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Design & Experimental Analysis of Solar Adsorption Refrigeration System

#1Mr. Ashwinikumar Hade, #2Dr. C.M.Sedani, #3Prof.Irfan M.D

1ashwinikumar.hade@gmail.com,
2cmsedani@gmail.com,
3irfanmd777@gmail.com

#123M.S.S. College of Engineering and Technology, Jalna, India

ABSTRACT

The sun is known to be the main source of energy to earth. It is further more outstanding since it is clean and comes to the earth with no costs. However, mankind does not utilize most of this precious energy effectively. In India, emerging farmers need their agricultural products preserved in storage or in transit. Solar adsorption cooling machines would be of benefit to these farmers as they do not require any additional source of energy and are completely autonomous. This study presents a theoretical and experimental analysis of a solar assisted adsorption fridge, as well as the cost effectiveness when compared with the vapour compression method. The cooling machine was designed, developed and tested. It does not contain any moving part; nor consume any mechanical energy. The results show that the refrigerator can chill 10 litres of water from 35 to 7°C per day. The best coefficient of performance was 0.054.

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I. INTRODUCTION

Refrigeration is defined as "the process of cooling of bodies or fluids to temperatures lower than those available in the surroundings at a particular time and place". It should be kept in mind that refrigeration is not same as "cooling", even though both the terms imply a decrease in temperature. In general, cooling is a heat transfer process down a temperature gradient; it can be a natural, spontaneous process or an artificial process. However, refrigeration is not a spontaneous process, as it requires expenditure of exergy (or availability). Thus cooling of a hot cup of coffee is a spontaneous cooling process (not a refrigeration process), while converting a glass of water from room temperature to say, a block of ice, is a refrigeration process (non-spontaneous). "All refrigeration processes involve cooling, but all cooling processes need not involve refrigeration". Refrigeration is a much more difficult process than heating; this is in accordance with the second laws of thermodynamics. This also explains the fact that people knew 'how to heat', much earlier than they learned 'how to refrigerate'. All practical refrigeration processes involve reducing the temperature of a system from its initial value to the required temperature that is lower than the surroundings, and then maintaining the system at the required low temperature. The second part is necessary due to the reason that once the temperature of a system is reduced, a potential for heat transfer is created between the system and surroundings, and in the absence of a "perfect insulation" heat transfer from the surroundings to the system takes place resulting in increase in system temperature. In addition, the system itself may generate heat (e.g. due to human beings, appliances etc.), which needs to be extracted continuously. Thus in practice refrigeration systems have to first reduce the system temperature and then extract heat from the system at such a rate that the temperature of the system remains low. Theoretically refrigeration can be achieved by several methods. All these methods involve producing temperatures low enough for heat transfer to take place from the system being refrigerated to the system that is producing refrigeration.

The objectives of the study are

1. To investigate the feasibility of composite adsorption pair of Silica and Calcium chloride with water as refrigerant.
2. To investigate the design parameters of the solar fridge components, these being the adsorber, condenser and evaporator.
3. To integrate and evaluate fridge design parameters for cost effectiveness and user-friendliness during development of the solar fridge.
4. To evaluate the cooling capacity of the system.
5. To investigate the feasibility of pairing composite adsorbent and refrigerant with reference to adsorption capabilities in order to find scope for development of a solar assisted adsorption refrigeration system.

II. LITERATURE REVIEW

Abdulateef et al. studied the objective of this paper is to provide a literature review on solar-driven ejector refrigeration systems and to give useful guidelines regarding background and operating principles of ejector. This paper describes a basic background and development on solar-driven ejector refrigeration technologies. One may conclude that solar-powered ejector refrigeration technologies could be used for producing a wide range of temperatures of cold. They are attractive technologies that not only can serve the needs for refrigeration, air-conditioning applications and ice making, but also can meet demand for energy conservation and environment protection. Comparatively, absorption systems are more suitable for air-conditioning while adsorption systems are more employed for low temperature purpose. A variety of options is available to convert solar energy into refrigeration effect. Solar thermal with single-effect absorption system appears to be the best option closely followed by the solar thermal with single-effect adsorption system. Solar photovoltaic options are significantly more expensive.

Anyanwu et al. presented the design, construction and test run of a solid adsorption solar refrigerator. He used activated carbon/methanol as the adsorbent/adsorbate pair. The refrigerator has three major components: collector/generator/adsorber, condenser and evaporator. Its flat plate type collector/generator/adsorber used clear plane glass sheet of effective exposed area of 1.2 m2. The steel condenser tube with a square plan view was immersed in pool of stagnant water contained in a reinforced sandcrete tank. The evaporator is a spirally coiled copper tube immersed in stagnant water. Adsorbent cooling during the adsorption process is both by natural convection of air over the collector plate and tubes and night sky radiation facilitated by removing the collector box end cover plates. Ambient temperatures during the adsorbate generation and adsorption process varied over 18.5–34ºC. The refrigerator yielded evaporator temperatures ranging over 1.0–8.5ºC from water initially in the temperature range 24–28ºC. Accordingly, the maximum daily useful cooling produced was 266.8 kJ/m2 of collector area.

Boubakri et al. studied solar adsorptive ice maker model is presented and experimentally validated. In order to determine the model parameters, the identification procedure is carried out employing an experimental data base obtained from tests carried out on two adsorptive solar-powered ice-makers using a methanol/carbon pair. The model is then used to study daily ice production sensitivity vice versa critical physical parameters of the unit and to estimate the limits of the collector–condenser technology with flat plate collectors. With the help of a model based on experimental measurements obtained from tests on adsorptive solar-powered ice makers, the convective heat transfer coefficients on the front and the rear part of the collector–condenser and the global heat transfer coefficient inside the condenser are identified. These coefficients are first analyzed and thus the effect of a radiation shield which equips one of the machines is evaluated. This component leads to a 40% reduction of adsorbent rear losses. Conclusive results are obtained, especially in the calculation of the D.I.P., regarded as a validation criterion. Thus, the validated model allows us firstly to study the D.I.P. sensitivity to variation of the main physical parameters of the machines. The major limiting factor appears to be h. Except for this parameter, the machines are found to be quite well designed. The model then permits to estimate the limits of ice production by means of adsorptive collector–condenser Technology: if the machines were working in the best conditions of physical and meteorological parameters, D.I.P. could reach 11.5 kg per m of collector, corresponding to a COPs5 19%. This represents the limit of collector–condenser technology with flat plate collectors.

Buchter et al. built and tested an adsorptive solar refrigerator in May 1999 in Ouagadougou, Burkina-Faso. The adsorption pair is activated carbon + methanol. The adsorber is also the solar collector (2m2, single glazed), the condenser is air cooled (natural convection) and the evaporator contains 40 lit of water that can freeze into ice. This amount of ice acts as a cold storage for the cold cabinet (available volume of 440 lit). Elements such as valves and a graduated bottle are installed, but only for experimental purposes. Apart from these valves, and also ventilation dampers which are open at night time and closed at daytime, the machine does not contain any moving parts and does not consume any mechanical energy. Within the requirement of vacuum technology, the machine is relatively easy to manufacture, so that construction in Burkina-Faso is feasible. Experimental performance is presented in terms of gross solar COP. During the test period, irradiance were quite good (between 19 and 25 MJ /m²), but the ambient temperature was relatively warm (averagely 27.4ºC at sunrise and 37.4ºC at mid-afternoon). The experimental values of the gross solar COP lie between 0.09 and 0.13. Despite a warm climate, the performance of the machine compares favorably to previously published results.

Li et al. 2002 stated that based upon the prior research of the solar hybrid water heater and refrigerator, a new flat plate solar hybrid system with heating and cooling was proposed and experimental prototype device was constructed. With this new hybrid system, the heat and mass transfer can be improved effectively both in desorption process and adsorption process. The conventional flat plate solar water heater collector absorber is immersed inside adsorbent bed in the new hybrid system. The experimental results show that not only the cooling effect can be obtained, but also both the sensible heat of the adsorbent bed and the adsorption heat can be recovered effectively to produce hot water for domestic use. The COP of this new flat plate hybrid system can reach 0.11 and the heat efficiency is about 0.45, this achievement has demonstrated an efficient way of the application of solar energy.

Vasiliev et al. 2000 presented the solid sorption short cycle heat pump (≤10 kW) which uses physical adsorption and is of interest to the space and domestic application is designed and tested. This heat pump has a very short (12 min), non intermittent, two adsorber heat recovery cycles with an active carbon fiber as a sorbent bed and ammonia as a working fluid. It has two energy sources: solar and gas flame. The system management consists only in actuating the special type valves to change the direction of the heating circuit and water valves to change the water cooling circuit.

III. DESIGN OF SYSTEM

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.

Fig 02: Photograph of experimental system

Following sub parts are designed to develop the experimental setup

i) Cooling Cabinet
ii) Evaporator
iii) Condenser
iv) Adsorber Bed

3.1 Cabinet specifications

Interior dimensions: 0.6m x 0.6m x 0.6m deep.
Usable capacity: 0.216m3 or 216 lit.
Exterior dimensions: 0.8m x 0.8m x 0.8m high.
Cabinet construction: 3mm Perspex sheeting lined interior and exterior.
Insulation: 100mm thick Energylite on all sides.

3.2 Evaporator specifications

i) Outside pipe diameter	: 16 mm.
ii) Evaporator Tube length	: 5.33m.
iii) Wall thickness	: 1.5 mm.
iv) Usable capacity	: 0.01 m3 or 10 lit.
v) Construction material	: Copper.

3.3 Condenser specifications

1) Outside pipe dameter	:	12 mm.
2) Condenser Tube length	:	6.408m.
3) Wall thickness	:	1 mm.

3.4 Adsorber Bed specifications

25 copper tubes of dimension 30 mm OD × 33 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.

IV. RESULTS AND DISCUSION

Coefficient of performance (COP)

The coefficient of performance (COP) for each day is defined as the ratio of the heat extracted from the evaporator Qe to the daily solar irradiation (I) received by the collector. This is given by

$$COP = \frac{Q_e}{I}$$

Sample of performance calculations

I = 5026.26 W/m² per day.
A = 1.478 m2. (Adsorber area).

I_{Total} = I x A

= (5026.26 x 1.478 x 3600) / 1000

= 26743.72 W

Ti = 40.450C

Tout = 8.020C

Cp = 4.2 kJ/kg.K

M = 10 kg (Load mass)

Qe = m x Cp x (Tin - Tout)

Qe = 10 x 4.187 x (40.45 – 8.02)

= 1357.84 W

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

$$= \frac{1357.84}{26743.72}$$

= 0.051

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	5026.26	1.47	26743.72	10	40.4	8.02	4.187	32.43	1357.84	0.051
DAY 2	4948.25	1.47	26328.65	10	41.4	9.0	4.187	32.46	1359.12	0.052
DAY 3	4589.51	1.47	24419.86	10	39.5	10.1	4.187	29.46	1233.49	0.051
DAY 4	4285.35	1.47	22801.49	10	38.7	7.4	4.187	31.3	1310.53	0.057
DAY 5	4125.62	1.47	21951.6	10	39.1	8.9	4.187	30.18	1263.63	0.058
DAY 6	4865.59	1.47	25888.83	10	38.8	10.2	4.187	28.64	1199.15	0.046
DAY 7	4230.84	1.47	22511.45	10	39.1	9.3	4.187	29.79	1247.30	0.055

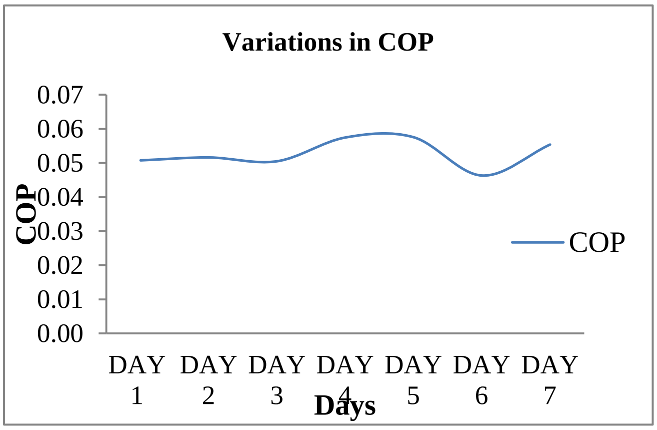

Fig 03: Variation in System COP

Fig. 03 represents variations in system COP. Maximum COP of system is achieved up to 0.058. Variation in system COP depends on the solar intensity.

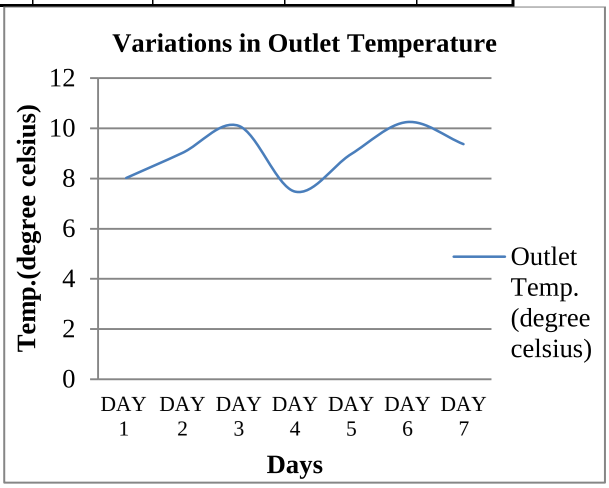

Fig 04: Variation in Outlet Temperature of System

Fig 04 Represents variations in Outlet temperature of system. Maximum outlet temperature of system is achieved up to 7.48°C. Variation in outlet temperature of system depends on the solar intensity.

V. CONCLUSIONS

i) Test results show that only chilled water with temperatures between 8 and 10ºC is produced. Vegetables and fruits with preservation temperatures in the range of 4 to 10ºC are within the scope of the present system.

ii) The coefficient of performance of 0.054 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.

iii) The low coefficient of performance of 0.054 might have been caused by air leaking into the system, the thickness of silica gel packing, the conductivity of silica gel with calcium chloride and water combination, the ineffectiveness of silica gel adsorption capability, solar irradiation and the ambient temperature.

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