

# Experimental Analysis of Zeolite Base Solar Vapour Adsorption Refrigeration System

Mehta Chirag  
P.G Student  
MGITER

Patel Hiren  
Assistant Professor  
MGITER

## Abstract

Solar adsorption refrigeration represents important criteria of solar energy due to excellent matching between high sun-shine and the refrigeration need. The refrigerant pair can be taken by zeolite in powder form and water as refrigerant. The experiment used different parameters like co-efficient performance, temperature different, solar collector design, cooling unit, mass flow rate, pressure difference etc. Several literatures are used to develop experimental analysis to prepare an experimental setup and their results validation. Analysis new style structure adsorbent bed had been designed ,which has some character follows: compact structure, good performance in bearing strength, high efficiency in heat & mass transfer, great packing amount of adsorbent & uniform temperature field in the bed.

**Keywords:** refrigeration, adsorption, cop, zeolite, water

## I. NOMENCLATURE

A	Area through which heat is transferred (collector area (m <sup>2</sup> ))
C <sub>p</sub>	Specific heat (kJ/kg-K)
D	diameter of adsorber tube (m)
f	focal length (m)
L	length of CPC trough (m)
m	quantity of adsorbent/adsorbate (kg)
P	Pressure (Nm <sup>2</sup> )
Q <sub>e</sub>	Heat evaporator (kJ)
Q <sub>g</sub>	Heat of generator (kJ)
T <sub>c</sub>	Condenser Temperature (C)
T <sub>e</sub>	Evaporator Temperature (C)
T <sub>g</sub>	Generator Temperature (C)
U	Overall heat transfer coefficient.(kJ/h-rm <sup>2</sup> K)
V	Volume (m <sup>3</sup> )

### Subscripts

A	Amb ambient
a	adsorber
c	condenser
d	desorbed
E	evaporator
f	final

## II. INTRODUCTION

Refrigeration is a term used to describe a process which maintains a process space or material at a temperature less than the ambient temperature. To accomplish this, heat must be transferred from the materials to be cooled into a lower temperature substance referred to as a refrigerant. The role and function of refrigeration and its application have steadily become indispensable to the existence of the modern society.

The concept of using solar energy for powering a refrigerator appeared forty years ago with a prototype using a liquid sorption cycle, the use of sorption processes to produce refrigeration has been extensively studied in the last twenty years as a technological alternative to vapour compression systems. Solar-powered refrigeration can also use solid sorption, with either a chemical reaction, or adsorption. Several theoretical and experimental studies demonstrated that sorption refrigeration systems especially those using solid-gas heat cycles are well adapted to simple technology applications. They can operate without moving parts and with low grade heat from different sources such as residual heat or solar energy. The main two technologies concerning the solid-gas sorption concept are the adsorption and the chemical reaction, including metal hydrides.

### A. Choice of the Adsorbent-Adsorbate Pair:

The choice of the adsorbent-adsorbate pair is a very crucial task for the successful functioning of the system. The selection of a suitable pair depends upon various important parameters:

- 1) Adsorption capacity.
- 2) Regeneration temperature.
- 3) Coefficient of performance (COP) of the system.
- 4) Required evaporator temperature.

The various pairs which were chosen for study are:

- Zeolite and Water
- Activated carbon and Methanol
- Silica gel and Water
- Activated carbon and Ammonia

The important characteristics of each pair are as follows:

#### 1) Zeolite and Water:

Zeolite is basically alumina-silicates having a porous structure. They are molecular sieves which can selectively adsorb molecules based on their shape and size. The regeneration temperature (temperature at which desorption starts) of this pair is greater than 150 °C. Thus, this pair is not suitable for use along with a flat plate collector as temperatures attainable by using a flat plate collector typically range from 70 °C to 100 °C. Concentrating collectors need to be used, which increase the initial cost of the system. The adsorption capacity of zeolite is about 30% of its weight, and it remains fairly constant for most of the adsorbate. One characteristic of zeolite which aids its use in solar cooling applications is that its adsorption isotherm has extremely non-linear pressure dependence. This means that zeolite can absorb large quantities of water vapour even at low partial pressure, and it can desorb most of the vapour at high partial pressure.

#### 2) Activated Carbon and Methanol:

The activated carbon and methanol pair requires low vacuum pressures for operation and so it does not require a robust system. Also, the low vacuum pressure ensures a safety factor in case of any leakage. However, methanol is a toxic and flammable substance and so precautions should be taken while working with it. Also, as methanol has a low decomposition temperature, it results in low cooling performance due to decomposition of methanol during heating.

#### 3) Silica Gel and Water:

This pair has a low regeneration temperature, ranging from 75 °C to 100 °C, and so, it is well suited for use with a flat plate collector. The adsorption capacity of this pair is fairly high (35% to 40% of the weight of silica gel). Silica gel is also available easily as it is widely used in filtration systems as a desiccant. The evaporator temperature achievable by using this pair is around 4 °C, and so, it is widely used for air-conditioning applications. Many companies have commercialized silica gel and water based adsorption chillers. This pair also requires high vacuum pressures to operate which may pose a hurdle.

### III. ACTIVATED CARBON AND AMMONIA

The regeneration temperature of this pair is around 150 °C and so, this pair is not suitable for use with flat plate collectors. This pair can be successfully used for ice production and refrigeration purposes. This pair requires a highly pressurized system in order to function successfully. Hence, a robust system is required, which increases the cost. Also, as the system operates at a higher pressure than the atmospheric pressure, there is risk in case of a leakage. Ammonia is a toxic and flammable refrigerant, and it is corrosive to copper, and hence unsafe for use.

### A. Adsorption Cycle for Solar Cooling:

The adsorption cycle is best understood with reference to the p-T-x (pressure-temperature concentration) diagram. An ideal cycle is presented in duhring diagram (LnP vs. -1/T). This process proceeds in an evacuated (airless) environment as shown in fig 3.1. The attraction of water by the Zeolite is so forceful that the internal pressure drops dramatically. The remaining water in an attached vessel evaporates, cools down and freezes immediately due to the heat of evaporation. If a valve is included between the two vessels, the heat or cold production can be interrupted for any periods without loss of energy.

The first phase of this process proceeds up to the point when the Zeolite is saturated with water. The reverse process is initiated by heating the Zeolite at high temperatures in the second phase fig 3.2. The adsorbed water molecules are forced to evaporate (desorption). Condensation takes place in the water tank (condenser). The sequence of adsorption/desorption processes is completely reversible and can be repeated indefinitely.

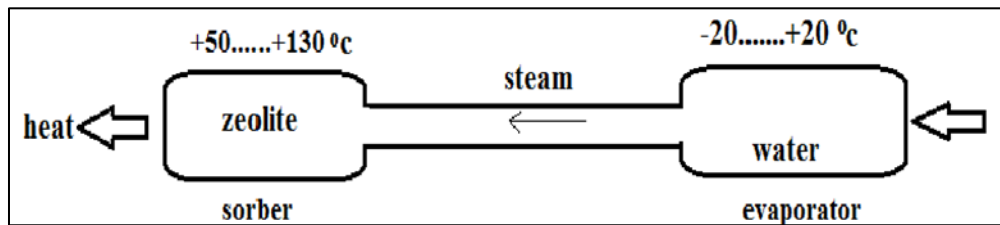


Fig. 1: Adsorption phase of a Zeolite system

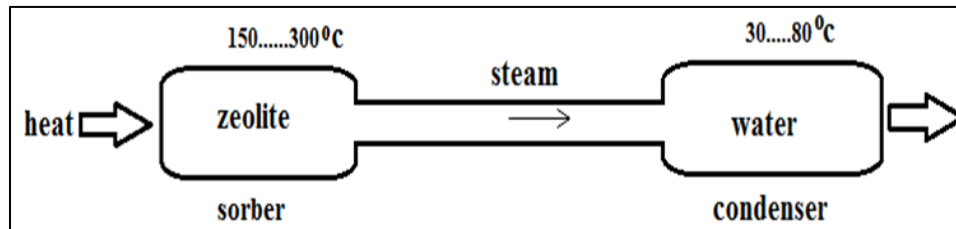


Fig. 2: Desorption phase of a Zeolite system

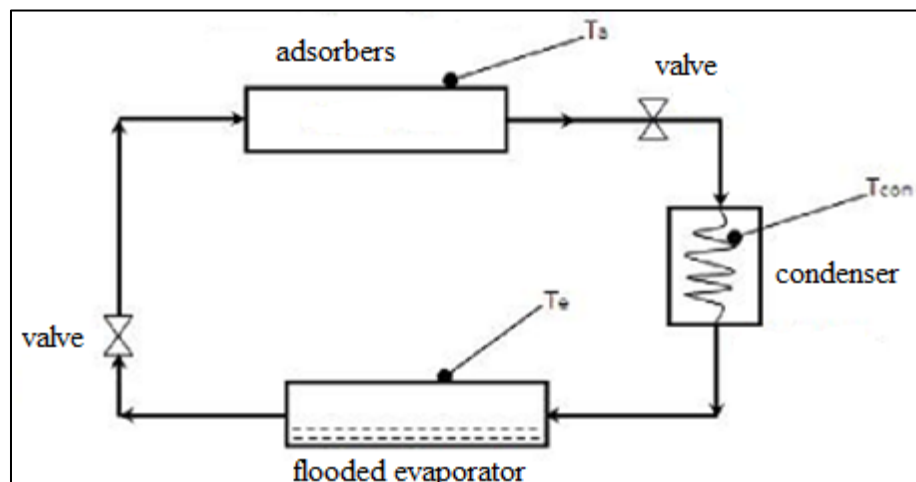


Fig. 3: Schematic diagram of the simple adsorption refrigerator.

#### B. Refrigeration Process Entails:

- 1) Starting in the morning with the valve open and at ambient temperature. Concentration of adsorbent in the generator/absorber is heated by solar energy until the pressure reaches a level that enables refrigerant to desorb and be condensed in an air or water cooled condenser.
- 2) Refrigerant is driven off at constant pressure, the adsorbent becoming more and more dilute until the maximum cycle temperature) is reached. The condensed liquid is collected in a receiver.
- 3) The valve is shut, and the adsorbent cools and reduces its pressure. At some stage of the evening or night its pressure will be the saturated vapour pressure of refrigerant which is sufficiently low for ice production.

The valve is now opened, and the liquid refrigerant starts to boil in the evaporator. Initially the Refrigerant within the evaporator and receiver simply cools itself, but having dropped below condenser temperature it can start to freeze water. Adsorption is completed by the following morning, completing the cycle. During this process heat is released in the absorber and so the generator/absorber must be cooled by ambient temperature air or water.

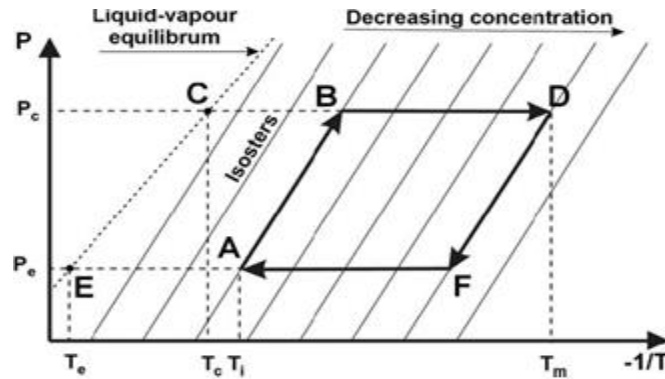


Fig. 4: ideal adsorption cooling cycle

Saturation liquid-vapour curve for the refrigerant (EC dashed line), Isosteric curves (thin lines), and adsorption cycle (thick lines). Heating period: step AB (7 a.m.→10 a.m.) and step BD (10 a.m.→4 p.m.); cooling period: step DF (4 p.m.→7 p.m.) and step FA (7 p.m.→7 a.m.).

The cycle is explained in detail we can summarize in four stages:

- 1) Step 1: Isosteric heating (A B): The system temperature and pressure increase due to the solar irradiance.
- 2) Step 2: Desorption and condensation (B D): Desorption of the water steam contained in the Zeolite: condensation of the water steam in the condenser; the water in the evaporator is drained through the valve.
- 3) Step 3: Isosteric cooling (D F): Decrease in period of sunshine; cooling the adsorbent; decrease of the pressure and temperature in the system.
- 4) Step 4: Adsorption and evaporation (F A): Evaporation of water contained in the evaporator; cooling of the cold cabinet; production of ice in the evaporator: read sorption of water steam by the Zeolite.

#### IV. LITERATURE REVIEW

N.O.Omisanya et.al<sup>[p-1]</sup> studied “performance of a zeolite-water adsorption refrigeration” in 2012. they studied the parameters are presented in terms of values of system temperature and cooling performance coefficient.

In this study, parameter of range of coefficient of performance with use of concentrating parabolic collector with 1.029m<sup>2</sup> collector areas and 1.8 concentration ratios truncated to height/aperture ratio of 1.19. with use of refrigerant pair of zeolite-water. The experimental results are presented in terms of values of system temperature and cooling performance coefficient. They measured hourly instantaneous COP ranges from 0.2 to 2.5 while the hourly insolation ranges from 34W/m<sup>2</sup> to 345W/m<sup>2</sup>. Evaporator temperature of 11°C and maximum adsorber temperature of 110°C was recorded. The minimum daily – hourly mean COP of 0.838 with the corresponding maximum COP value of 1.48 was achieved.

The solar powered adsorption refrigerator was designed to achieve cooling by operating on adsorption – desorption principle. The system has no moving parts. Water is used as working fluid and synthesized highly porous silicon compound (Zeolite 4A) is used as adsorbent.

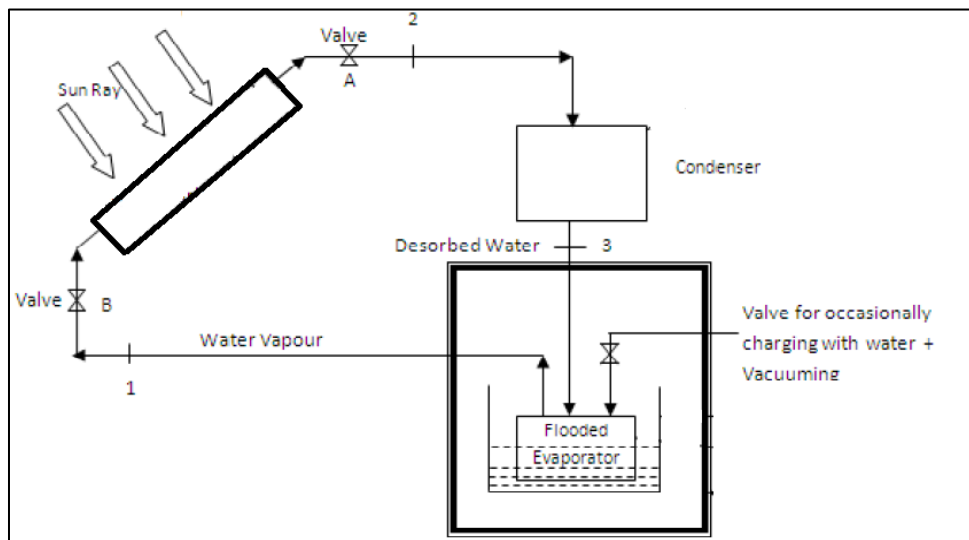


Fig. 5: Adsorption Refrigerator Design flow diagrams

The system consist of the following components as shown in Figure 1; The solar compound parabolic concentrating collectors (CPC), the condenser, the flood evaporator, airtight cap (valve) and control valve. The operation concept is based on the fact that when cool (at night) the Zeolite acts like a sponge soaking up or adsorbing the water vapour and when heated during the sunning day the water vapour is desorbed or released. The system operates under a partial vacuum, the water vapour moves with high efficiency under low pressure. At the desorption temperature of water, water vapour begins to desorb from the Zeolite. Thus the receiver act as a boiler and the water vapour leaves through the perforated holes on the duct to the condenser. This water vapour is condensed into water droplet as heat is given off by the heat exchanger (condenser) as depicted in the flow diagram (Figure 1). The resulting water runs down due to gravity into a sealed storage tank inside the refrigerator compartment. During the night, Zeolite is cooled close to ambient temperature and start adsorbing water vapour. The liquid water in the storage tank (an evaporator) adsorbs heat from the space to be cooled and is converted into water vapour. Since the system is sealed under very low pressure the remaining water in the storage tank freeze's into ice. This ice will melt slowly during the next day thus providing sustained cooling at reasonable constant temperature.

## V. RESULT AND DISCUSSION

Global solar radiation is the total amount of solar energy received by the Earth's surface, usually expressed as  $W m^2$ . About 99 percent of global solar radiation has wavelengths between 300 and 3000 nm. This includes ultraviolet (300-400 nm), visible (400-700 nm), and infrared (700-3000 nm) radiation. Global solar radiation is the sum of direct, diffuse, and reflected solar radiation. Direct solar radiation passes directly through the atmosphere to the Earth's surface, diffuse solar radiation is scattered in the atmosphere, and reflected solar radiation reaches a surface and is reflected to adjacent surfaces.

Gujarat receives second largest amount of solar radiation in India. Gujarat receives 5.5 to 6 Kwh/  $m^2$ /day with 300 days/year. Most locations in Gujarat receive an annual Direct Normal Incidence (DNI) in between 1,800-2,000 Kwh/ $m^2$ . This data will be collected on website of [www.mnre.gov.in](http://www.mnre.gov.in).

Table – 1  
Average Solar Radiation per Day in Valsad

Month	Average Solar Radiation Per Day In Valsad
January	4.36 kwh/ $m^2$ /day
February	5.08 kwh/ $m^2$ /day
March	5.89 kwh/ $m^2$ /day
April	6.29 kwh/ $m^2$ /day
May	6.56 kwh/ $m^2$ /day
June	5.90 kwh/ $m^2$ /day
July	4.71 kwh/ $m^2$ /day
August	4.39 kwh/ $m^2$ /day
September	5.07 kwh/ $m^2$ /day
October	5.07 kwh/ $m^2$ /day
November	4.52 kwh/ $m^2$ /day
December	4.03 kwh/ $m^2$ /day
Average	5.15 kwh/ $m^2$ /day

The temperatures at different places in the system will be measure. i.e. absorber, evaporator, adsorber and ambient. Where taken simultaneously with the same instrument. The results of the cooling experiments are shown in the table below.

Table – 2  
Temperature reading on date 22/3/2016

Time (hrs)	Ambient temp(c)	Absorber temp	Condenser temp	Evaporator temp
8:00	18	14	18	-
9:00	19	20	19	-
10:00	21.5	30.5	21.5	-
11:00	24	39.8	24	-
12:00	28	48.2	28	-
13:00	32	54	32	-
14:00	34	59	34	-
15:00	31	52.5	31	27
16:00	30	50	30	25.5
17:00	28	46	28	23
18:00	25	43	25	20
19:00	20	40	20	17.5
20:00	19	38	19	16

## VI. CONCLUSION

The objective of this research which was to construct and test a solar adsorption refrigerator using Zeolite as the adsorber and water as a refrigerant, with locally available materials was achieved. It has been shown that refrigeration effect can be produced

by a very simple adsorption cycle using locally produced Zeolite as adsorbent and water as the refrigerant in such a simply designed solar adsorption refrigerator as presented in this work.

Theoretically a solar irradiation of  $300\text{W/m}^2$  is sufficient to reach the required desorption temperature in the range of  $150^\circ\text{C}$ - $170^\circ\text{C}$  which is attainable in the main solar testing period in Zaria. Total pressures in the system may increase due to leakages in piping network or desorption of air from inner surfaces. This effect can reduce the adsorption rate and boiling temperatures of the refrigerant. The efficiency of the whole system depends on the efficiency of the solar collector and the system operates on an intermittent water-Zeolite adsorption cycle which is capable refrigeration for food conservation in rural areas where no electricity is available.

#### REFERENCES

- [1] N.O.Omisaniya et.al, "performance of zeolite-water adsorption refrigeration", advances in applied science research (2012), 6.3737-3745.
- [2] Mohand Berdja et.al, "design and realization of a solar adsorption refrigeration machine powered by solar energy", energy procedia 48(2014) 1226-1235.
- [3] Shu Xu<sup>a</sup> et.al, "experiment on new adsorption bed about adsorption refrigeration driven by solar energy", energy procedia 14(2012) 1542-1547.
- [4] [http://fc.uni.edu.pe/mhorn/ISES2003%20\(solar%20refrigeration\).pdf](http://fc.uni.edu.pe/mhorn/ISES2003%20(solar%20refrigeration).pdf)
- [5] Siegfried kreussler et.al "experiments on solar adsorption refrigeration using zeolite and water" applied science 15(2014) 441-452.
- [6] Xiangbo song, Ming li and Yuan Dai et.al, "effect of desorption parameters on performance of solar water bath solid adsorption ice making system", applied thermal engineering 89(2015) 316-322.