Solar Coefficient of 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. The devices need to gather its energy is simple, quiet and non-polluting. International environment protection initiatives have led to the intensification of research efforts on development of ozone layer and global warming safe refrigeration technology. In recent years, more attention is being given to the use of waste heat and 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 for refrigeration both reach maximum levels in the summer season. The conventional cooling technologies are generally based on the electrically driven refrigeration system. These systems require high levels of primary energy consumption, causing electricity peak loads and employ refrigerants which cause environmental pollution. Solar adsorption refrigeration is an option to gain on the drawbacks of the conventional cooling system.

The objective of this project is to set down an alternative eco-friendly refrigeration cycle for producing a temperature usually comes upon in a conventional refrigerator. By manufacturing such type of refrigerator adds new importance to the world of refrigeration. This refrigerator gives some amount of relief to the refrigeration world by making it freewheeling from electric power supply and zero running cost.

Keyword - *Adsorption, Adsorbent, Refrigerants, Solar powered refrigeration (SAR), COPs.*

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1. INTRODUCTION

Solar refrigeration system (SAR) is more recognized as a priority in developing countries. This is due to the needs for refrigeration, for food as well as for vaccine & medicine preservation. The system is perfect for transporting temperature sensitive vaccines and life-saving medical supplies because the portable units will maintain a constant temperature for the vaccines [1]. The SAR system is one of the cleanest technologies because it is environmentally friendly. It has the advantages of zero Ozone Depletion Potential and zero Global Warming Potential compared to the CFC emissions where it is considered responsible for about one-third of the global greenhouse effect as shown in the environmental impact of fluorocarbon traces in the atmosphere. 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 considered as possible solution to the emission problem since they operate with water, which are fully ecologically compatible and non-toxic refrigerant fluids. In addition to domestic applications[2], the SAR system is applicable for market demands because:

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

Adsorbents are materials possess a permanent porous structure that, at low temperatures, acts like a sponge, soaking up or adsorbing the refrigerant (water). As the temperatures elevated, the refrigerant released or desorbed. 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[3]. In the SAR system the adsorbent packed in a sealed collector painted black to enhance the solar radiation absorption. The solar energy heats 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 moves by gravity to the receiver or directly to the evaporator. The adsorbent is cooled down to near ambient temperature, during the night cycle, thus reducing the pressure of the entire system. The refrigerant boils in the evaporator and causes heat to be absorbed from the immediate environment and the adsorbent pressure equals the saturated vapor pressure of the refrigerant, As a result 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 quantify the cooling coefficient of performance (COP) with respect to the operating temperatures. The disadvantage of such systems was the low heat transfer coefficient in the adsorbent bed, which influence the thermodynamic efficiency of the SAR system[1]. Recently a lot of attention has been paid to use adsorption refrigeration systems for both 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 period at high pressure (saturation pressures of the adsorbate at the temperature of the condenser);
2) cooling-adsorption-evaporation period at low pressure (saturation pressures of the adsorbate at the temperature of the evaporator).

In this research an experimental study of a solar adsorption refrigeration system was performed with composite adsorber (Activated Carbon 25% & Silica Gel 75.

2. DESIGN OF EXPERIMENTAL SET-UP

The proposed machine has as main parameters mechanical simplicity, cost effectiveness and reliability rather than high levels of performance. Factors considered in the design and construction of the fridge includes: solar irradiance, materials for construction, adsorption and desorption temperature, evaporation and condensation temperature. Figure 1 shows the cycle flow diagram for the machine. The machine will have to ensure safety in function and satisfy the accepted design standards

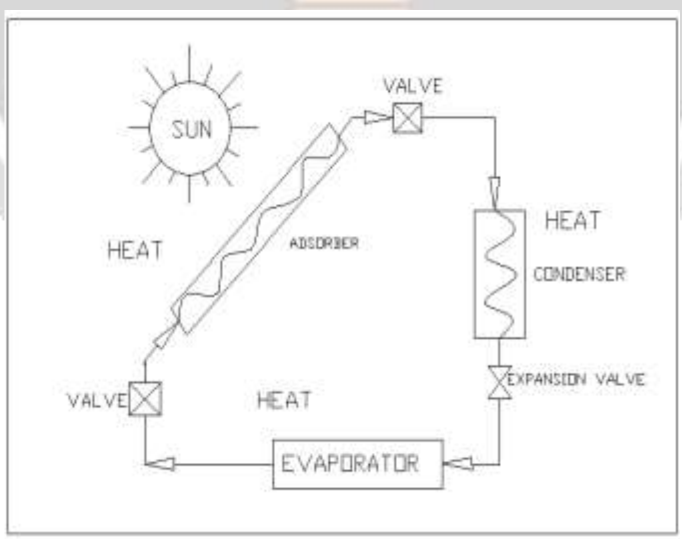

Fig -1: Cycle flow diagram for the machine

In this study, we have an experiment that includes factor that we think they will be an important part of the way we learn about how the system works. Those factors are

i. Composite Adsorbent
- 75% Silica Gel & 25% Activated Carbon

ii. The 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)

The levels of the factors were selected randomly from larger populations of factor levels to insure unbiased results, and we wish to extend our conclusion to the entire population of factor levels. The composite type of adsorbent were selected because they can 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/m2) and the sun rises in all days of the year. For example, Pune and parts of Maharashtra in summer times have solar radiation time exceeding eleven hours and few full cloudy days. For these reasons, Pune will be a good place to construct solar cooling systems.

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. The components were connected to develop the final system. In this system refrigerating effect was produced during the heating of the adsorber.

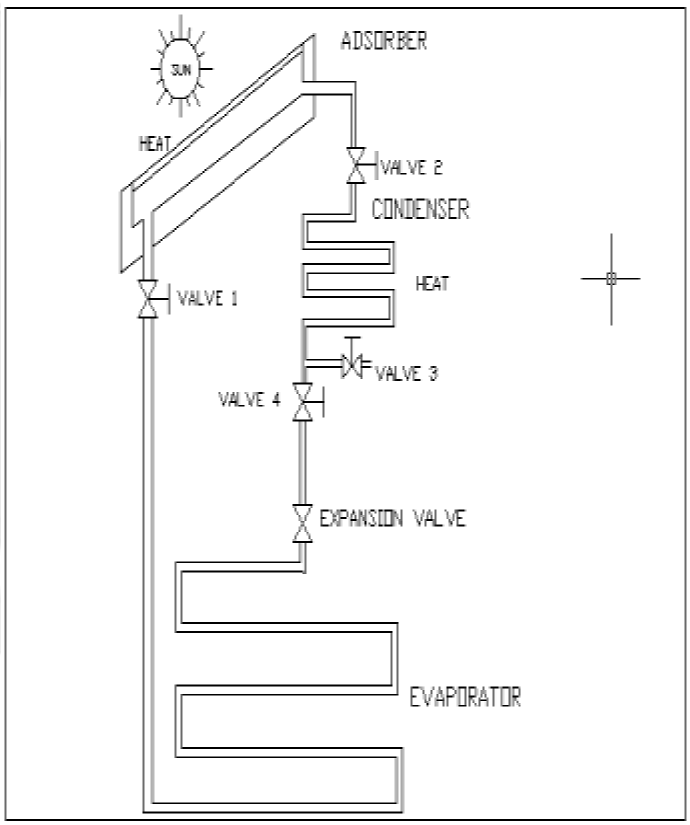

Fig -2: Diagram of set up with valve arrangement

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

The experiment was run according to the procedure as set out in Table 2 and the explanation below

Table -2: Procedure for operating the experimental system

Time	Valve 1	Valve 2	Valve 3	Valve 4	Process
07.00	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. To acquire the heat that will be released during the adsorption processes copper tube pass through the adsorber. 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: $0.216m^3$,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 to used 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 $250^{o}C$ 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.

3. RESULT AND DISCUSSION

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

Solar coefficient of performance calculation (COPs)

I = 4589.58 W/m^2 per day.

A =1.478m^2(Adsorber Area)

I_{Total} = I x A

= (4589.58 x 1.478 x 3600) / 1000

= 24420.237 W

Ti = 39.50ºC

T_{out} =8.04ºC

C_p =4.187KJ/kg.K

M =10 kg (Load mass)

Qe =m x C_p x (Tin-Tout)

Qe =10 x 4.187 x (39.50-8.04)

= 1317.23 W

$$COP = \frac{Q_e}{I_{Total}}$$

$$COP = \frac{1317.23}{24420.237}$$

= 0.0539

Table -3: Calculation of COP

No of Days	Intensity	Area	Total Intensity	Mass of Water	Water Inlet Temp	Water Outlet Temp	Specific Heat of Water	Temp difference of Water	Solar Energy Supplied	COP
	I	M^2	I_{total}	m	Ti	To	CP	ΔT	Qe	
DAY 1	4589.58	1.478	24420.24	10	39.50	8.04	4.187	31.46	1317.23	0.051
DAY 2	5026.30	1.478	26743.94	10	40.86	8.84	4.187	32.02	1340.67	0.052
DAY 3	4948.28	1.478	26328.80	10	40.40	9.02	4.187	31.38	1313.88	0.051
DAY 4	4236.88	1.478	22543.60	10	40.04	8.88	4.187	31.16	1304.67	0.057
DAY 5	4125.60	1.478	21951.49	10	37.58	10.48	4.187	27.10	1134.67	0.058
DAY 6	4230.92	1.478	22511.88	10	39.20	9.41	4.187	29.79	1246.97	0.046
DAY 7	5008.82	1.478	26650.93	10	40.94	8.24	4.187	32.7	1369.15	0.055

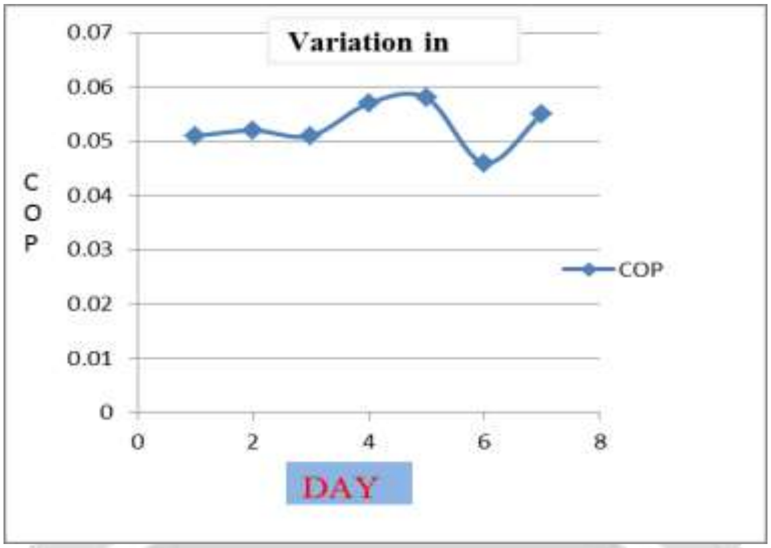

Chart -1: Variations in System COPs

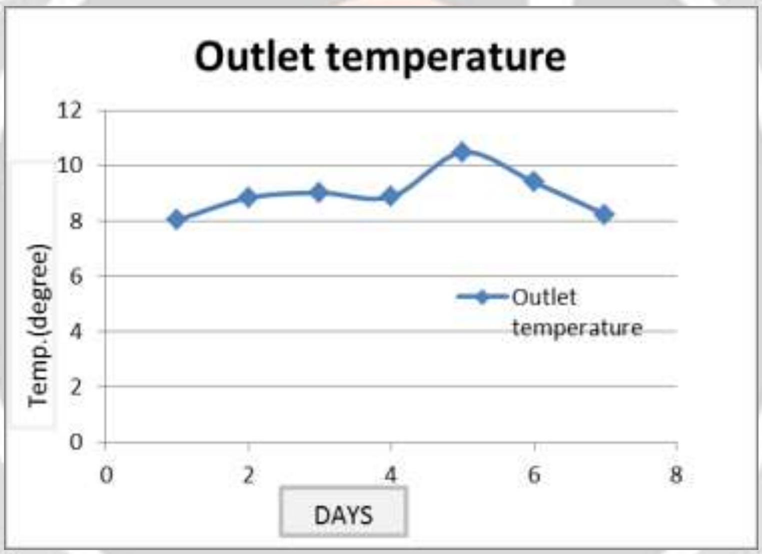

Chart -2: Variation in Outlet Temperature of System

4. CONCLUSIONS

A solar powered adsorption-cooling fridge employing silica gel & activated carbon-water vapour pair was designed, developed and evaluated. The natural cooling arrangement was sufficient. Condensing temperature averaged at 35ºC. Test results show that only chilled water with temperatures between 7 and 11ºC is produced. Vegetables and fruits with preservation temperatures in the range of 4 to 10ºC are within the scope of the present system. . The coefficient of performance of 0.058 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 0.046 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 ineffectiveness of silica gel & activated carbon adsorption capability, solar irradiation and the ambient temperature. 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 attained. This comes from the higher heat gain of the box than expected. An improved box of lower heat losses must be built 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 do not diffuse well through air, and air obstructs the adsorption, condensation and evaporation processes

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