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ORIGINAL ARTICLE

Drying of chilli using solar cabinet dryer coupled with gravel bed heat storage system

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Abstract

The solar cabinet dryer coupled with gravel bed heat storage system was evaluated for drying of green chilli. The loading capacity of the dryer was about 15 kg of fresh produce per batch. An exhaust fan was provided in the drying chamber to suck the hot air from gravel bed heat storage during off sun shine hours for better heat retrieval. The temperature was recorded in the solar dryer at three position viz., lower, middle and upper drying trays using thermocouples and average temperature was observed in the range of 25 to 55°C. Drying time for drying green chilli from initial moisture content of 88.5% (wb) to 7.3% (wb) was estimated to be 56 h in solar dryer whereas 104 h was observed in the open sun drying. Drying time due to introduction of heat storage system was extended by 4 h after sunset. Drying efficiency of the solar cabinet dryer was found to be 34 %. The ascorbic acid content in chilli, dried in solar dryer coupled with gravel bed heat storage system and in open sun drying was found to be 55.3 mg/100g (d.b) and 50.22 mg/100g (d.b), respectively. The benefit cost ratio and pay back period for drying chilli in solar dryer coupled with gravel bed heat storage system was found to be 1.11 and 7 month and 11 day respectively.

Keywords: Drying, green chilli, solar intensity, thermal storage, flat plate solar air heater, drying efficiency.

Introduction

In India, sun drying is the most commonly used method to dry the agricultural material like grains, fruits and vegetables. In sun drying, the crop is spread in a thin layer on the ground and exposed directly to solar radiation and other ambient conditions. The rate of drying depends on various parameters such as solar radiation, ambient temperature, wind velocity, relative humidity, and initial moisture content, type of crops, crop absorptive and mass of product per unit exposed area. This form of drying has many drawbacks such as degradation by windblown, debris, rain, insect infestation, human and animal interference that will result in contamination of the product. People may use energy for many purposes, but a few general tasks like heating, cooling, electricity generation, transport and industry consume most of energy.

Drying rate get reduced due to intermittent sunshine, interruption and rains. Solar energy is most - important among renewable energy sources due to its quantitative abundance. In order to face the problem of energy crisis and environmental threat as a result of continuous use of fossil fuels, scientist and researchers are putting effort to develop technologies and effective use of solar store energy can be applied to all these tasks with different levels of success. However, intermittent nature of solar energy demands an integration of energy storage system with the solar collectors in order to make solar energy sources more reliable. Solar energy is available only during the day, and hence, its application requires efficient thermal energy storage so that the excess heat collected during sunshine hours may be stored for later use during the night. Short term storage of only a few hours is essential in most applications; however, long term storage of a few months may be required in some applications. Similar problems arise in heat recovery systems where the waste heat availability and utilization periods are different, requiring some thermal energy storage. Also, electrical energy consumption varies significantly during the day and night, especially in extremely cold and hot climate countries where the major part of the variation is due to domestic space heating and air conditioning. Such variation leads to an off peak period, usually after midnight until early morning.

Use of gravel bed for the improvement of performance of solar air heater has been proposed by several investigators. However, this enhanced efficiency is accompanied by substantial increase in pressure loss, which results in higher running cost of the system. So, the solar energy collection system should be optimized in such a way that it will give energy with minimum cost. In the present study, a gravel bed based solar air heating collector which required no power for the storage of heat, was used. The solar air heating collector was directly coupled with drying box to reduce heat loss and energy requirement to push hot air in to the drying box.

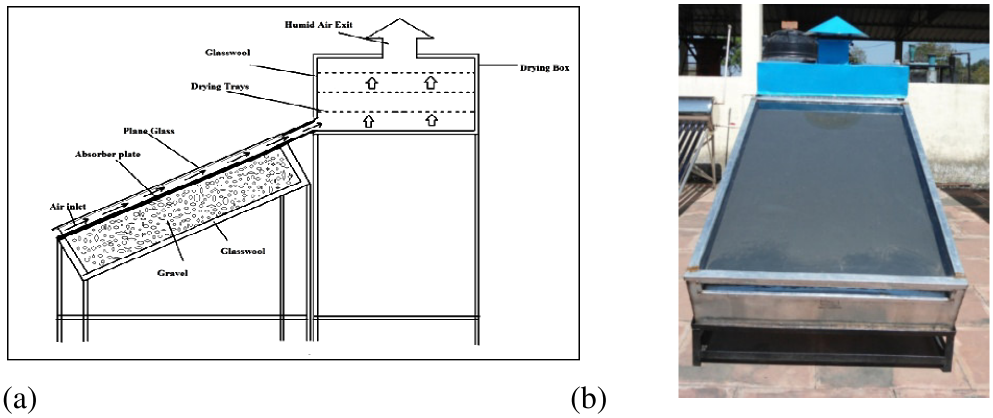
Solar dryer reduces operating cost by input of solar heat energy as compared to the electrical dryers. Solar dryer reduces drying time as compared to the open sun drying. Quality of the dried product (with respect to physical appearance and reduced microbial count) has been found better as compared to the open sun drying. In many cases continuous drying is preferred. However, solar dryer is operated only during day time for 7- 8 h. The conventional source of energy is used to continue the drying after sun set. Thermal storage system can be coupled with the solar dryer to improve its efficiency, operating hours and saving conventional source of energy. Hence, the present study was undertaken to evaluate solar cabinet dryer integrated with gravel bed as heat storage system for drying green chilli.

Material and Methods

A solar cabinet dryer integrated with solar air heater cum gravel bed heat storage system, developed at Central Institute of Agricultural Engineering, Bhopal, was evaluated for its performance during drying of chilli. The dryer consisted of gravel bed heat storage box and solar air heating panel (Fig. 1 (a) and (b)). The gravel bed heat storage unit along with solar air heating system was connected to the exiting medium height solar cabinet dryer to continue drying operation a few hours after sun set or cloudy period.

The solar dryer consisted of flat plate solar air heater having area of 2m^2 and connected with drying chamber. The solar air heater has 1 mm thick aluminium sheet coated with black paint to absorb the incident solar radiation. The absorber plate was placed directly behind the transparent cover (glass) with a layer of air separating it from the cover. The air to be heated passes between the transparent cover and the absorber plate. To increase the temperature of air by green house effect, a glass cover of 5 mm thickness was placed. The gap between the glass and the absorber surface was maintained at 50 mm for air circulation. The 250 mm gap between the absorber and insulation was maintained with gravel bed (50 mm size) to absorb and store heat during sunshine hours and to obtain hot air during off sunshine hours. An exhaust fan was also provided in the dryer box to suck the hot air from bed during off sun shine hours. The drying chamber is made up of ms sheet of 1 mm thickness. The size of the cabinet dryer was 1 × 0.5 × 0.25 m (height). The holding capacity of the dryer was about 15 kg of chilli per batch. The drying chamber was insulated with glass wool of 50 mm thickness. The solar air heater was tilted to an angle about 25^o with respect to horizontal. The system was oriented to face south to maximize the solar radiation incident on the solar collector. The specifications of the solar cabinet dryer integrated with heat storage system are given in Table 1.

Performance of the system was evaluated at no load and at loading condition by drying green chilli. Under no load conditions, air temperature inside the cabinet dryer across at different trays was recorded at definite intervals of time during a typical sunny day. Fifteen kg fresh green chilli was spread in the drying trays uniformly and loaded in the cabinet dryer for drying in the month of March. Five kg of green chilli was also spread on floor of around 0.50 m^2 area for comparing the study with open sun drying. The quantity of the product loaded, drying time, drying temperature in the cabinet dryer, solar intensity, moisture content of the product, ambient temperature, relative humidity were measured during drying. The increase in temperature in the gravel bed heat storage during the day was measured. After the sun set, the temperature in the drying box due to heat supplementation from the gravel bed was measured. The air flow through the cabinet dryer was estimated by measuring air speed with a digital anemometer and cross-sectional area of the exit of the dryer. Humidity of the ambient air was obtained from psychometric chart by measuring wet bulb and dry bulb temperature of air.The temperature was measured in the solar dryer at three position viz., lower, middle and upper drying trays and gravel bed using pre-calibrated thermocouples. Similarly, temperature of the gravel bed was also measured at three levels (lower, middle and upper portion of the gravel bed).



(a) (b)

Fig. 1: Schematic view and photograph of the solar cabinet dryer integrated with gravel bed heat storage system.

Table 1: Specifications of the solar cabinet dryer integrated with heat storage system

Sr. No.	Particulars	Specifications
1	Drying capacity of the solar cabinet dryer	15 kg/batch
2.	Outer size of the solar cabinet dryer	1220 × 400mm
3.	Inner size of the cabinet dryer	1120 × 280mm
4.	Thickness of insulation to drying box	50 mm glass wool
5.	Number of drying trays	6
6.	Size of the drying tray	500 × 480 mm
7.	Solar air heating collector area	2 m^2
8.	Overall size of the gravel bed heat storage box	1700 x 1110 x 250 mm
9.	Gravel pebble filled in the heat storage box	600 kg
10.	Top cover of the box	Glass covers of 4 mm thick
11.	Thickness of box insulation to solar air heater cum gravel bed	50 mm glass wool
12.	Inclination of the solar air heater with respect horizontal	25°

Increase in drying hours after sunset and temperature provided by the packed bed heat storage was measured and analyzed.The thermal efficiency (η_{th}) of the solar air heater was estimated using following equation (Shanmugam and Natrajan, 2007).

$$\eta_{th} = \frac{\text{Heat output as latent heat of evaporation}}{\text{solar heat input}} \times 100 \quad --- (1)$$

Heat output as latent heat of evaporation = $M_w \times l_w$

Where,

M_w = quantity of water removed, kg/h
l_w= latent heat of water evaporation, kJ/kg

Solar heat input = I × A × t

Where,

I = Solar intensity, kW/m^2,
A = solar collector area, m^2
t = time, h

Ascorbic acid of the dried chilli sample was determination and the procedure (Anonymous, 2012) followed is given as below:

1) Pipette out 5 ml of the working standard solution into a 100 ml conical flask.
2) Add 100 ml of 4 per cent oxalic acid and titrate against the dye (V_1 ml). End point is the appearance of pink colour, which persists for few minutes. The amount of the dye consumed as equivalent to the amount of ascorbic acid.
3) Extract the sample (0.5 - 5 g depending on the sample) in 4 per cent oxalic acid and make up to a known volume (100 ml) and centrifuge.
4) Pipette out 5 ml of this supernatant, add 10 ml of 4 per cent oxalic acid and titrate against the dye (V_2 ml).

The amount of ascorbic acid present in the chilli was found out by using the following equation.

$$Amount\ of\ ascorbic\ acid\left(\frac{mg}{100}g\ \ sample\right) = \frac{0.5\,mg}{V1\,ml} \times \frac{V2\,ml}{5\,ml} \times \frac{100\,ml}{wt.of sample g} \times 100 \quad --(2)$$

Cost economic of the solar cabinet drying system: Following different economic indicators were used for economic analysis (Khan *et al.,* 2011) of solar cabinet drying system

1) Net present worth (NPW)
2) Benefit cost ratio (B/C ratio)
3) Payback period

Net present worth (NPW): The difference between the present value of all returns and the present money require making an investment is the net present worth. The present value of the future returns was calculated through the use of discounting. Discounting essentially a technique by which future benefits and cost streams can be converted to their present worth.

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where, C_t = Cost in each year, Rs
B_t = Benefit in each year, Rs
t = 1, 2, 3................n
i = discount rate, %

Benefit cost ratio: This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream. The mathematical benefit-cost ratio can be expressed as:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

Where, C_t = Cost in each year, Rs
B_t = Benefit in each year, Rs
t = 1, 2, 3................n (year)
i = discount rate, %

Payback period: The payback period is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment. The payback period of the project is estimated by using the straight forward formula:

$$P = \frac{I}{E}$$

Where, P= Payback period of the project in years,
I = Investment of the project, Rs.
E = Annual net cash revenue, Rs.

Results and Discussion

Physical properties of the stone pebbles used in heat storage system were studied and presented in Table 2.

Table 2: Physical properties of stone pebbles

SN	Properties	Values
1	Bulk density, kg/m^3	1650
2	True density, kg/m^3	3300
3	Porosity, %	60
4	Specific heat, kJ/kg^oC	0.88
5	Specific heat of air, kJ/kg^oC	1
6	Thermal conductivity, W/mk	29
7	Average diameter of stone pebble, mm	50
8	Colour	Gray black

No load test of solar cabinet drying system: Performance of the solar cabinet dryer integrated with gravel bed heat storage system was evaluated at no load condition. The average temperature in the said dryer during the day and after sunset without exhaust fan was recorded. The average temperature in the dryer was found 46^{o}Cduring day time. The temperature raised slowly during morning till late afternoon and after that it started declining during evening and reached to near ambient after four hours after sun set. The average ambient temperature was 29^{o}C and solar intensity was 704 W/m^2 (Fig. 2).

Temperature developed in gravel bed heat storage system: Fig. 3 shows that the temperature got increased in gravel bed heat storage during a day time. It was observed that temperature in the gravel bed was under increasing trend even during the after noon hours up to 1700 hours, despite of slowly decreasing solar intensity. This is attributed to absorption and accumulation of the solar heat into the gravel bed. The average gravel bed temperature and ambient temperature was found in the range of 29.5 to 45.5°C and 24 to 35^{o}C, respectively where as the average solar intensity was ranged from 252 to 988 W/m^2. Saravanakumar and Mayilsamy (2010) reported in their experiment of flat plate solar air heater with gravel as

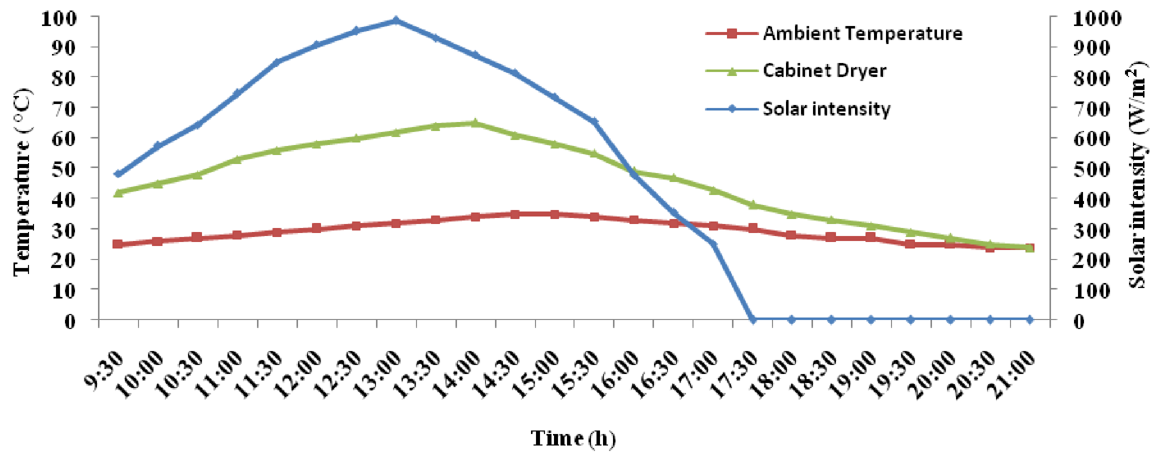


Fig.2 Temperature variation in the solar cabinet dryer (no exhaust fan operated after sunset)

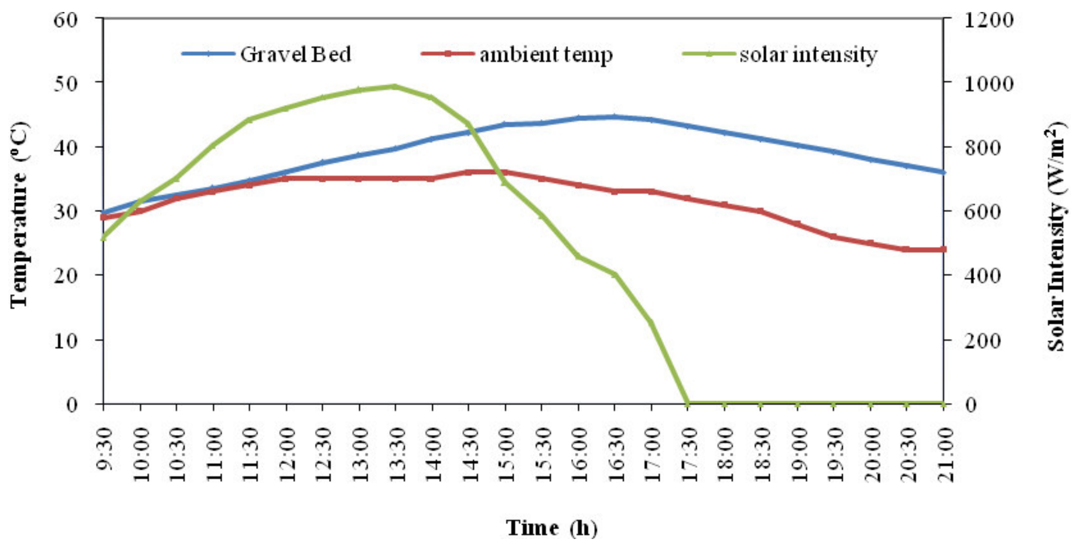


Fig. 3 Variation in temperature in the gravel bed heat storage system

thermal storage material and confirmed the temperature attended at collector outlet in the range of 29°C to 47°C at peak solar intensity of 900 W/m^2. The difference in temperature of gravel bed heat storage system and that at ambient was observed in the range of 5.5 to 10.5°C when no exhaust fan was operated.

Performance of solar cabinet dryer after sunset: Initially the test on heat retrieval from the gravel bed was conducted under natural convection (without operating the exhaust fan). The average air flow rate through dryer without exhaust fan was 29m^3/h. From Fig. 3, it is seen that the ambient temperature was observed to be 25 to 35°C during 0930 to 1700 h. The temperature in the dryer at 29m^3/h air flow rate was 42 to 65°C, which was 17 to 30°C higher than that at ambient condition. Around 23 to 30°Ctemperature difference was observed in drying box and in ambient temperature. After 1700 h, the temperature in the drying box decreased from 38-24°C where as the ambient temperature was 30-24°C. Around 0 to 8°C temperature difference was found in drying box and in ambient during 1700 to 2100 h. Similarly, the gravel bed temperature was recorded to be increased from 29 to 47.5°C during 0930 to 1700 h and thereafter got reduced steadily from 47.5 to 37.5°C during 1700 to 2100 h, and till it was higher by 17.5 to 13.5°C than that at ambient condition. This shows that there was good amount of unused heat stored in the gravel box. This may be attributed to partial retrieval of stored heat in the gravel bed under natural convection (29 m^3/h air flow). Therefore, the heat retrieval from the gravel bed was studied at different accelerated air flows (58 m^3/h, 87 m^3/ h and 115 m^3/h) obtained using the exhaust fan after sun set for faster heat retrieval.

Heat supplementation from gravel bed heat storage system at no load condition: Table 3 shows the temperature in the drying box due to heat supplementation from gravel bed heat storage after sun set (during 17.00 to 21.00 h) at different air flow rates at no load condition. Average temperature in the drying box was 29.66 °C, 31.55 °C, 29 °C and 28.55 °C at 29 m^3/h, 58 m^3/h, 87 m^3/h and 115 m^3/h air flow rate, respectively. It was observed that temperature in the drying box was highest at 58 m^3/h flow rate as compared to other air flow rates. This may be attributed to proper match of the air flow rate and heat release from the surface of the gravel bed. Therefore, the air flow rate of 58 m^3/h was maintained for better heat retrieval from the gravel bed after sun set for drying of chilli in the dryer. Jain (2007) reported in his study on effect of thermal storage on the natural mass flow rate in the drying system. A 30^0 inclined absorber plate with in-built thermal storage and 0.12 m width of airflow channel induced the mass flow rate in the range of 0.032–0.046 kg /s during the drying process.

The solar cabinet dryer was evaluated for drying of chilli. After sun set, the exhaust fan was used to maintain air flow rate of 58 m^3/h for better heat retrieval. On first day of drying, the average temperature in the solar dryer was observed in the range of 25-55 °C. It was observed from Fig. 4 that the drying time due to heat storage system in the gravel bed could be increased by 4 h after sunset up to 21.00 h.The average ambient temperature and relative humidity during the experimentation first day of drying was observed in the range of 24-36 °C and 30-68%, respectively and the solar intensity was recorded in the range of 287-977 W/m^2 . Similar trend was observed in the cabinet dryer on2nd, 3rd, 4th and 5th day of drying (Fig. 4).

The variation in moisture content with drying time is illustrated in Fig. 5. Drying time for drying of chilli from initial moisture content of 88.5% (wb) to 7.3% (wb) was found to be 56 h in the solar dryer as compared to 104 h in the open sun drying and it was found to be 46% less than the open sun drying. Leon and Kumar (2007) reported 66% reduction in drying time compared to open sun drying for drying red chilli in solar biomass rock bed storage drying system. Drying efficiency of the drying system was estimated to be about 34%. Mohanraj and Chandrashekhar (2009) studied an indirect forced convection solar drier integrated with different sensible heat storage material for drying chilli and average drier efficiency was estimated to be about 21%.

Effect of drying on ascorbic acid content of dried green chilli: The results of effect of drying methods on ascorbic acid content are presented in Table 4. The ascorbic acid content of chilli sample dried using solar cabinet dryer was found to be 55.34 mg/100g (d.b.) and in sample dried under open sun, it was 50.22 mg/100g (d.b). The retention of ascorbic acid was found more in solar cabinet dried sample than sample dried in open sun drying.

Table 3: Temperature developed in the dryer after 17.00h with heat supplement from gravel bed heat storage under no load test at different air flow rates

Time, H	Temperature in solar cabinet dryer coupled with gravel bed heat storage system , °C				Ambient temperature °C
	Air flow rate, m^3/h				
	29	58	87	115	
17.00	41	41	41	41	32
17.30	36	38	39	40	30
18.00	33	36	33	31	29
18.30	31	34	29	27	27
19.00	29	31	26	26	26
19.30	27	29	25	25	25
20.00	25	27	24	24	24
20.30	23	25	22	22	22
21.00	22	23	21	21	21
Average	29.66	31.55	29.0	28.55	26.22

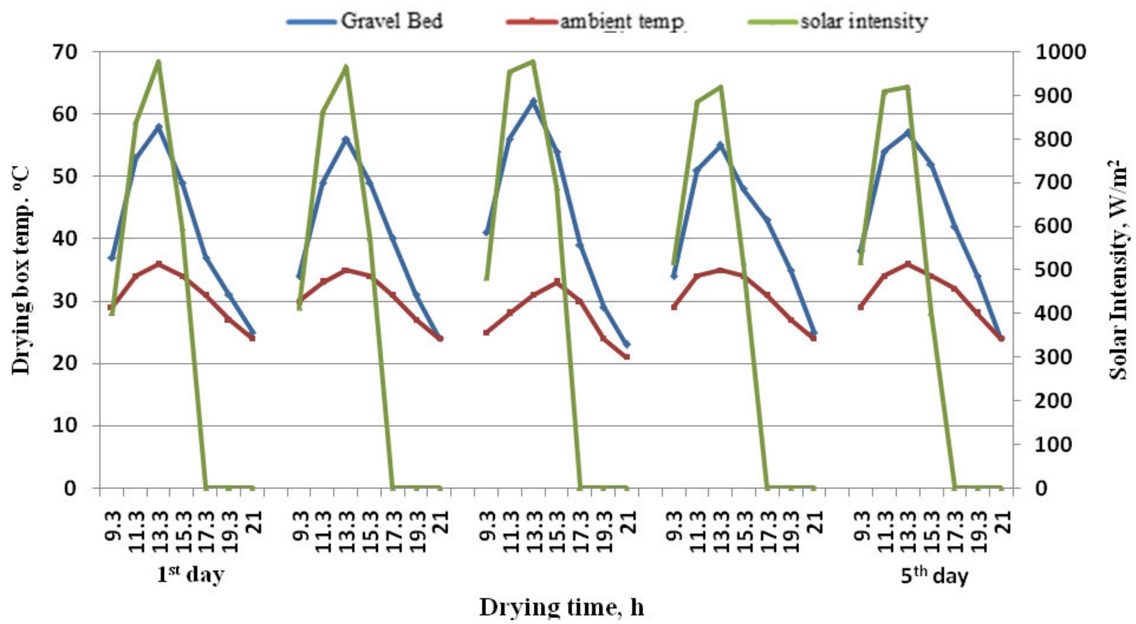


Fig. 4: Variation in temperature developed in drying box, ambient temperature and solar intensity during drying of green chilli

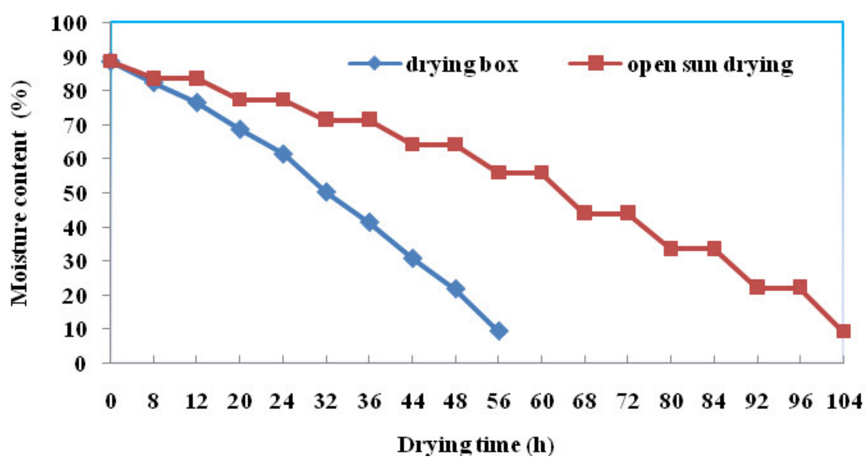


Fig. 5: Variation in Moisture content in cabinet drying box and open sun drying of green chili

Cost economics of solar cabinet dryer for drying of green chilli: The economic feasibility of the solar cabinet dryer for the drying of green chilli was calculated by considering the initial investment of dryer, average repair and maintenance cost, cost of raw material and selling price of the material after drying. The cost of operation for chilli samples dried in solar cabinet dryer was computed (Table 5).

Net present worth: The net present worth for chilli is presented in Table 5. The net present worth of total cash inflow and outflow for drying of chilli under solar cabinet dryer was found to be Rs. 13096.32.The benefit cost ratio of chilli in solar cabinet dryer was found to be 1.11.The payback period for drying of chilli in solar cabinet dryer was found to be 7 month and 11 day. Therefore, it was concluded that drying of chilli in solar cabinet dryer found to be economical as it showed more NPW, BC ratio and less payback period. The drying in solar cabinet dryer seems to be economical because solar energy is freely available throughout the year thus no additional expenditure was incurred for air heating.

Table 4: Ascorbic acid content of green chilli

Sr. No.	Sample	Ascorbic acid (mg/ 100g)
1	Open sun dried	50.22
2	Solar cabinet dried	55.34

Table 5: Economic analysis of solar cabinet dryer for drying green chilli

Sr. No.	Particulars	Values
1	Initial investment (Rs)	25,000.00
2	Annual use no. of batches	48
3	Cost of raw green chilli (Rs yr^{-1})	11520.00
4	Cost of labour for drying (Rs yr^{-1})	2400.00
5	Operation and maintenance cost (Rs yr^{-1})	1250.00
6	Total electrical charge for operating exhaust fan @ Rs. 6/kW (Rs yr^{-1})	330.4.00
	Economic indicators	
A	Net present worth, Rs	13092.32
B	Benefit- cost ratio	1.11
C	Payback period	7 Month and 11Day

Conclusions

The solar cabinet dryer coupled with gravel bed heat storage system was found suitable for drying green chilli. Heat stored in the storage unit during day time, can be utilized during off sun hours and drying time can be extended up to 4h every day. The drying time in solar cabinet dryer for reducing moisture content from 88.5% to 7.3% (wb) was found to be 46% less than the open sun drying.

Acknowledgement

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