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Design, Development and Performance Analysis of Photo Voltaic Powered Solar Dryer

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Abstract

This paper studied on performance, comparison between open drying and drying inside the solar dryer. It also focuses that, a small increase of the technique and cost increases performance and durability of solar dryer in a large scale. In this research, different objects like chili, potato slice, and tomato were used and performance was calculated on the basis of weight change, drying time, heat gain, moisture percentage reduction, etc. In addition, an enthalpy-based calculation was made this research shows a vast difference between conventional drying and PV powered solar dryer by means of trapped heat amount, radiation gaining etc. Necessary diagrams, equations, graphs, and tables attached.

Keywords: Cooling fan; Exhaust duct; Ventilation; Heat traps; Enthalpy; Moisture reduction

Abbreviations

PV: Photo Voltaic; MC: Moisture Content; IMC: Initial Moisture Content; EMC: Equilibrium Moisture Content; DC: Direct Current

Introduction

Climate of Bangladesh always offers a great humidity. During summer, the warm and humid weather brings a disaster to biological products. Hence drying vegetative products and fisheries is a great challenge in the summer [1,2]. In a day of bright and intense sunlight, it is easier to dry those materials, but during cloud covered condition or rainy day; it becomes hard and fungus formation is enhanced due to moist weather [1]. So in this research, performance of PV powered solar dryer is evaluated and compared with an open drying condition [3,4].

In general, the main items are dried using sunlight in Bangladesh are- paddy, wood, fish, red chili, potato, green mango slice, pickles, pulse, rice, etc. [5]. Bangladesh is in a position on the surface of earth that is blessed by a pretty good amount of solar radiation over the year. So, if a closed system can be maintained and the moisture removal can be done properly, drying process becomes sustainable. The solar irradiance can exceed 980W/m^2 in a bright sunny day and effective sunshine duration may lie within 6-7 hours [6]. That's a very sustainable condition for drying. Generally, in Bangladesh, the relative humidity in summer ranges from 58-67% in average and in winter, it ranges from 24-40% [6,7]. The main challenge is not only humidity removal of high ambient moisture condition, but also gaining the solar heat properly. While the subjects having a huge aqueous percentage, the task becomes tougher [8]. Using a solar panel, we can empower exhaust fans those can remove moisture. The Combination of these two options may increase the cost in a little amount, but increase the performance in a high scale [8].

Experimental Setup

Experimental Set up of conventional PV powered dryer is shown in (Figure 1). Here, the perspective view of that solar dryer is shown and the portions indicated-

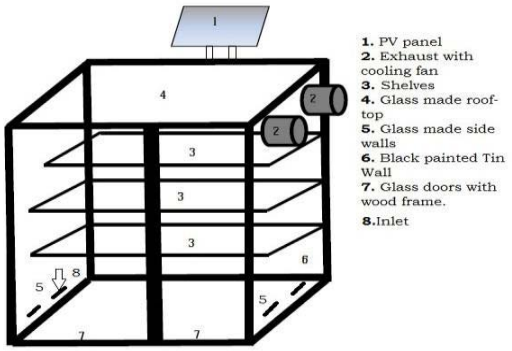

Figure 1: Skeleton perspective view PV powered solar dryer.

- PV module (3Watt-peak)
- Exhaust enhanced by cooling fan (1.5watt each)
- Black painted shelves (3)
- Glass made rooftop
- Glass made sidewalls
- Black painted tin made back wall
- Glass doors with wood frame
- Inlet

The construction of conventional PV powered dryer is (Figure 2) simple and can be broken down into three parts- Inlet, Drying chamber and Outlet. It's made of wood, glass and tin sheet [9,10]. The exhaust outlet is on the chamber wall, directly connected with the chamber environment. Four surfaces of the chamber wall are glass made and the other two surfaces are of MS sheet [11]. The frame is

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Figure 2: PV powered solar dryer.

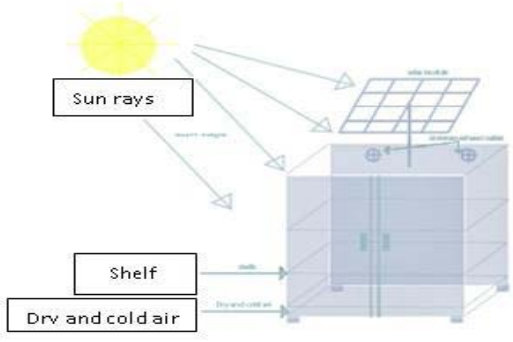

Figure 3: Schematic diagram of PV powered solar dryer.

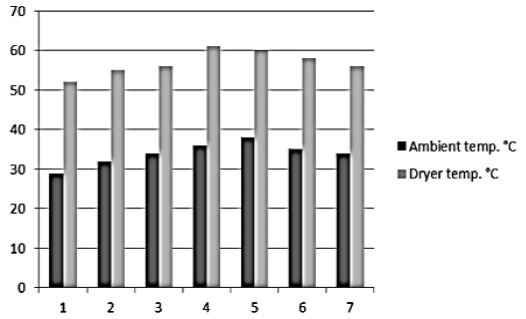

Figure 4: Ambient temp *vs* dryer temp on 23 June 2013.

made of wood. The total outer and inner surfaces except glass surfaces are painted black [12]. The dimension of the dryer is 30"×30"×54" [10]. The two outlets are guarded by two exhaust fans apart by 16" from each other having 4" of diameter. Those are powered by a 3Wp solar module placed on the top of the dryer [13,14]. There is two part door in front of the solar dryer made of wood and glass. This door is used for material input and removal [15]. There are three shelves inside the drying chamber arranged in stairway format [16]. Each of the succeeding shelves is reduced in span [13,17].

Working Procedure of PV Powered Dryer

The working principle of solar dryer (Figure 3) is based on the greenhouse effect [5,18]. The sunlight with heat of smaller wavelength enters through the transparent glass wall. Then the energy is absorbed partially by inner system and the incident heat radiation turns into

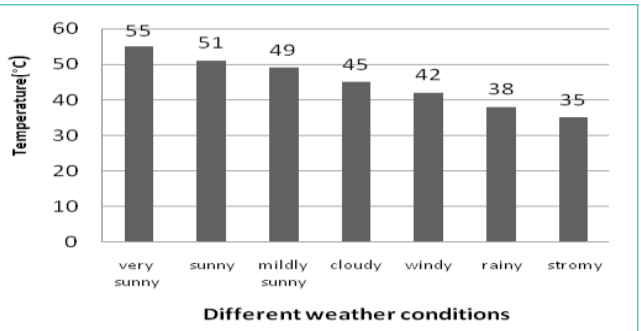

Figure 5: Variation of average dryer temperature in different weather conditions.

radiation of bigger wave length [19,20]. For that wavelength, glass becomes opaque for heat inside, but not for light. That's how heat is trapped inside and maximum portion is absorbed [19,20].

This heat works as latent heat for the water inside the substances subjected to be dried [19]. After that, the moisture is removed by the exhaust fans to environment [20].

Measurement Approach

For measurement and evaluation of the PV powered solar dryer, the topics mentioned below are needed:

Moisture Content: The percentage moisture content was determined by using the following formula,[**]

$$\text{M.C.(w.b.)}\% = \frac{W1 - W2}{W1} \times 100\%$$

$$\text{M.C.(d.b.)}\% = \frac{W1 - W2}{W1} \times 100\%$$

Where, $W1$ = Weight of sample before drying in gram.

$W2$ = Weight of bone dried sample in gram.

Drying Rate: The drying rate (g/h/100g of bone dry weight) of fish samples during drying period was determined as follows,

$$\text{Drying rate } (DR) = \frac{\Delta W}{\Delta t}$$

Where, ΔW= Weight loss in one hour interval (g/100g of bone dry weight)

Δt = Different in time reading (h)

Moisture Ratio: The Moisture ratio was computed by using IMC and EMC.

$$\text{Moisture Ratio} = \frac{M - Me}{Mo - Me}$$

Where, M = Moisture content (d.b.) %

Me = EMC, (d.b), %

Mo = IMC, (d.b), %

Exact moisture content and specific heat of used biological subjects are given below (Table 1).

Observation

All the experiments and observations were done in Dhaka, at University of Dhaka (23.73°N), Energy Park. The observation session was from May to July. The average direct solar irradiance was near

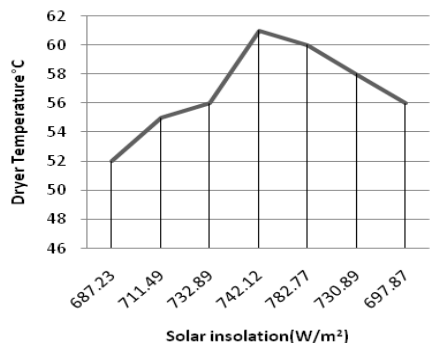

Figure 6: Dryer temperature *vs* solar insolation curve at no load condition.

Table 1: Exact moisture content and specific heat of used biological subjects are given below.

Subject	Moisture content [5]	Heat Capacity[3] kJkg^{-1}
Tomato (green)	92	3.32
Potato	79	2.67
Green Chili	82	2.94

Table 2: The ambient humidity and temp *vs*. dryer humidity and temp on 23 June 2013.

Time	Ambient		Dryer	
	Temperature °C	Humidity %	Temperature °C	Humidity %
9:00	28	45.2	41	45
10:00	29	47.4	52	46.2
11:00	32	49.7	55	47.4
12:00	34	51.2	56	48.3
13:00	36	53.9	61	40.8
14:00	38	56.1	60	42.2
15:00	35	54.9	58	48.6
16:00	34	53	56	48.4

600 W/m^2 from time 09:00 to 17:00. The ambient relative humidity was found from 50-60%.

No Load Test for Conventional Dryer

At first the dryer door was locked and no materials were put inside the chamber. Then the ambient and inner humidity and temperature were logged continuously for several hours. Here, below the ambient humidity and temp *vs*. dryer humidity and temp on 23 June 2013 (Table 2) (Figure 4,5,6).

The solar insolation vs temperature at no load condition are given below (Table 3):

Load Test for Dryer

In this test, sample weight is taken inside the dryer, ambient and dryer humidity and temperature is taken with a multi-probed digital RH thermometer. Then after each hour, sample weight, temperature, humidity is logged, so that drying rate can be calculated. For each three sample- potato, chili and tomato, the process was repeated for three individual days.

After, the sample initial weight, drying time and final weight was

Table 3: The solar insolation *vs* temperature at no load condition are given below.

Time	Solar insolation, W/m^2	Dryer temperature °C
10:00	687.23	52
11:00	711.49	55
12:00	732.89	56
13:00	742.12	61
14:00	782.77	60
15:00	730.89	58
16:00	657.87	56
17:00	507.32	53

Table 4: Sample weight *vs* moisture loss in dryer as below.

Sample	Initial weight (kg)	Drying time (hour)	Final weight (kg)	Moisture removal (kg)
Tomato	1kg	14.21	0.15	0.85
Potato slice	1kg	6.37	0.23	0.77
Chili	1kg	10.14	0.24	0.76

Table 5: The same parameters in open dry condition, maintaining almost the same area of the surface on which drying was done.

Sample	Open bed area m^2	Initial weight Kg	Drying time hr	Final weight kg	Moisture removal Kg
Tomato	0.13	1	18.14	0.145	0.855
Potato slice	0.4	1	8.39	0.24	0.76
Chili	0.2	1	14.35	0.21	0.79

calculated in order to gain the moisture removal (Figure 7,8).

The below table shows moisture loss, drying time, and initial weight of the samples in our PV powered dryer.

Sample weight vs moisture loss in dryer as below (Table 4):

Then the sample of a same item and same weight was dried in open condition and measurement was logged. Below are shown the same parameters in open dry condition, maintaining almost the same area of the surface on which drying was done (Table 5).

Calculation and Performance Evaluation

Here, dryer performance is evaluated on drying efficiency of the dryer compared with efficiency in the case of the open dry condition.

Dryer efficiency [21] $\eta_d = \dfrac{W \times \left(\Delta H_L + C_p\right)}{A_c \times I_d \times t_d}$

Where, W= Moisture evaporated (kg)

ΔH_L= Latent heat of vaporization of water, 2260 (kJkg^{-1})

C_p= Heat capacity of the subject

I_d= Average total hourly insolation upon collector, (Wm^{-2}) = 693.47

A_c = Area of collector (m^2) = 0.58063

T_d = Drying time in second by multiplying 3600

Performance comparison based on efficiency is given below (Table 6).

Results and Discussion

This section analyses the experimental results and discuss. The PV

Table 6: Performance comparison based on efficiency is given below.

Sample	Open dry efficiency %	Dryer efficiency %
Tomato	7.31	9.46
Potato	14.14	18.82
Chili	8.6	12.16

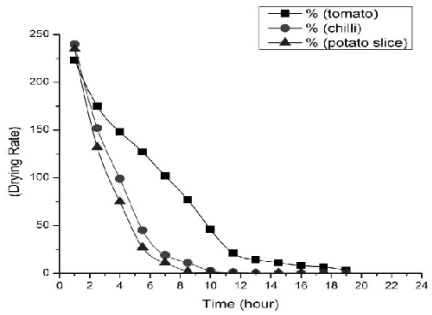

Figure 7: Drying rate *vs* time curve (open dry condition).

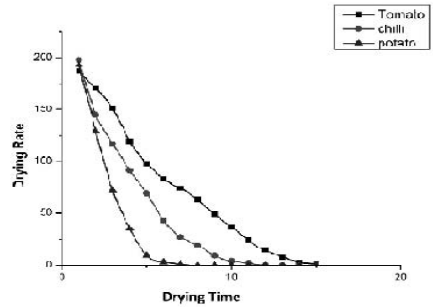

Figure 8: Drying rate *vs* time curve (inside dryer).

powered solar dryer efficiency ranges from 9-19% for the fruits and vegetables with high moisture content and efficiency ranges 7-14% at open dry condition. In addition, to enhance the performance of that dryer, a sand bed at the bottom of the dryer can be attached. In addition, a DC heater can be attached, which will get electricity from the solar panel. The main problem with that dryer was heat leakage due to its old infrastructure; it also affects the proper temperature gain and moisture removal.

Conclusion

By extracting the experimental results it is clear that the efficiency of Photo-Voltaic (PV) powered solar dryer improved the overall efficiency of the system. The PV powered solar dryer efficiency lies in between 9-19% for the fruits and vegetables with high moisture content. On the other side, the efficiency of the conventional dryer system (open type) lies in between 7-14% at open dry condition. In addition, a supplementary sand bed could be attached at the bottom of the dryer to enhance the performance of the proposed dryer. Moreover, a solar driven Direct Current (DC) heater could be attached to improve the proposed dryer efficiency also. The conventional or open type dryer system suffered with heat leakage due to old infrastructure and also failure to temperature gain and moisture removal. The PV powered solar dryer replaced the above limitations which performed much better than the conventional (open type) drying system and also provided the security and sustainable drying.

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