reliable and qualitative when compared with earlier experimental results.

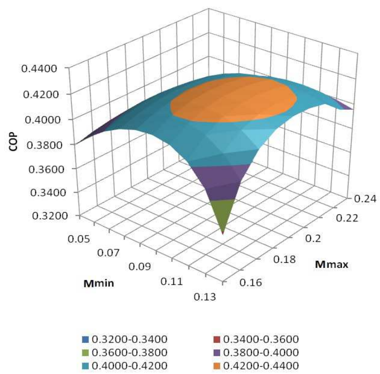

Figure 5: COP vs- Mass Concentration Ratio

In this Simulation four input parameters like T evap, T cond, M max, M min are varied micro level increments one by one and its effect in the COP of the system is studied. The other input parameters Q evap is varied by the requirement. The Minimum adsorption capacity of water on zeolite is 0.05 and maximum adsorption capacity is 0.25. Capacity of the evaporator is approximately taken as 1000 kJ/hr and surrounding temperature is varying at any range is to be taken as temperature of the condenser and the evaporator temperature is to be maintained like any range depending upon the requirement.

From this analysis clearly understand that the performance of the system is linearly increasing with increase in evaporator temperature. The heat requirement and amount of working pairs required decreases. It can be concluded that the evaporator temperature should be maintained within the required operational limit and high as possible to get higher performance. For the further analysis 278K is chosen as evaporator temperature.

Increasing the ambient temperature, performance of system decreases. a 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. So it means the heat requirement or solar collector harvesting area can be reduced respectively. For further analysis 298K is taken as condenser temperature.

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 M min. When the opening of the valve between the condenser and adsorption bed is delayed, value of M min decreases. Adsorption pairs required is constantly increases. The maximum COP is obtained at minimum concentration ratio of 0.0947.

Maximum isosteric curve in the Clapeyron Diagram shifted to right and Length of isobaric desorption period increases. Mmax can be increased by closing the valve between the adsorption bed and evaporator earlier. The maximum COP is obtained at maximum concentration ratio of 0.1935.

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 concentration ratios can be kept in better accuracy.

The 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.

CONCLUSIONS

The present work focused on developing a new mathematical model capable of describing a new solid adsorption refrigeration cycle. which can operate solar energy with intermittency. The governing equations are fully solved with the help of Visual Basic.net programme and the values of systems parameters with clear intervals are studied. A systematic study has been carried out with clear physical interpretation. The main conclusions are that the performance of the system is very sensitive to the mass concentration ratio of adsorbent and the adsorbate with COP, are optimized based on the capacity. In this system equation are solved with micro level intervals and accurate answers were obtained.

These information is available at any time any place and on any device. Visual Basic.Net programming language is used for these adsorption data base applications. Visual Studio Windows form application is used to solve the adsorption problems because of its interoperability, Base Class Library, Simplified deployment and security. The only drawback of the .Net Framework was not platform independence, i.e. a program written to use the framework should run without any change on any type of computer. The advantage of .Net Framework is its Common Language Runtime. The .Net Framework is an efficient, agile and powerful means of application development. The .Net represents an advanced new generation of software that will drive the next generation internet. Visual Studio Ultimate 2012 version of Net Services is used as platform to develop various adsorption Equations and to drive the accurate, enormous, micro incremental and desirable results by providing Various incremental input data. The result obtained by the program can be used as a data storage library for future reference. The result obtained by this program correlates with earlier experimental results and any future adsorption system developers may approach this data storage library for their reference.

- 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 system does not depend much on the evaporator and condenser temperatures.
- Evaporator capacity of the system has no effect on the performance of the system.

This work can be considered as a 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.

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