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Seasonal Performance Study of Solar Cooling System under Indian Climatic Conditions

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Abstract: ***This paper provides performance analysis of an adsorption refrigeration system under three seasons viz., winter, monsoon and summer. The present system is studied in terms of the solar coefficients of performance (COP_{solar}). An average radiation was obtained 512 W/m^2 in winter, 602 W/m^2 in monsoon and 846 W/m^2 in summer season. The yearly mean ambient temperature was recorded in the range of 25.6–39.5°C. Desorption temperature varied from 80-83°C, 83-110°C and 80-117°C for the respective seasons. The test results show that COP_{solar} varied for winter, monsoon and summer seasonsas 0.55, 0.59 and 0.71, respectively. It is found out that radiation under which 700-850W/m^2 the adsorption refrigeration system was given better performance for Indian climaticconditions.***

Keywords: Solar refrigeration, Seasonal performance, Year round analysis, Solar coefficient of performance

1. Introduction

Annually India produces 110 million tonnes of milk, which is top in the world market, second in vegetable and fruit, third [1]in food grain sectors. It is evident that agricultural productivity is strong in Indiawhile wastage of food is massive. Lack of cold storage facility caused huge wastage, and it is estimated that the value is approximately 8095 MillionUSD annually [1]. Currently, Indian cold storage industry using two major commercial refrigeration technologies, which are absorption refrigeration [2,3] and vapour compression refrigeration (VCR) [4]system. The absorption technologyisbulky in nature and VCR consumes more conventional [5] energy and causing environmental degradation. However, an alternative refrigeration technology would increase cold storage facility, reduce electricity usage and its related anthropogenic emissions. Adsorption technologies are thermally driven system, in which a 'thermal compressor' and a sorbent act as a conventional mechanical compressor of the common vapour compression cycle [6].

A lot of solar adsorption refrigeration systems has been proposed [7]and are under development for the recent years. Most research on this kind of system is related to the evaluation of adsorption working pairs [8-14], different type of solar collector [15-17] and study of different cycles [18-22]. From this perspective, this paper provides the performance analysis of solar adsorption refrigeration system in three different seasons (winter, monsoon and summer) of Indian climatic conditions.

2. System Description and Operating Principle

The solar-driven cooling system consists of vacuum tube solar collector, adsorption bed, condenser, evaporator and cooling chamber (preservation chamber) are the main components.

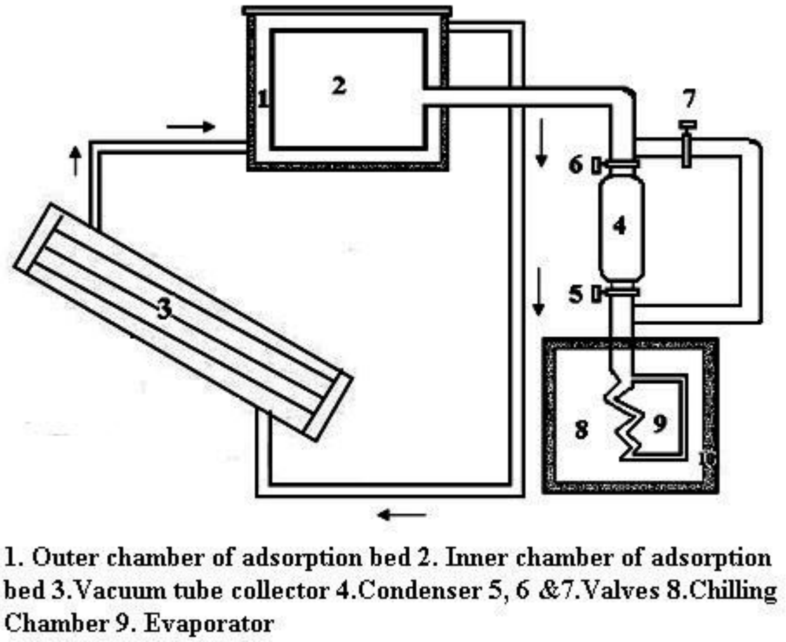

Figure 1: Schematic diagram forsolar refrigeration system [2]

as shown in Fig.1. The vacuum tube collector hasa total area of 2.0 m^2, adsorption bed was fabricated using stainless steel material with an area of 0.32 m^2. The adsorption bed, condenser, evaporator, and ambient temperature data were measured by RTD sensorswith a ±0.01°C accuracy. The recorded data was stored in the data logger system. The solar radiation data was observed by the pyranometer with adirectional errorof ±25 W/m^2.In the current investigation, activated carbon used as an adsorbent and methanol used as a refrigerant material and their properties are reported in Table 1. During daytime collector was heated which causes activated carbon to desorb the refrigerant. It was condensed and stored in the evaporator. During daytime, valve V_5 and V_6were in open and valve V_7 in closed position for desorption process. After sunset, collector temperature decreases to the ambient temperature, then valve V_5 and V_6were closed and valve V_7in unclosed position to allow adsorption process. The experimental results were recorded at every 15-minutes interval with the help of a data logger system.

Table 1: Properties of activated carbon-methanol

Activated carbon		Methanol	
Type	Granular	Density	791 kg/m^3
Density	455kg/m^3	Boiling point	65°C
Average thermal conductivity	0.16W/m K	Latent heat of vaporization	1102 kJ/kg
Specific heat capacity	0.93kJ/kg K		
Total surface area	1150 m^2/g		

3. Results and Discussion

The seasonal performance of solar adsorption refrigeration system was analysed in terms of COP_{solar} as defined as [2,4]

$$COP_{solar} = \frac{\Delta m.[L - C_p(T_{cond} - T_{ev})]}{A_c.\int_{sunrise}^{sunset} I(t).dt} \quad (1)$$

where L is latent heat of vaporization, C_p is the specific heat of liquid refrigerant, Δm is the evaporated refrigerant mass, $A_c$is the collector area and I is the irradiance. In the above Eq. (1),denominator is solar thermal energy supply; the numerator is gross production of cold which is to be spent to cool the liquid refrigerant from condensertemperatureto evaporationtemperature.

3.1. Meteorological Study

The experimental study site is located at tropical zone of latitude 9°58’N and longitude78.10’E at Madurai. It has an average elevation of 101 metres from sea level. The study area come across Eastern Ghats and contains several mountain spurs.

Table 2: Weather conditions of Madurai city

Meteorological parameters	Value
Ambient Temperature (Summer)	29.9°C to 39.5°C
Ambient Temperature (Winter)	26.7°C to 30.2°C
Ambient Temperature (Monsoon)	25.6°C to 28.8°C
Solar radiation (Annual average)	680 W/m^2
Rainfall (Annual average)	85cm
Wind speed (Annual variation)	1.36 to 7.62 m/s

The season wise variation of meteorological parameters are illustrated in Table 2. In the study,ambient temperature varies from 26.7 to 30.0°C for winter, 25.6 to 28.8°C for monsoon and 29.9 to 39.5°C for summer season as reported in Fig.2. It was observed that highest ambient temperature recorded in May and it was the hottest month during summer season. For monsoon season minimum ambient temperature was recorded at 25°C and it was rarely drop below 25°C. The relative humidity varied from56 to 68% for winter, 68 to 73% for monsoon and 41 to 55% for summer. The average annual rainfall of the study area was recorded about 85 cm as reported in Table 2. The study area usually receives major share of rainfall in monsoon. The year round variation of wind speed was ranged from7.26 to 1.36 m/s. Solar radiation during the study period recorded a minimum of 468W/m^2 and a maximum of 950 W/m^2.

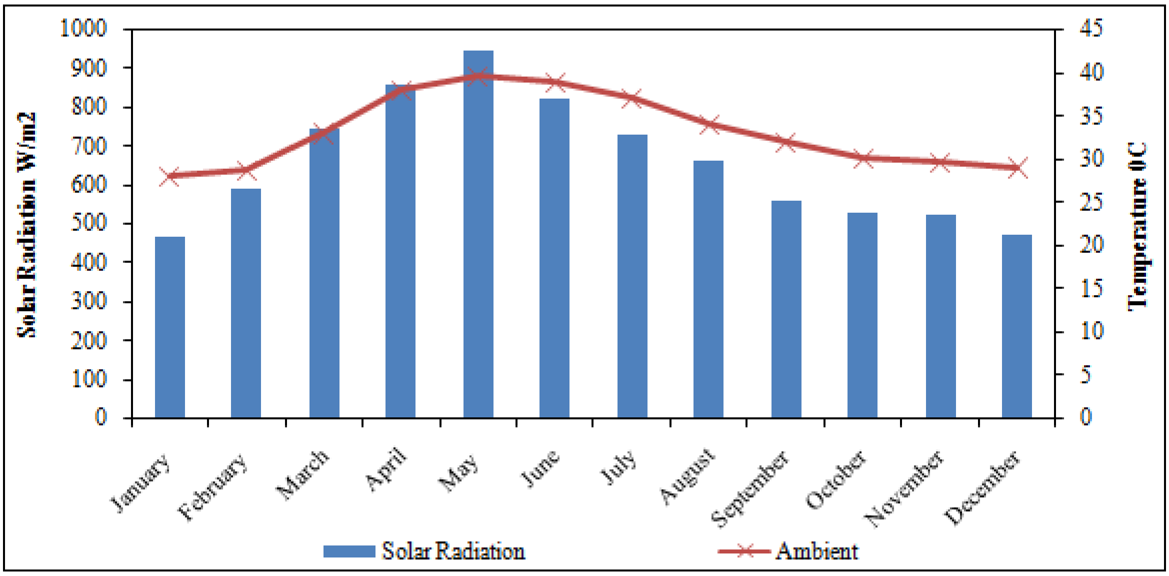

Figure 2: Climatic conditions of Madurai

3.2. Daily performance variation of the refrigeration unit

The thermal behaviour of present system for a typical day is presented in Fig.3. In this experiment desorption bed temperature were increased from 37 to 109°C from 9.00 a.m. to 3.00 p.m. and it was gradually decreased from 3.00 p.m. to 6.00 a.m. In the study, the condenser temperature varied from 24 to 39°C. The year round daily performance analysis of an adsorption refrigeration system is presented in Table 3. As it is evident from Table 3, during the investigation period the COP_{solar}differs from 0.33 to 0.75 with respect to variation of evaporator temperature from 13 to 8°C. Moreover, it is found out better evaporation and COP_{solar}were achieved when adsorption capacity was high.

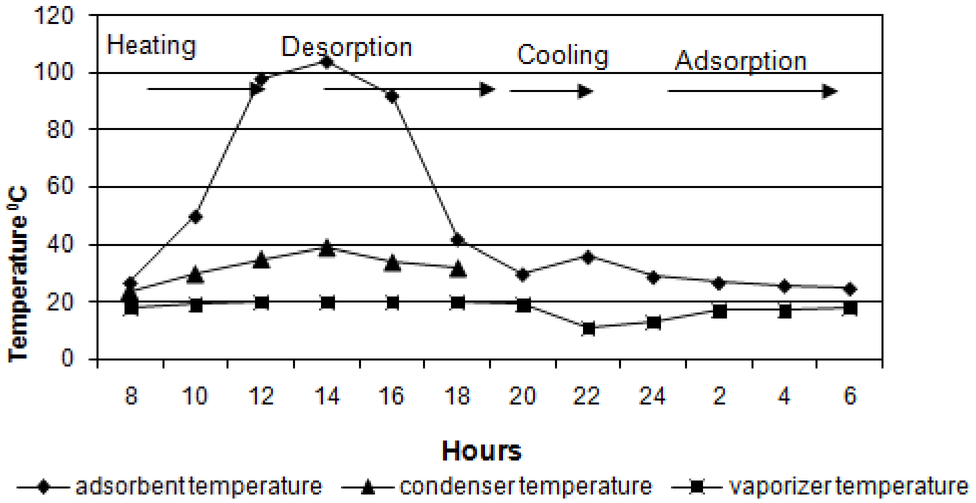

Figure 3: Thermal behaviour of solar refrigeration system for typical day

Table 3: Daily performance of the solar adsorption cooling system

Date	Solar radiation W/m²	Evaporator Temperature °C	COP_{solar}
10/01	340	13.76	0.35
16/02	408	12.57	0.41
05/03	680	12.21	0.59
09/04	775	9.34	0.68
17/05	810	8.37	0.75
06/06	730	10.37	0.65
12/07	632	11.40	0.53
15/08	540	11.45	0.47
28/09	480	12.37	0.44
24/10	387	12.47	0.39
19/11	380	13.57	0.36
26/12	376	14.45	0.33

3.3 Seasonal performance analysis

The average seasonal analysis of solar refrigeration system is presentedin Table4 which showsthat among the three different seasons summer season received the maximum solar radiation and also attained higher performance.

Table 4: Climatic performance variation of solar cooling system

Parameters	Winter	Monsoon	Summer
Solar radiation (W/m²)	512	602	846
Ambient Temperature °C	28.5	32.5	37.4
Adsorption Bed Temperature °C			
During Day	81.6	100.6	101.7
During Night	27.5	31.0	33.5
Condenser Temperature °C	30.0	32.6	35.5
Evaporator Temperature	15.23	12.06	11.15
COP_{solar}	0.55	0.59	0.71

The Fig.5 shows the amount of solar radiation was recorded a maximum of 595 W/m² and a minimum of 468 W/m² during winter season. The desorption temperature was slightly varied between 80°C and 83°C because of low radiation intensity as shown in Fig.4. Due to low variation of desorption temperature and low intensity of solar radiation, the $COP_{solar}$was slightly varied from 0.53 to 0.54. The current investigation found that from Table 4, winter season $COP_{solar}$was lower than other two season as of low level of radiation. Therefore, it was found out that winter season was unfavourable for solar adsorption refrigeration system.

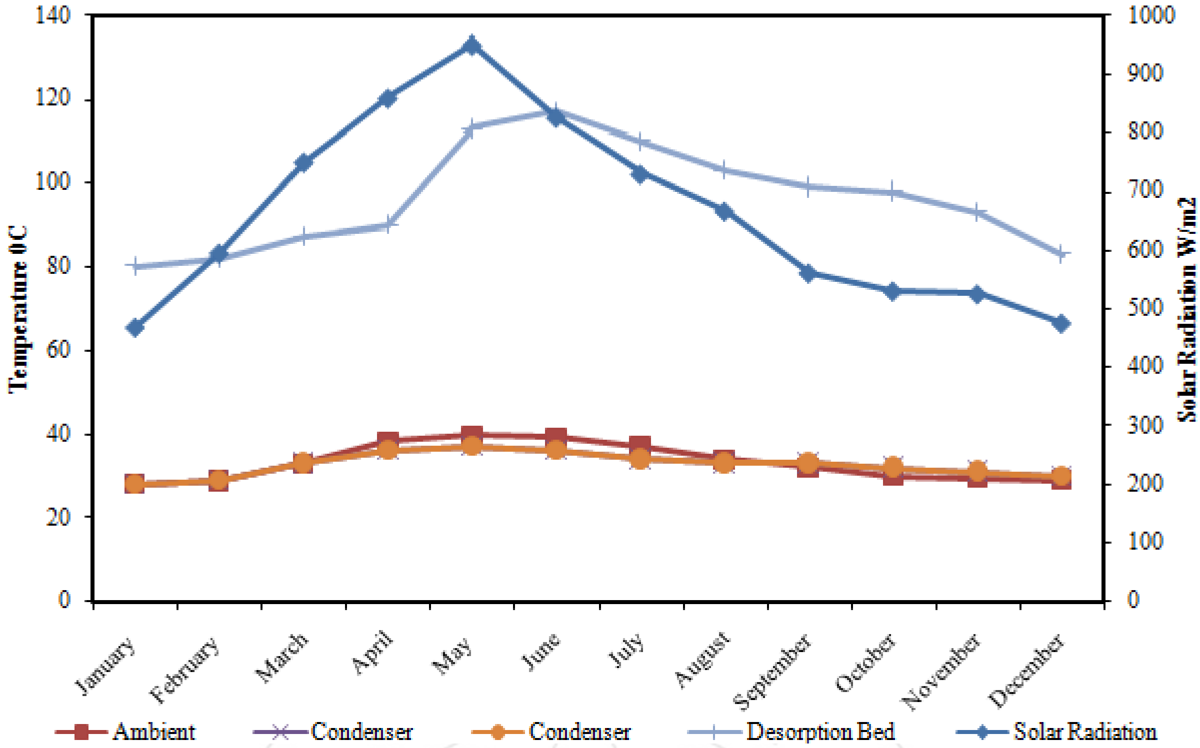

Figure 4: Temperature variation of solar refrigeration unit

During monsoon season, solar radiation was recorded from 525 to 730 W/m^2 as shown in Fig.4,withan average radiation of 602 W/m^2which is 15% higher than winter season. In this season evaporator temperature reached at a lower level of 11°C, which is 3°C lower than winter season as shown in Fig.5. Moreover, low ambient temperature was reachedin night and it caused increase in the adsorption capacity. The test results found that, there is not much difference of COP_{solar} when compared to winter season caused by the low intensity of solar radiation.

The Fig. 5 shows variation of evaporator temperature from 12 to 9°C during summer season. The lowest evaporator temperature of 9°C was achieved in May and it caused by more solar radiation received for the particular month. The variation of solar radiation during the summer season from 860 to 950 W/m^2 since April to May. It is found that summer season received maximum solar radiation of 846 W/m^2 as compared to other two seasons. It is also found that when compared with other two seasons summer attained maximum desorption temperature of 117°C. The evaporator temperature compared with other two seasons 4.9°C and 1.0°C lower than winter and monsoon season, respectively as shown in Fig.5. Throughout the summer season, the COP_{solar} varies in the range of 0.68 to 0.78.

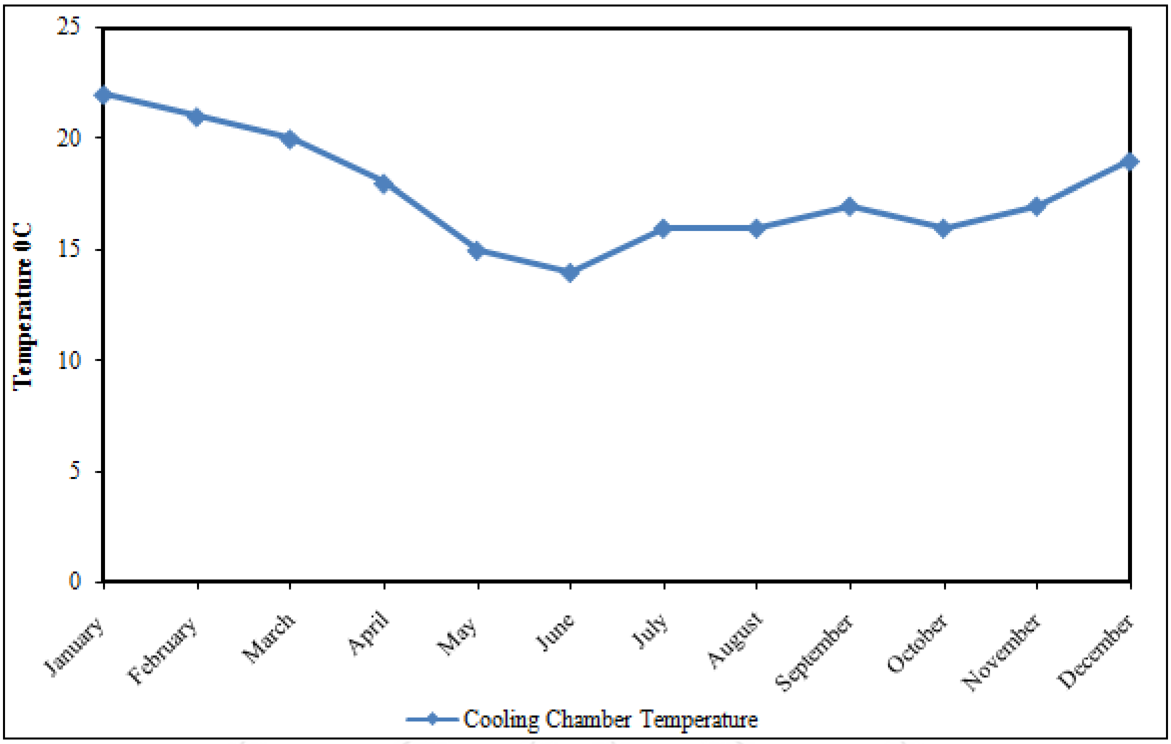

Figure 5: Variation of evaporator temperature

4. Uncertainty Analysis

In this study, uncertainty was calculated for calibration of instruments. Uncertaintyanalysis is based on a careful specification of the uncertainties in the various primary experimental measurements. Precise method of uncertainty estimation presented by Holman [23]. The total uncertainties of the various parameters for the current systempresented in Table 5.

Table 5: Uncertainty parameters for the current system

Description	Total uncertainty %
COP_{solar}	± 6.04%
Adsorption bed	±2.09%
Condenser	± 3.52%
Evaporator	±2.95%

5. Conclusion

The current study investigated the seasonal performance analysis of adsorption refrigeration system under Indian climatic conditions. Based on the test results, the following conclusions are drawn:

1) During the investigation period, the evaporator temperature daily varies from 13 to 8°C and COP_{solar} differ in the range of 0.33-0.75.
2) In winter $COP_{solar}$of system 0.53 to 0.54and temperature of evaporator varies from 15-14°C.
3) Solar radiation was recorded during the monsoon season in the range of 525-730 W/m^2 and evaporator temperature fluctuate between12.9 to 11.2°C. The COP_{solar} varies from 0.64 to 0.54 and this result indicate that there was no difference in COP_{solar} when compared to winter season.
4) In summer season, the lowest evaporator temperature of 9.0°C was achieved in the month of May.

The present study found that under the climate condition of study area, during the summer season achieved better performance than monsoon and winter season.

6. Acknowledgement

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