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Design and Analysis of Drying Chamber Used in Hybrid Solar Dryer

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Abstract - *The objectives of this study is to develop a solar dryer chamber in which the chilies are dried by hot air induced by suction fan which are operated on electricity generated by PV solar panel. Poor air velocity in the sun drier chamber, resulting in low moisture transfer from the chilies to the air. Due to this the time required for drying is relatively high. To overcome this problem suction fan located at outlet of drying chamber will be used to evacuate air with high rate. Therefore, the rate of moisture removal will be increase. Therefore, this work will be based on importance of the solar dryer chamber to increase its efficiency.*

The dryer recorded a raised temperature of 55°C attainable in the drying chamber of solar dryer. The moisture content of chilies was reduced from 80 % wet basis to 10 % wet basis in 10 working hours for solar dryer. The obtained average drying rate was 0.240 Kg/hr.

Key Words: Design, Solar dryer, Red chili, Evacuated tube, Drying rate.

1. INTRODUCTION

Drying process is an important post-harvest process in agriculture in India. Productivity and quality of products are affected by the drying process. More appropriate ways are needed to improve the quality of products as well as the hygienist aspects. At also to improve the productivity and economics of the farmers. The utilization of solar energy using to an open sun drying method. The solar drier was found to keep color and flavor while reducing moisture content from 86 solar dryers is one way for this purpose.

Solar radiation can be directly converted into heat and/or electricity using a solar device collector. Conventional photovoltaic (PV) panels usually used solely for generating electricity. It converts the solar energy falling into the electricity. This electricity generated by PV panel can be used to induce suction fan located at the outlet of the drying chamber for increase air velocity in the chamber. Due to this moisture transfer rate between the air and agricultural product will increase by forced convection which help to dry product in relatively low time.

2. LITERATURE REVIEW AND OBJECTIVE

This Ankur Gupta et al.[1] The chilies had a moisture ratio of 0.11 when dried in the sun and 0.28 when dried in the open sun. When compared to open-air drying, the hybrid solar drier is more effective. Green chilies were dried in a solar drier at a pace 130 percent faster than they were dried in the open sun. Electrical energy, thermal energy, and overall thermal energy for the PV/T solar dryer o were found to be 0.409, 0.859 and 1.933 kWh/day, respectively in all over the experiment. Average electrical efficiency, thermal efficiency, and overall thermal efficiency of the PV/T solar dryer were found to be 12.29%, 18.81%, and 51.18%, respectively

Ragul Kumar N. et al. [2] Solar dryer reduced the moisture content of red chili from 79% (w.b.) to about 10% (w.b.) in 55 h compared to 124 h taken by open-sun drying by saving 56% of drying time compared to open drying. Thermal efficiency of the dryer found to be 16.25% for chili drying with a specific energy consumption of 6.06 kWh/kg.

Muhammad Zakaria Hossain [3] A DC fan of 10 watt was used for exhaust moisture with the help of a solar panel of 15 watt. In the solar dryer 8.75 kg dried chili was obtained from 30 kg of red ripe chili. The final drying levels of the red chili were obtained after 41 hours but took about 91 hours in the open sun drying system, having the same weather condition. Final moisture content of dried chili in dryer and sun was 10% and 18% respectively. Average temperature in the dryer and open sun was 45°C and 34°C respectively. Due to DC fan shows maximum efficiency at maximum solar radiation.

Wenceslaus Pantaleo Missana [4] 1 kg of red pepper is dried at a temperature of 19.6 to 62.4°C. The average ambient temperature was 19.3°C to 37.4°C, and the heat storage media's highest temperature was 87.8°C to 125°C. With 1 kg of red pepper, the solar drying process was compared percent to 10% for 24 hours, compared to 36 hours for air drying.

A. O. Adelaja [5] This solar dryer has a dc suction fan that is powered by a solar PV module near the chamber's exit. Without the need of external power sources such as grid electricity, fossil fuels, or batteries, a dc suction fan is utilized to create forced air circulation. The operational efficiency of the collector is 83.2% and mass flow rate 1.58kg/min, the maximum temperature achieved in the chamber was 58°C.

J.B. Hussein [6] The hybrid drying method reduced the moisture content of tomato slices from 94.22 percent w.b. to 10% w.b. in 6 hours, whereas the solar dryer required 9 hours to achieve the same moisture content reduction. The average drying rate and efficiency for hybrid dryers were calculated to be 0.0800kg/h and 71 percent, respectively, and 0.0578kg/h and 65% for solar energy dryers.

E. O. M. Akoy [7] To dry a batch of 100kg sliced mango (195.2 kg fresh mango at 51.22 percent pulp) in 20 hours, a minimum of 16.8m2 solar collector area is required. Initial and final moisture content considered were 81.4% and 10% w.b., respectively. The average ambient temperature is 30°C, with a relative humidity of15%, and daily global solar energy incident on the horizontal surface is roughly 20MJ/m2/day.

Ubale et al.[8] An evacuated tube solar collector is conceived, constructed, and examined in this experimental research. Then, in the active convection mode of heat transmission, a performance study was carried out. This solar drier with evacuated tubes is designed to dry grapes in batches of 10kg. Thomson seedless grapes were used as the drying material for this project. Experiments were carried out in the month of April. Raisins produced from this dryer were tested for different parameters to check its quality and found the best results.

The objectives of this study is to develop a solar dryer chamber in which the chilies are dried by hot air induced by variable speed suction fan which are operated on electricity generated by PV solar panel. The problem of low air velocity in the solar dryer chamber which cause low moisture transfer from the chilies to air. Due to this the time required for drying is relatively high. To overcome this problem suction fan located at outlet of drying chamber will be used to evacuate air with high rate. Therefore, the rate of moisture removal will be increase. Therefore, this work will be based on importance of the solar dryer chamber to increase its efficiency.

$$ML = W_i - W_f \quad (1)$$

$$D_R = dM/dt \quad (2)$$

$$M_d = [(M_i - M_f)/M_i] \times 100 \quad (3)$$

$$\eta_d = [(\text{Moisture loss} \times \text{latent heat of vaporisatio})/(\text{Area of collector} \times \text{Average solar radiations} \times \text{Time})] \times 100 \quad (4)$$

3. MATERIALS AND METHODS

This setup mainly consists of a evacuated tube collector, drying chamber, suction fan, PV panel, digital thermocouple temperature indicator, DC to AC converter and battery. The schematic sketch with the main parts is shown in Figure 3.1. These parts are briefly discussed below,

3.1 Evacuated tube collector

Evacuated tubes are made up of two coaxial borosilicate glass tubes. These coaxial tubes are joined at the top and sealed at the bottom. The vacuum is present between two tubes. The outer tube of evacuated tube collector is transparent. Solar radiations pass through the tube. The inner tube has an absorber coating on it. The working fluid passes through the inner tube. Absorber coating absorbs solar energy and converts it into heat energy. This heat energy absorbed by the air. The space between inner and outer tubes is evacuated, it acts as a thermal insulator. Due to this convective and conductive heat losses are reduces. Thus the trapped solar energy absorbed and transmitted to the working fluid, gets prevented from escaping back to the environment. This is called as a greenhouse effect.

3.2 Drying chamber

The drying chamber is insulated enclosed structure. The drying material is placed in the drying chamber. Trays are present in the drying chamber for placing drying material. There is one door for loading and unloading drying material. To reduce heat losses to the surrounding drying chamber must be insulated.

3.3 PV panel

PV panel used to the generate electricity by capturing solar radiation. Following are various PV panels.

3.4 Suction fan

The suction fan of is used for suck air from the chamber. Suction fan is located at the top of chamber as shown in figure.

3.5 Thermocouple and Digital temperature indicator

Thermocouples are used to measure temperature at various parts in the dryer. And digital temperature indicator shows temperature at these parts.

3.6 Battery

Battery is used for store electric energy from the PV panel and supplies it to exhaust fan.

3.7 DC to AC converter

DC to AC converter used to convert PV panel DC current in AC current for run exhaust fan. It has two outputs for connect load on it.

3.8 Measuring instruments and devices

The temperature is measured by using a chromel-alumel thermocouple and temperature indicator. An electronic weighing scale is used for weight measurement. Anemometer is used for velocity measurement. Psychrometer is used for measure DBT and WBT.

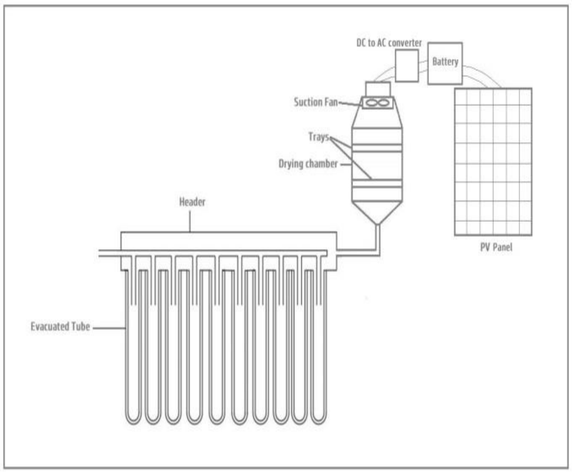

Figure 1: Schematic diagram of the set-up

Table 1: Chilli weight, moisture content and with time of upper and lower tray

Time (min.)	Weight (Kg) Lower Tray	Weight (Kg) upper tray	Moisture content (%) Lower tray	Moisture content (%) Upper tray	Average Moisture content (%)
0	2.5	2.5	80	80	80
30	2.35	2.375	74	75	74.5
60	2.225	2.275	69	71	70
90	2.125	2.15	65	66	65.5
120	2.075	2.1	63	64	63.5
150	1.95	1.975	58	59	58.5
180	1.85	1.875	54	55	54.5
210	1.775	1.812	51	52.5	51.75
240	1.725	1.75	49	50	49.5
270	1.65	1.7	46	48	47
300	1.6	1.675	44	47	45.5
330	1.525	1.625	41	45	43
360	1.475	1.6	39	44	41.5
390	1.425	1.55	37	42	39.5
420	1.375	1.5	35	40	37.5
450	1.35	1.45	34	38	36
480	1.3	1.4	32	36	34
510	1.25	1.375	30	35	32.5
540	1.205	1.35	28	34	31
570	1.175	1.325	27	33	30
600	1.155	1.32	26	32.5	29.25

Table 2: drying rate with time of upper and lower tray

Time (min.)	Drying rate (Kg/hr) Lower tray	Drying rate (Kg/hr) Upper tray	Sum of lower and upper tray Drying rate (Kg/hr)
0	0	0	0
30	0.3	0.25	0.55
60	0.25	0.2	0.45
90	0.2	0.25	0.45
120	0.1	0.1	0.2
150	0.25	0.25	0.5
180	0.2	0.2	0.4
210	0.15	0.126	0.276
240	0.1	0.124	0.224
270	0.15	0.1	0.25
300	0.1	0.05	0.15
330	0.15	0.1	0.25
360	0.1	0.05	0.15
390	0.1	0.1	0.2
420	0.1	0.1	0.2
450	0.05	0.1	0.15
480	0.1	0.1	0.2
510	0.1	0.05	0.15
540	0.09	0.05	0.14
570	0.06	0.05	0.11
600	0.04	0.01	0.05
Average	0.128	0.112	0.24

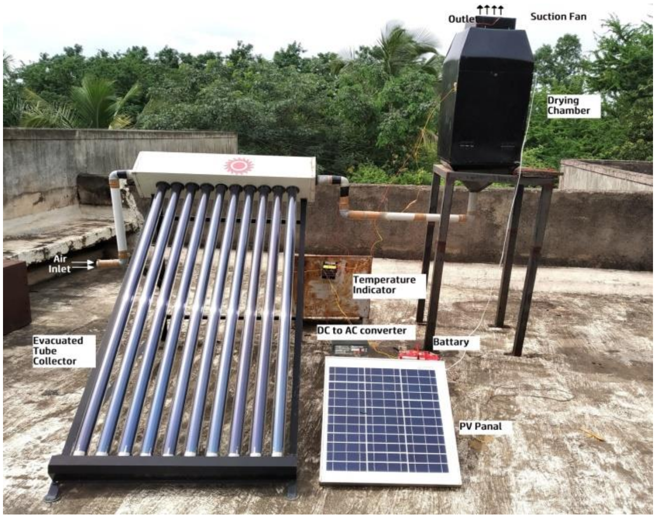

Figure 2: Experimental setup

4. RESULTS AND DISCUSSION

Around 65-80% w. b. moisture is available in chili [2]

For 5 Kg chilies: -

Assuming 80% w. b. moisture in chilies Initial mass of chillies [2] = 5Kg

Moisture available in chili= 80% w.b.

i.e. Mw = 80% w.b.

$$M_w = \frac{W_W}{W_T} \times 100$$

Where, M_W = moisture content in sample

W_T = total weight of sample

W_W = weight of water present in sample

$$M_{W1} = \frac{W_{W1}}{W_{T1}} \times 100$$

W_{W1}= 4 Kg

Around 4Kg weight of water present in the 5Kg sample

W_D= weight of dry content =1Kg

For better quality of chilies, we need to have approximately 8-10% moisture in the chilli after drying [2]

Assuming 10% w.b. moisture content after drying

$$M_{W2} = \frac{W_{W2}}{W_{T2}} \times 100$$

Where, W_{W2} = final weight of water present after drying

W_{T2} = total weight of sample after drying = $1+W_{W2}$

W_{W2} = 0.111 Kg

W_{T2} = 1.111 Kg

Moisture to be removed

Moisture removed is given by [8],

$$M_R = \frac{M_p(M_i - M_f)}{(100 - M_f)}$$

Where, M_R = Moisture to be removed

M_P = sample weight in Kg

M_i = initial moisture content in %

M_f = final moisture content in %

M_R = 3.889 Kg

Moisture content on wet basis

$$M_{WB} = \frac{m_i - m_f}{m_f}$$

M_{WB}= 0.7778 = 77.78%

Drying Temp.

For chillies drying temp must be in between 40-60°C

Consider drying temp. T_p = 55°C

Ambient temp. T_a = 30°C

Heat energy required to remove moisture content

Consider around 10 working hours in two days i.e.from 11AM to 4PM [8]

$$Q_{req} = \frac{M_R \times L_W}{t}$$

Where, Q_{req}= Heat energy required to remove moisture content

L_W = latent heat of vaporization of water

t = working time

Latent heat of vaporization is calculated by [9]

$L_W= C_{pw} \times [\text{sensible heat} - 0.56 \times (T_P + 273)]$

L_W = 1730157.52 J/Kg = 1730.157 KJ/Kg

Q_{req} = 186.95 W

Sizing of collector

The average solar radiation in the month of February to June is 980w/m² in Sangli. The optical efficiency of the ETC system is 0.85. So effective solar radiation absorbed by the inner tube is 840 w/m².The overall efficiency of the evacuated tube dryer system is 15% to 20%. So, the area required for the solar ETC system is given by the equation [9].

$Q_{req} = A_C \times I \times 0.15$
$A_C = 1.48\ m^2$

There are different sizes of tubes available in the market. Here we select the evacuated tube with length 1800mm, outer diameter 58mm and inner diameter 47mm. The number of tubes required for the collector is calculated by following equation [8].

$A_C = \pi/2 \times D \times L \times n$

n = 9.18~10

So, the number of evacuated tubes is 10

Drying chamber

Size of chamber

Length = 0.5m

Height = 1m

Width = 0.5m

Volume = 0.25m^3

Drying chamber specifications

The drying chamber made up of galvanized iron with volume 0.25m3 is used for the experiment. It is observed in the literature that the collector surface to the dryer volume ratio (R) must be more than 3 to have efficient utilization of the system [8].

R=*surface area of collector/drying chambervolume* > 3

R=1.48/0.25 = 5.92 > 3

So, above mentioned dryer we can used as it is.

Fan design

Mass flow rate of air (Kg/s)

Mass flow rate M_a (Kg/s) of the air

$$M_a = \frac{heat\ for\ remove\ moisture}{Cpa\ \Delta T\ td}$$

Where Cp_a = specific heat of air

ΔT = temp. difference

t_d = time per day in sec

M_a = 0.0744 Kg/s

Volumetric flow rate V_a (m^3/s)

$$V_a = \frac{M_a}{\rho a}$$

Where ρ_a= density of air at 55°C = 1.2754 Kg/m^3

V_a= 0.05833 m^3/s

V_a= 210 m^3/hr = 123.6 cfm

Analytical Calculations

Moisture loss from product calculated by using formula [10],

$ML = W_i - W_f$

Where, ML=Moisture loss.

W_i= Initial mass of sample

W_f= Final mass of sample

Drying rate:

Drying rate is given by [10]

$$\text{Drying rate} = \frac{dm}{dt} = \frac{\text{initial moisture} - \text{final moisture}}{\text{time}}$$

= 0.3889 Kg/hr = 0.108 g/sec

Loss of moisture on wet basis

The loss of moisture on wet basis is given by [10],

$$M_d = \frac{Mi - Mf}{Mi} \times 100$$

M_d = 77.7 %

a) System drying efficiency

System drying efficiency is given by [10],

$$\eta_d = \frac{\text{Moisture loss} \times \text{latent heat of vaporisatio}}{\text{Area of collector} \times \text{Average solar radiations} \times \text{Time}} \times 100$$

η_d=22.93%

Location and climate

WCE, Sangli, Maharashtra

Latitude 16°52' N

Longitude 74°3 E

Tilt angle = 12 to 15° addition to latitude

= 31°52'

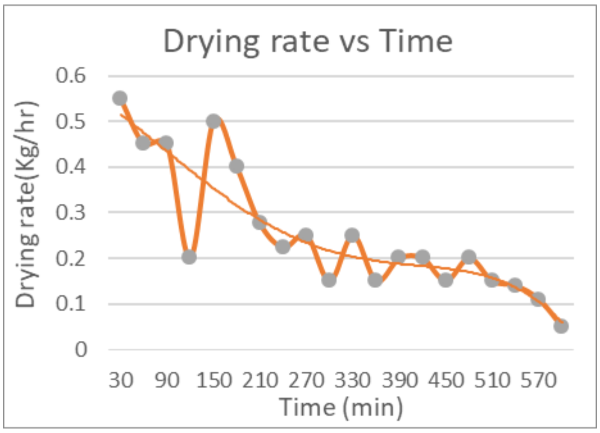

Figure 3: Drying rate with moisture content

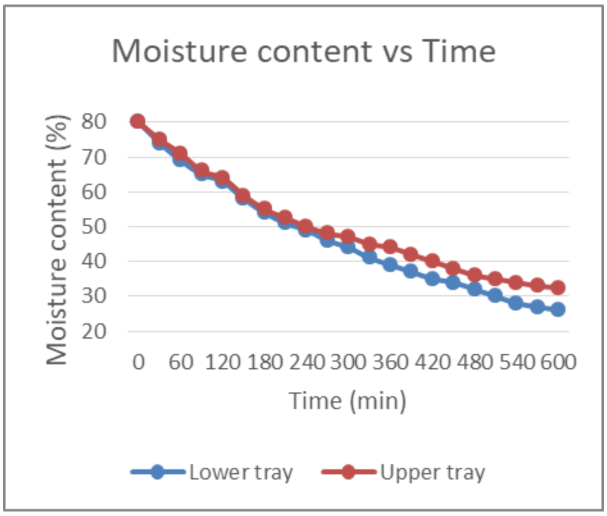

Figure 4: Moisture content with Time

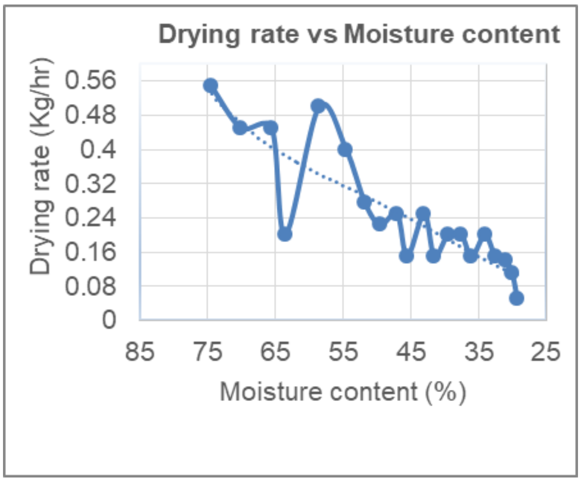

Figure 5: Drying rate with moisture content

5. CONCLUSIONS

(a) The temperature obtained in the solar collector is mainly dependent upon solar radiation and weather conditions.

(b) At 1 p.m., when radiation is at its peak, the highest temperature is reached.

(c) The temperature rises until 1 p.m., after which it drops again.

(d) The average temperature of the collector output was 56.8°C, which is 25.4°C higher than the average ambient temperature of 31.4°C.

(e) According to theoretical calculations, 5 kg of chili will dry to 1.111 kg in 10 hours, resulting in an average drying rate of 0.388 kg/hr.

(f) In a 10-hour trial, 5 kg of chili was reduced to 2.525 kg. As a result, the average drying rate attained is 0.24 kg per hour.

NOMENCLATURE

M_W	moisture content in sample	%w.b
W_T	total weight of sample	Kg
W_W	weight of water present in sample	Kg
W_D	weight of dry content	Kg
W_{W2}	final weight of water present after drying	Kg
W_{T2}	total weight of sample after drying	Kg
M_R	Moisture to be removed	%w.b
M_P	sample weight	Kg
Mi	initial moisture content	%
M_f	final moisture content	%
T_p	drying temperature	°C
T_a	Ambient temperature	°C
Q_{req}	Heat energy required to remove moisture content	W
L_W	latent heat of vaporization of water	KJ/Kg
t	working time	Sec
M_a	Mass flow rate of air	Kg/s
C_{pa}	specific heat of air	KJ/Kg-K
ΔT	temperature difference	°C
t_d	time per day	Sec
V_a	Volumetric flow rate	m^3/s

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