Performance Evaluation of an Intermittent Adsorption Refrigeration System with Composite Adsorbent

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Abstract: The sun is a magnificent energy source for us. It is clean and harmless comes to the earth for free and it can be used as it is. The devices need to gather its energy is simple, quiet and non-polluting. In recent years, more attention is being given to the use of solar energy in the field of engineering refrigerating systems. Solar powered refrigeration and air-conditioning system have been very attractive during the last twenty years, since the availability of sunshine and the need of refrigeration both reach maximum levels in the summer season. Solar adsorption refrigeration is an option to gain on the drawbacks of the conventional cooling system. The adsorption refrigeration is mainly based on the evaporation and condensation of a refrigerant mixed with adsorption. This paper will describes the design and fabrication of the experimental set up, the experimental method and its usefulness towards development of an alternative environmental-friendly refrigeration cycle for replacement of conventional refrigerants like chlorofluorocarbons. The objective of this paper is to set down an alternative eco-friendly refrigeration cycle for producing a low temperature as in a conventional refrigerator. By constructing such type of refrigerator adds new importance to the world of refrigeration. This refrigerator gives some amount of alleviation to the refrigeration world by making it freewheeling from electric power supply and zero running cost.

Keywords: **The Adsorption, Adsorbent, Refrigerants, Solar powered refrigeration (SAR). COP.**

I. INTRODUCTION

Solar refrigeration system (SAR) is more recognized as a priority in developing countries. This is due to the use for refrigeration, for food as well as for vaccine & medicine preservation. The system is perfect for conveying temperature sensitive vaccines and life-saving medical supplies because the portable units will retain a constant temperature for the vaccines. The SAR system is one of the cleanest technologies because it is eco- friendly. It has the advantages of zero Ozone layer Depletion Potential and zero Global Warming Potential compared to the CFC emissions where it is considered liable for about one-third of the global greenhouse effect as exposed in the environmental impact of fluorocarbon indication in the atmosphere (Mahsa Sayfikar et al, 2013). The interest for adsorption refrigeration is due to the fact that they are environmentally friendly and that they can use low heat source such as solar energy as driving force. Therefore the SAR cooling system can be investigated as possible solution to the emission problem since they operate with water, which are fully ecologically compatible and non-toxic refrigerant fluids. In inclusion to domestic applications, the SAR system is applicable for market demands because:

i. The system is easy to operate;
ii. The system needs low operating cost and Care.
iii. The system does not contain any noisy components such as compressors and pumps.
iv. Simple to control the capacity of the system.

Adsorbents are materials retain a long-lasting porous structure that, at low temperatures, actions like a sponge, soaking up or adsorbing the refrigerant (water). As the temperatures inflated, the refrigerant released or desorbed (Ghassan M. Tashtoush et al, 2012). This adsorption cycle is silent in operation and most suited for remote locations without electricity supply since they can be powered by purely thermal energy like solar energy (G. Moreno Quintanaret al, 2011). In the SAR system the adsorbent filled in a sealed collector painted black to enhance the solar radiation absorption .The solar energy warmth the high concentration of adsorbent and container to the maximum cycle temperature during the day time where the refrigerant starts desorbing from the adsorbent. In the condenser the refrigerant vapor changed to liquid and flow is by gravity to the receiver or directly to the evaporator. The adsorbent is cooled down to nearby ambient temperature, during the night cycle, thus decreasing the pressure of the entire system. The refrigerant boils in the evaporator and matter heat to be absorbed from the immediate environment and the adsorbent pressure equals the saturated vapor pressure of the refrigerant, asareaction the refrigerant vapor is re-adsorbed into the adsorbent, while cooling effect is produced. Various studies conducted to determine the suitable adsorbent–adsorbate pairs for various applications also to assess the cooling coefficient of performance (COP) with respect to the operating temperatures. The disadvantage of SAR systems was the low heat transfer coefficient in the adsorbent bed, which influence the thermodynamic efficiency of the SAR system(XuJi et al, 2014). Recently a lot of attention has been paid to use adsorption refrigeration systems for the pair of ice-making and air conditioning. For example, activated carbon 25% & Silica gel 75% -Water is a good working pairs. The adsorption cycle for refrigeration or heat pumping is a succession of two periods: 1) Heating-desorption-condensation cycle at high pressure (saturation pressures of the adsorbate at the temperature of the condenser); 2) cooling-adsorption-evaporation cycle at low pressure (saturation pressures of the adsorbate at the temperature of the evaporator)(Ghassan M. Tashtoush et al, 2012). In this research an experimental study of a solar adsorption refrigeration system was performed with composite adsorber (Activated Carbon 25% & Silica Gel 75%).

II. DESIGN OF EXPERIMENTAL SET-UP

The proposed SAR is designed with a view of mechanical simplicity, cost effectiveness and reliability rather than high levels of performance. Factors considered in the design and construction of the SAR includes: solar irradiance, materials for construction, adsorption and desorption temperature, evaporation and condensation temperature. Figure 1 shows the flow diagram of SAR.
For the experimentation purpose two factors are selected while designing which includes composite absorbent of 75 % silica gel with 25% activated carbon and time interval.

- This factor contains seven levels for each cycle i.e. seven levels for desorption cycle (day cycle) and seven levels for adsorption cycle (night cycle).

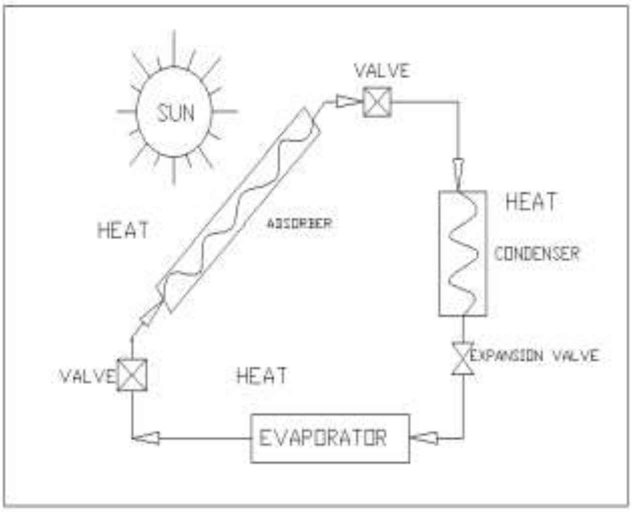

Fig.1 Flow diagram of SAR

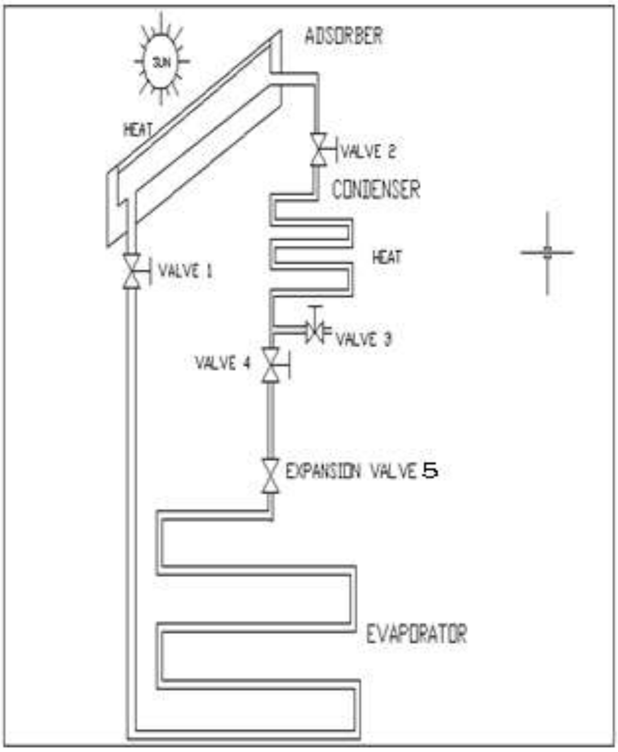

Fig.2 Schematic diagram of set up

The levels of the point were selected randomly. The composite type of adsorbent were selected because they will be desorbed or charged by using low-grade thermal energy provided by copper tube adsorber bed solar collector, which is commercially available in India. India has different climatic regions with a very good solar insolation level (mean insolation is 650 W/m^2) and the sun rises in all days of the year. The system was developed with adsorber bed, condenser, evaporator, pressure gauges and control valves. The condenser and evaporator were made from copper tubes. Pressure gauges were connected to adsorber. Fig.2 shows schematic diagram of setup. The components were connected to develop the final system. In this system refrigerating effect was produced during the heating of the adsorber.

For the proper functioning of SAR various connected valves and expansion valves are introduced in experimental setup. Purpose of individuals valves are explained in Table 1.

Table 1 Purpose of valve used

Valve	Purpose
1	To isolate Adsorption reactor from the evaporator.
2	To isolate Adsorption reactor from the condenser.
3	To connect with the vacuum pump
4	To isolate the condenser from the expansion valve
5	To evacuate the refrigerant from the evaporator

Standard operating procedure is defined to come out experimentation. A Table2 show summarizes the procedure for experimentation along with closing and opening of control valves during entire day.

Table 2 Procedure for operating the SAR

Time	Valve 1	Valve 2	Valve 3	Valve 4	Process
08.00	Close	Close	----	Close	Heat adsorbent
11.00	Close	Open	----	Close	Heat adsorbent Condensation
19.00 -7.00	Open	Close	----	Open	Evaporation: Cooling cycle
….	Open	Open	Open	Open	For charging & Discharging or Evacuate the refrigerant

The experimentation is performed using the composite adsorbent contained in the bed. Copper tubes are passed through adsorber bed to acquire heat released during adsorption processes.. A grid holds 3kg of activated carbon and 9kg of Silica gel. 15 copper tubes of dimension 33 mm OD × 30 mm ID × 1240 mm and 2 copper header tubes of 51 mm ID x 54 mm OD x 1400 mm long were chosen. The choice of these pipes was necessitated due to heat conductivity of Copper, minimization of space and because there must be enough Volumetric space for silica gel & activated Carbon. The pipes and the rectangular container were painted with a black paint of reasonable absorptivity. This was done to improve thermal performance and to assist absorptivity. The cooling cabinet is made by 3mm Perspex sheeting lined interior and exterior having usable capacity of $0.216m^3$,insulation is provided using 100mm thick Energylite on all sides. The evaporator is made of a number of copper pipes having wall thickness of 1.5mm and outside diameter of 16 mm inside these pipes the refrigerant is allowed to boil under very low pressure conditions. The condenser is used to dissipate heat from the vapour so that the vapour can condense back into a liquid during the process of desorption for this Outside pipe diameter of 12mm having wall thickness of 1mm cooper pipe is used. For depressing the freezing point of water, calcium chloride is used to prevent ice formation and to deice. Calcium chloride dissolution is exothermic, and the compound is relatively harmless to plants and soil RTD’s–PT-100 Sensor (8 No.) with Digital Temperature Indicator of Range 0-400. The temperature sensors are required to measure the temperature of inlet and outlet of the water. The eight RTD’s (PT-100) and corresponding temperature indicator will be selected to measure the temperature up to 250°C with indicator three and half digit. Five pressure gauges are used to measure the initial and final pressure of refrigerant water and at different section of system.

III. RESULT AND DISCUSSION

Sample results for the following day/night periods were chosen for analysis and evaluation of the solar refrigerator. Graphs for COP versus time and Outlet temperature versus time were plotted. Analysis for the adsorber's desorption and adsorption modes; condenser's condensation mode and evaporator's evaporation mode were analyzed and evaluated

COP is the ratio of final output to input which used as an index of performance of a refrigerator.

$$COP_R=\frac{Q_l}{W_{net.in}} \quad (1)$$

Where,
Q_l=heat absorbed from the *cooled* space.
$W_{net.in}$=Work input.

The maximum COP for the refrigeration may be calculated as,

$$COP_R=\frac{Q_l}{Q_H-Q_l}=\frac{Q_C}{Q_C}=\frac{T_g\,(T_a-T_e)}{T_e\,(T_g-T_c)} \quad (2)$$

Where,
T_g =adsorber bed temperature
T_a =Ambient temperature
T_e =minimum temperature reached in refrigerator.
T_g =91.08°C
=273+91.08
=364.08K
T_a =27°C =300K
T_e =8.84°C=282.02K

$$COP_R=\frac{T_g\,(T_a-T_e)}{T_e\,(T_g-T_c)}$$

$$=\frac{361.2\,(300-281.04)}{281.04\,(361.2-300)}$$

=0.398

The detailed calculation table is shown in the tabulated form as shown in below lines. Fig. 3 & 4 shows graph of variation of COP & temperature against days.

Table 3 Calculation of COP

No of Days	Ambient temperature	Area	Bed Temperature	Mass of Water	Water Inlet Temp	Water Outlet Temp	Temp difference of Water	COP
	T_a, °C	M^2	T_e,°C	m	Ti, °C	To, °C	ΔT	
DAY 1	27	1.478	88.20	10	39.50	8.04	31.46	0.398
DAY 2	27	1.478	91.08	10	40.86	8.84	32.02	0.366
DAY 3	27	1.478	90.58	10	40.40	9.02	31.38	0.365
DAY 4	27	1.478	90.14	10	40.04	8.88	31.16	0.369
DAY 5	27	1.478	86.58	10	37.58	10.48	27.10	0.352
DAY 6	27	1.478	88.80	10	39.20	9.41	29.79	0.367
DAY 7	27	1.478	90.26	10	40.94	8.24	32.7	0.383

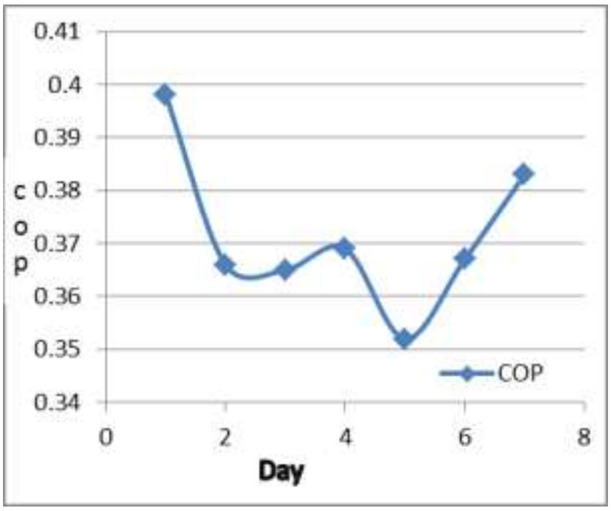

Fig.3 Variations in System COP

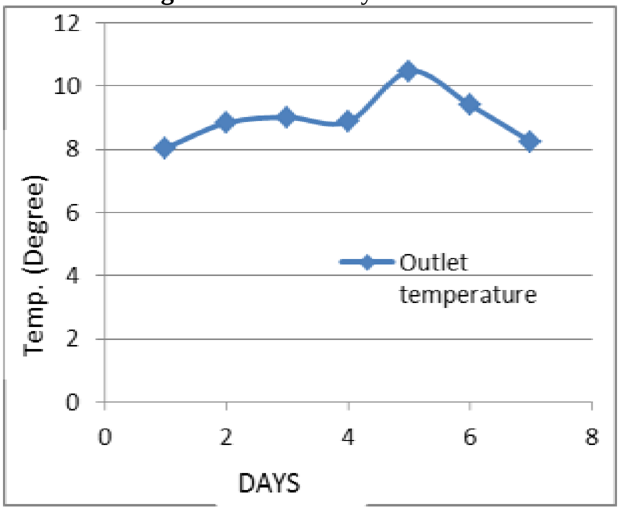

Fig.4 Variation in Outlet Temperature of System

Test results show that only chilled water with temperatures between 7°C and 11°C is produced. Vegetables and fruits with preservation temperatures in the range of 4°C to 10°C are within the scope of the present system. . The coefficient of performance of 0.398 obtained was rather low. The low collector efficiency and useful coefficient of performance are indicative of the inefficiencies in both the collector and the evaporator. The low coefficient of performance of 0.352 might have been caused by air leaking into the system, the thickness of silica gel & activated carbon packing, the conductivity of silica gel & activated carbon with calcium chloride and water combination. The cold box temperature increased over 11°C and up to 35°C during the day phase, thus the aim of maintaining low temperatures in the chamber was not obtained. This comes from the higher heat gain of the box than expected

IV. CONCLUSIONS

A solar powered adsorption-cooling refrigerator employing silica gel & activated carbon-water vapour pair was designed, developed and evaluated. The natural cooling arrangement was sufficient. Condensing temperature averaged at 35°C. It is observed that COP of SAR varies between 0.352 to 0.398 which is low and doesn't serve purpose of maintaining very low temperature. An improved box of lower heat losses must be constructed in order to improve the results, especial the connection between the condenser and the evaporator. Testing was also carried out continuously over a period of 7 days and it was observed that air was slowly leaking into the system (the difference of 5 kPa was noted on the gauges). As a result solar adsorption cooling requires careful manufacturing methods, since any leakage causes refrigerator malfunction. The refrigerants don't diffuse well through air, and air obstructs the adsorption, condensation and evaporation processes.

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