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Design, Construction and Performance Study of a Low Cost Solar Dryer for Food Preservation in Bangladesh

PiasKumar Biswas, Md. Milon Uddin, Saiful Huque and S.M.Nasif Shams*

Institute of Energy, University of Dhaka
Email: nasifshams@gmail.com

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ABSTRACT

Solar drying system utilizes solar energy to heat up air and to dry any food substance, which is beneficial in reducing wastage of agricultural products and helps in preservation. The objective of this research is to design, develop and evaluate performance analysis of solar dryer using thermal energy storage for the drying of vegetables and other foods. The system has been designed by considering various features such as cost, efficiency, durability and performance has been studied by testing the parameters such as temperature, air velocity, collector efficiency and weight loss. In this research it has been found that the use of this type of solar dryer reduces the drying time significantly and essentially provides better product quality compared to conventional drying method. The effect of temperature to moisture contents against time and rate of drying have been studied and presented in this paper.

Keywords: Solar Energy; Solar dryer; Design and Fabrication; Solar collector; Optimum Temperature

1. Introduction

Open drying is one of the oldest methods using solar energy where various products such as fruits, vegetables, fish and meat etc. to be dried are exposed directly to the sun. This method contains many demerits such as spoilt products due to wind, animal attack, rain, dust, insect infestation and fungi infection[6]. Taking much time the process of open drying causes the product's surface become hard as the moisture inside has a chance to evaporate completely and it will affect the quality of dried product due to over drying. Open sun drying also suffers from a high labor requirement and excessive crop handling particularly in periods of inclement weather which can result in high costs, crop damage and a loss in quality. Moreover electric dryer is very expensive and increases electricity demand. Farmers, rural workers and small entrepreneurs cannot afford these electric dryers due to high cost, absence of electricity etc. So in this study, the renewable energy based solar dryer has been designed to solve this problem and will adapt the ergonomics criteria and produce a better quality product. Many parameters have been considered before designing the solar dryer and materials with higher efficiency, durability, low cost have been used to make it cost effective and user friendly.

2. Design Consideration

- Temperature - The minimum temperature for drying food is 30°C and the maximum temperature is 60°C.Therefore, 45°C and above is considered average and normal for drying vegetables, fruits, roots and tuber crop chips, crop seeds and some other crops[2].
- The design has been made for the optimum temperature for the dryer to 60°C and the air inlet temperature or the ambient temperature T_1 = 30°C (approximately outdoor temperature)[5].
- Air gap - It is suggested that for hot climate passive solar dryers, a gap of 5 cm should be created as air vent (inlet) and air passage[8].
- Glass and flat plate collector – It suggested that the glass covering should be 4-5 mm thick. In this work, 4mm thick transparent glass has been used. It is also suggested that the metal sheet thickness should be 0.8 – 1.0 mm thick; here a mild steel of 1.0mm thick has been used. The glass used as cover for the collector is 60 × 60cm^2[9].
- Dimension – It is recommended that a constant exchange of air and a roomy drying chamber should be attained in solar food dryer design.Hence, the design of the drying chamber has been made as spacious as possible of average dimension of 60 × 57 × 55cm^3 with air passage (air vent) out of the cabinet of 60 × 5cm^2. The drying chamber has been roofed with glass of 60 × 60 cm^2 tilted at the same angle with that of the solar collector (33.77°). This is to keep the temperature within the drying chamber fairly constant due to the greenhouse effect of the glass.
- Dryer Trays - Net cloth has been selected as the dryer screen or trays to aid air circulation within the drying chamber. Two trays have been made having wooden edges. The tray dimension is 50 × 50cm^2 of 2.5cm × 2.5cm^2 wooden sticks used as frame.

3. Calculation of design parameters

Angle of Tilt (β) of Solar Collector/Air Heater: It states that the angle of tilt (β) of the solar collector should be β = 10° + lat ϕ where lat ϕ is the latitude of the collector location[1], the latitude of Dhaka where the dryer has been designed is 23.77°N. Hence, the suitable value of β use for the collector: β = 10° + 23.77° = 33.77°

Insolation on the Collector Surface Area: A research obtained the value of insolation for Bangladesh i.e. average daily radiation, H, on horizontal surface asH = 978.90W/m^2

and average effective ratio of solar energy on tilted surface to that on the horizontal surface, R, as; R = 1.0035. Thus insolation on the collector surface has been obtained as I_c = HT = HR = 978.90 × 1.0035 = 982.32W/m^2[10].

The mass flow rate of air, M_a, has been determined by taking the average air speed V_a = 0.15m/s. The air gap height has been taken as 5cm = 0.05m and the width of the collection was assumed to be 60cm = 0.6m. Thus, volumetric flow rate of air $V'_a = V_a \times 0.05 \times 0.6$;$V'_a = 0.15 \times 0.05 \times 0.6 = 4.5 \times 10^{-3} m^3/s$. Thus mass flow rate of air: $M_a = v_a \rho_a$. Density of air $\rho_a$was taken as 1.28kg/m^3 and $M_a = 4.5 \times 10^{-3} \times 1.28 = 5.76 \times 10^{-3}$kg/s

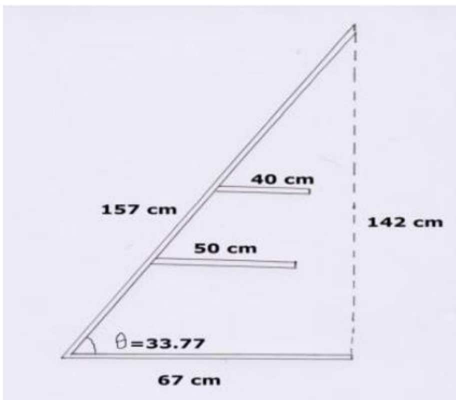


Fig 1: Side View of solar dryer

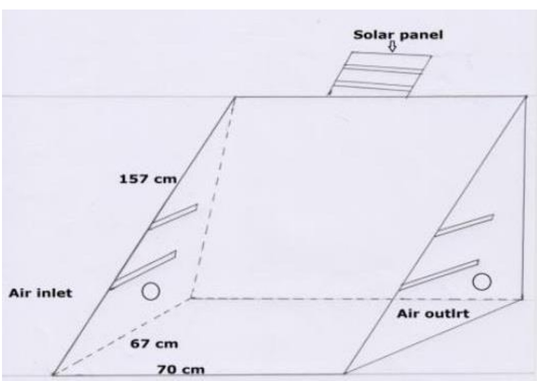


Fig 2: Front view of solar dryer

4. Drier Construction Materials

The following materials have been used for the construction of the domestic passive solar dryer: Wood - as the casing (housing) of the entire system.Wood has been selected being a good insulator and relatively cheaper than metals. Glass –used as the solar collector cover and the cover for the drying chamber. It permits the solar radiation into the system but resists the flow of heat energy out of the systems. Mild steel sheet of 1mm thickness (dimension 80cm × 60cm) has been used which is painted black with tar for absorption of solar radiation. Net cloth (cheese cloth) and wooden frames for constructing the trays. Nails and glue as fasteners and adhesives have been used.

5. Construction Procedure

The solar food dryer has been constructed using locally available and relatively cheap materials. Since the entire casing is made of wood and the cover is glass, the major construction works is carpentry works.The metal sheet wire, used in constructionwas mild steel of 1mm thickness. It is cut to the size of 68x140 cm to minimize the top heat loss. It has been painted black with tar for maximum absorption and radiation of heat energy. The metal sheet, together with the insulator of 5 cm thickness, has been placed inside the air heater (solar collector) compartment. The glass has been cut into size of 155 × 68 cm and two of these have been required. One is used as the solar collector's cover and the other as the drying cabinet cover. The glassis clear glass with 4 mm thickness. The trays are made with wooden frames and net cloth to permit free flow of air within the drying cabinet (chamber). Two trays have been used with average of 10cm spacing arranged vertically one on top of the other.The size of the tray is 50 × 65 cm. The interior of the solar food dryer are painted black with tar to promote adsorption of heat energy while the exterior is painted gray to minimize the adverse effects of weather and insect attack on the wood and also for aesthetic appeal.

Fig3: Frame Construction

Fig 4: Tray Construction

Fig 5: Side view of newlydesigned solar dryer

Fig 6: Front view ofnewly designed solardryer

Experiemnt

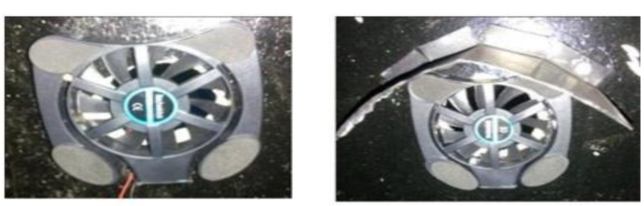
EQUIPMENT USED:

Digital temperature sensor- DS188B20, Rapitest Digital Moisture Meter, Weight Meter, Pyranometer & Pyrheliometer

METHODOLOGY

Digital sensor has been positioned to measure the air temperature at the inlet and outlet portion of the air heater. Again sensors have been placed at trays in order to measure the temperature and humidity of trays. Ambient temperature has been also recorded during the course of experiments with the help of digital sensor. The experiment has been conducted at the location of the Institute of Energy, University of Dhaka and the orientation of the solar collector has been fixed towards the south direction, inclined at an angle of 34°. Successful tests have been conducted on September 1,2&3, 2016 and in this project work, one of the test data is used to evaluate the drying curves, humidity and temperature measurements in the dryer. During the tests period, the heated air is used to dry potato, bitter gourd &chili. At the first day 250 grams of potato has been placed to dry in open drying system and solar (closed) drying system. The weight of potatoes have been found at evening**;** in open drying 178 grams and in closed drying it is 146 grams. At the first day 250 grams of Bitter Gourd has been placed to dry in open drying system and solar (closed) drying system. The weight of Bitter Gourd has been found at evening**;** in open drying 185 grams and in closed drying it is 132 grams. At the first day 250 grams of Chilihas been placed to dry in open drying system and solar (closed) drying system. The weight of Chiliis found at evening**;** in open drying 182 grams and in closed drying it is 201 grams.

Here keeping the air inlet and outlet open periodically at air flow speed at 0.5 m/s in both paths, the moisture content in the sample materials has been measured. Then it has been found that moisture content drastically decreased after 12.00 pm and got slow down at afternoon. Bitter Gourd has more moisture content and by drawing graphs the substantial decrease of moisture content with the increase of solar dryer temperature has been found.



(a) Air inlet **(b) Air outlet**

Fig 7: Air inlet and outlet

Figure 7 shows the inlet and outlet of air flow in the drier system. Two DC fans are used to control airflow inside the drier system. Forced flow is necessary

Result & Discussion

The table 1 shows the results of reduction of moisture content of potato and bitter ground. The potato reduced from 250 gm to 146 gm and lost 104gm which is 42% reduction in 8 hours. The bitter ground reduced from 250 gm to 132 gm which is more than 47% in 8 hours.

Table 1: Results of reduction of moisture content of potato

Time	Potato Weight (gm)	Moisture Reduction (gm)	Reduction %	Bitter Ground (gm)	Moisture Reduction (gm)	..Reduction %
09:00	250	--	--	250	--	--
11:00	241	09	6.43%	233	17	14.41%
13:00	214	27	25.96%	201	32	28.07%
15:00	179	35	33.65%	153	48	42.10%
17:00	146	33	31.73%	132	21	18.42%

Table 2 shows the results of reduction of moisture content of chili. In 8 hours it reduced from 250 gm to 182 gm which is more than 27%.

Table 2: Results of reduction of moisture content of chili

Time	Weight of Chili (gm)	Moisture Reduction (gm)	Reduction (%)
09:00	250	--	--
11:00	235	15	22.05%
13:00	218	17	25.00%
15:00	198	20	29.41%
17:00	182	16	23.53%

Table 3 is the comparison of solar closed drying and open drying of potato and bitter ground. For potato 42% weight reduction has been observed in closed dryer and 29% for open dryer. 47% weight loss has been observed for Bitter ground in close dryer and 26% in open dryer. For chili 27% weight loss has been observed for close system and 20% for open dryer system.

Table 3: Comparison of solar closed drying and open drying

Time	Weight of Potato in closed dryer	Weight of Potato in open dryer	Weight of Bitter Guard in closed dryer	Weight of Bitter Guard in open dryer	Weight of Chili in closed dryer	Weight of Chili in open dryer
09.00	250	250	250	250	250	250
11.00	241	245	233	241	235	246
13.00	214	231	201	225	218	235
15.00	179	195	153	204	198	218
17.00	146	178	132	185	182	201

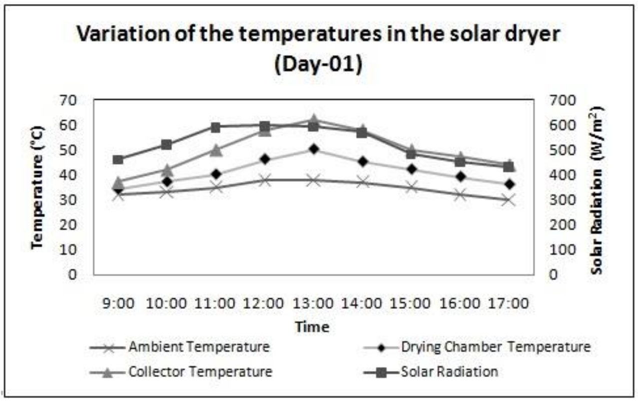


Fig 8: Variation of temperature in the solar dryer for day1

After putting the ambient temperature, drying chamber temperature, collector temperature along with the hourly solar radiation it has been found that after 12.00 pm the temperature and solar radiation both are high and after few hours they get slow down and goes back to normal temperature.

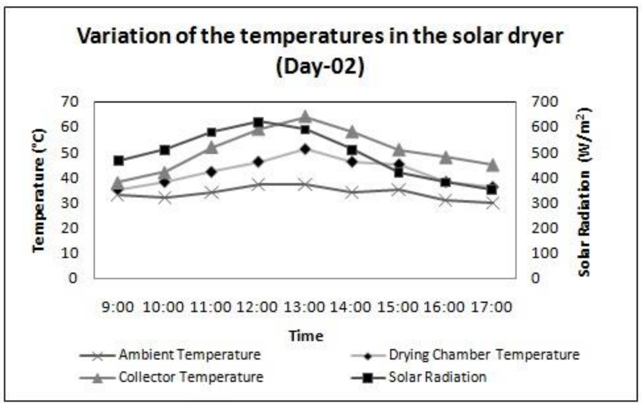


Fig 9: Variation of temperature in the solar dryer for day2

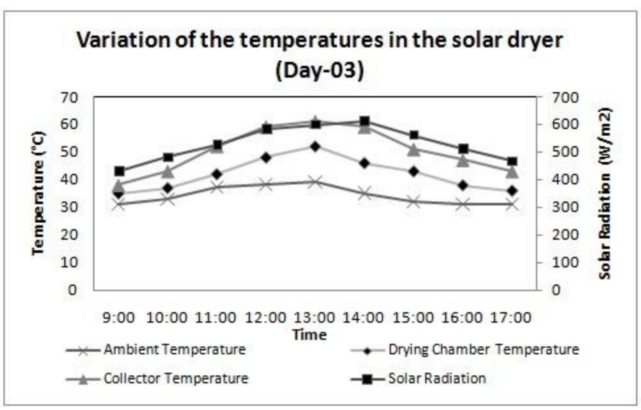


Fig 10: Variation of temperature in the dryer for day 3

To show the advantages over open drying system, the closed dryer has been compared with the open dryer. It has been simultaneously kept 250 gm of potato inside the solar dryer and in the open drying system. Hourly weight reduction of the item has been measured and found that solar dryer is more efficient in drying the item in fewer hours and weight reduction is very high compared to open drying system.

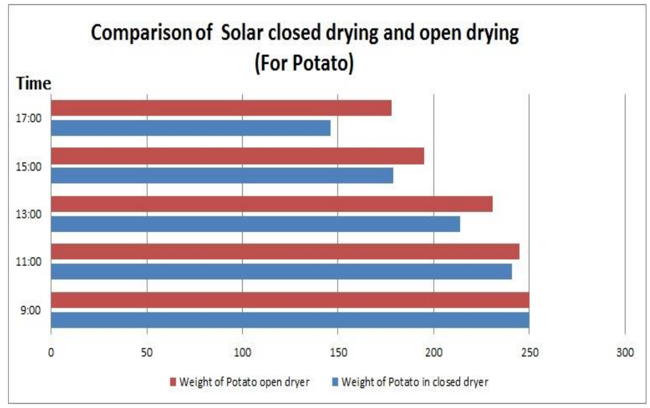


Fig 11: Comparison of solar closed and open drying for potato Similarly for Bitter Gourd and Chili

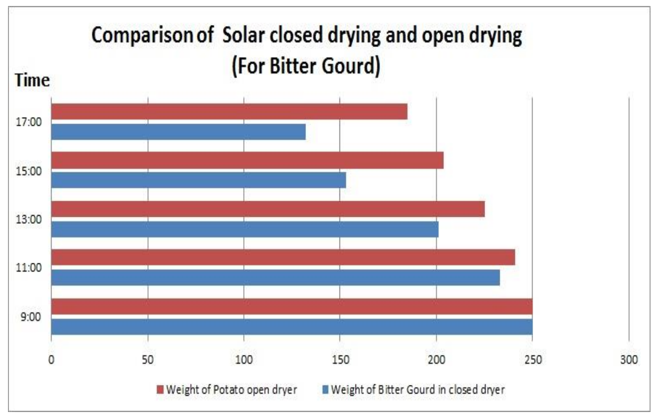


Fig 12: Comparison of solar closed and open drying for bitter ground

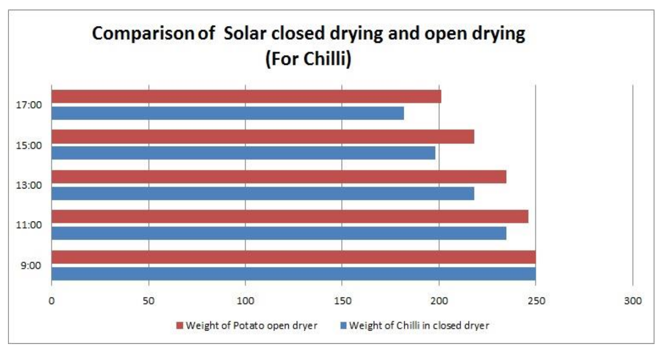


Fig 13: Comparison of solar closed and open drying for chilli

Table 3: Estimated cost of components of newly designed solar dryer system

Parameters Amount	(US$)
Land clearing and flooring	06
Solar collector and accessories	30
Dryer trough and frame	10
Glass, Small Fans	08
Nails and screws	03

Solar panel	10
Installation and labor costs	40
Total	107

Fig: 14 (a) Before drying of Potato

Fig: 14 (b) Before drying of Bitter Gourd

Fig: 14 (C) Before drying of Chili

Fig: 14 (d) After drying of Potato

Fig: 14 (e) After drying of Bitter Gourd

Fig: 14 (f) After drying of Chili

Conclusion

From the test carried out, the following conclusions can be made. The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The product inside the dryer requires less attentions, like attack of the product by rain or pest (both human and animals), compared with those in the open sun drying. Although the dryer has been used to dry Potato, it can be used to dry other crops like mangoes, apple, guava etc. There is ease in monitoring when compared to the natural sun drying technique. The capital cost involved in the construction of a solar dryer is much lower than that of a mechanical dryer. Also from the carried out test, the simple and inexpensive indirect solar dryer has been designed and constructed using locally sourced materials. The hourly variation of the temperatures inside the cabinet and air-heater are much higher than the ambient temperature during the most hours of the day-light. The temperature rise inside the drying cabinet has been found up to 28°C (94%) for about three hours immediately after 12.00h (noon). The dryer has exhibited sufficient ability to dry food items reasonably and rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product. The performance of existing solar food dryers can still be improved upon especially in the aspect of reducing the drying time, and probably storage of heat energy within the system by increasing the size of the solar collector. Also, meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry his agricultural produce and when not to dry them.

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