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Development of Light Weight Solar Dryer and Optimization of Drying Process for Bottle Gourd

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Abstract: The light weight solar dryer has been designed and fabricated to align with the atmospheric conditions of Kashmir valley. The experimental studies titled as " Development of a light weight solar dryer and optimization of drying process for bottle gourd " were conducted at the Sher-e –Kashmir University of Agricultural science and Technology , Shalimar, Srinagar J&K , in the northern part of India, during summer season of 2023. The solar dryer consists of drying chamber, drying tray, air inlet , exhaust fan for cross ventilation , temperature humidity controller module, solar panel, battery and solar charge controller. The dryer harnesses solar energy for the drying process and holds substantial promise for drying fruits, vegetables , herbs with medicinal properties and a variety of other products. The dryer has dimension of(length=36″ , width=24″, front height=30″, back height 40″ and a slope for attaining maximum sunlight intensity. This dryer has an average capacity of 4-5kg of the food product for drying. In this experiment tray is loaded with untreated and treated bottle gourd slices. In two separate trials drying completed in 20 and 32 hours for treated and untreated sample respectively . The temperature inside the dryer increased up to 60°C and relative humidity was reduced upto 27%. The moisture content in %d.b(dry basis) of untreated bottle gourd is reduced to 9.8% while as in pre-treated bottle gourd , moisture content is reduced to 8.8%.
Keywords: Moisture content, dry basis (%d.b), solar charge controller, temperature humidity controller module.

I. INTRODUCTION

Preservation of agricultural produce is one of the central problems faced by developing countries. And as time goes on, these problems will be aggravated by the growing dietary needs of the ever increasing population of these countries(Hauser *et al*. 1997). In numerous developing nations, substantial amounts of fruits and vegetables go to waste because of insufficient infrastructure, limited processing capabilities, and increasing challenges in marketing due to heightened competition in global agricultural markets. Drying these items can offer a solution to these issues while simultaneously playing a vital role in enhancing people's income and the availability of these products. Kashmir valley is under temperate climate and there is severe scarcity of local fruits and vegetables from November to April. During this season, cultivation of fruits and vegetables is not possible because of severe cold & snow (Kumar *et al* .2005). Therefore there is high market for dried fruits and vegetables under hygienic conditions so as to extend their availability during off season and fetch good money& enhances shelf life of products.

Bottle gourd is one of the excellent vegetable gifted by the nature to human beings having composition of all the essential constituents that are required for normal and good human health. It is extensively cultivated throughout the world. It is grown throughout India and is available in the market throughout the year. More than 80% of most fruits and vegetables contain water (GEPC, 2005). Microorganisms obtain nutrients and water for their growth from the crop in which they grow. Hence, the fruit must be dried in order to stop the multiplication of microorganism and store it for longer period. Drying is one of the primordial and rampant techniques for safeguarding food quoted by numerous people like Lima (2002) and Ratti(1997). The quality of the solar dried bottle gourd on the basis of moisture content, water activity, colour attributes, vitamin C retention and rehydration ratio determines that the solar dried products are significantly good as indicated by the T- test (Rehman *et al*. 2022). The samples are dried in hygienic conditions and drying time has reduced significantly. During solar drying there is very less chance of samples being exposed to rain, birds and are prevented from the direct exposure to the Sunlight which prevents the UV- exposure and make dried vegetables safe for consumption. Further there is an acute crises of electric power and other forms of fuel like wood, kerosene oil and coal in the Kashmir valley. Moreover, energy sources like wood, kerosene oil and coal have a serious impact on environment. As most of the Indian farmers are poor and unable to afford these energy resources, so there is a need of utilizing cheaper , easily available, non-conventional sources of energy like solar energy. A light weight solar dryer is one of the way to utilise solar energy in a controlled environment.

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II. DRYER DESIGN

While designing a dryer , various factors need to be taken into account to ensure that the resulting dryer is suitable for a specific purpose. It is essential to incorporate a suitable design for a solar dryer to succesfully meet its intented goals. The dryer consists of a drying chamber having one tray for loading vegetables. The dimensions of dryer are: length=36″ , width=24″, front height=30 ″, back height 40″ and a slope surface is giving to dryer for attaining maximum sunlight intensity. The drying tray is kept at a height of 12″ from the bottom . The dryer is covered with a transparent UV stabilized polyethylene cover of 0.2 mm thickness which is not affected by the atmospheric conditions and has transmissivity of 92% for visible radiation and thus traps the solar energy leading to the greenhouse effect and enhance the temperature inside the dryer to maintain it at optimum level for drying of vegetables. The top surface of the drying chamber have been designed in a sloping shape in order to increase the area for radiation. The advantage of slope is to maximize utilization of solar radiation inside the dryer. The shape and orientation plays an important role in the dryer (Odesola, 2012). The dryer is provided with an air inlet and exhaust fan The exhaust fan is on the upper side to remove hot air and inlet vents are placed at the bottom of the dryer for better cross ventilation. The dryer is made from the PPR pipes which is very light in weight and thus can be easily handled. Temperature and humidity is being controlled by temperature and humidity controller module. An exhaust fan works when temperature reaches 60℃ and the heat accumulated inside dryer is removed . when the temperature drops to 55℃ fan stops working. Meanwhile for operating temperature humidity controller , a 12 V , 7 Ah battery is used which gets charged by solar panel .The actual photograph, three dimensional and two dimensional view of the dryer is shown in figure 1a, 1b and 1c respectively.

Front view Rear view

Fig 1(a): Actual photograph of light weight solar dryer

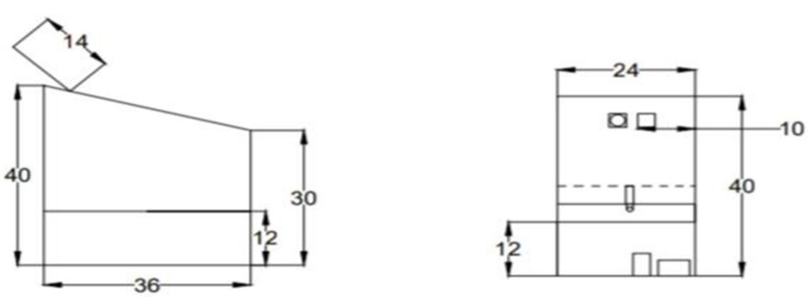

Fig 1(b) : Side view and rear view of dryer

Note : All the measurements are in inches

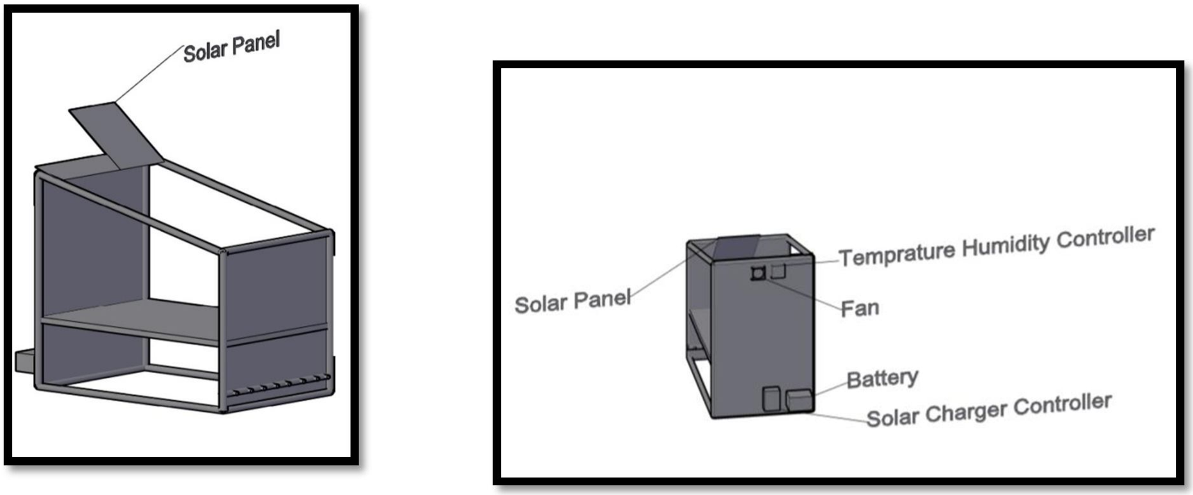

Fig 1(c): Three dimensional view of light weight solar dryer

III. METHODOLOGY

Fresh bottle gourd (Lagenaria Siceraria), is procured from local market . Bottle gourds is washed under tap water before each experiment to remove dirt, dust and other surface adhering. The peeling of these bottle gourd is then done manually, using a peeler as seen in figure 2. These peeled bottle gourds is cut as per the requirement of the investigation. Some of the bottle gourd slices are pre-treated with 2.5% NaCl solution. Bottle gourd slabs were removed from the solution and excess solution is drained from them. The treated and untreated bottle gourd slices are spread evenly on the drying tray . Temperature and relative humidity inside and outside of the solar dryer is observed after every 2 hours and is summarized in table (3a to 3f)

Fig 2: sample preparation

A. *Drying Characteristics of Botlle Gourd*

1) *Moisture Content*

The initial moisture content (wet basis) of the sample is determined using a laboratory scale infrared moisture meter, manufactured by Tasha Bah India Co. Infrared moisture meter used is a semi-automatic moisture meter, which gave moisture content directly .Infrared moisture meter is based on the principle that water molecules absorb and interact with specific wavelengths of infrared radiation. The moisture content on dry basis is given by the following equation :

$$\textit{Moisture content (\% db.)} = \frac{W_t - W_d}{W_d}$$

Where,

W_t = Weight of the sample (g)

W_d = Weight of dry matter (g)

2) Drying Rate

The rate of drying was calculated by the decrease in moisture content (% db) of the bottle gourd sample per unit time (min), as determined by the following equation (Brooker *et al.*, 1997).

$$\frac{dM_i}{dt_i} = \left[\frac{M_i - M_{i+1}}{T_{i+1} - T_i}\right]$$

Where,

$\frac{dM_i}{dt_i}$ = drying rate, loss of moisture per min, at ith drying time (% db.)

M_i = Moisture content at ith time interval

i = Drying interval

3) Rehydration Ratio

For performing this test ,4g of samples are dipped in 80 ml of water and covered with a watch glass . The rehydration continues for 40 minutes and after every 10 minutes sample was removed from the water and weighed. The rehydration ratio is calculated using the formula given by(Srivastava ,1993).

Rehydration ratio =B / A

B= weight of sample after rehydration
A= weight of sample before rehydration

IV. RESULTS AND DISCUSSIONS

A. Moisture Content

The initial measurement revealed that the bottle gourd has a moisture content of 94.8% on a wet basis. For Pre treated Bottle gourd sample, moisture content is reduced to 8.87%d.b, while as for untreated bottle gourd sample , moisture content is reduced to 9.89% d.b as seen in table 2(a) and 2(b) .This underscores the significance of pre-treatment done to the food sample . The initial stage of drying exhibited a pronounced decrease in moisture. This behaviour also highlights the importance of optimizing drying conditions for efficient moisture removal while ensuring product quality and stability. The loss of moisture wis rapid initially and then it decreased with a slower rate(Fig, 2(a) & 2(b)).

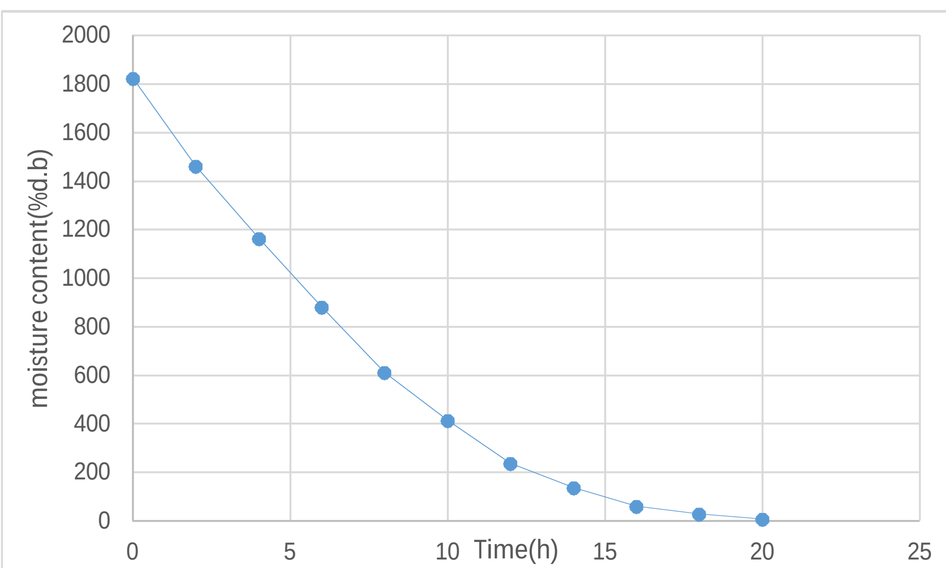

Fig 2a : Variation of Moisture content with time for treated bottle gourd

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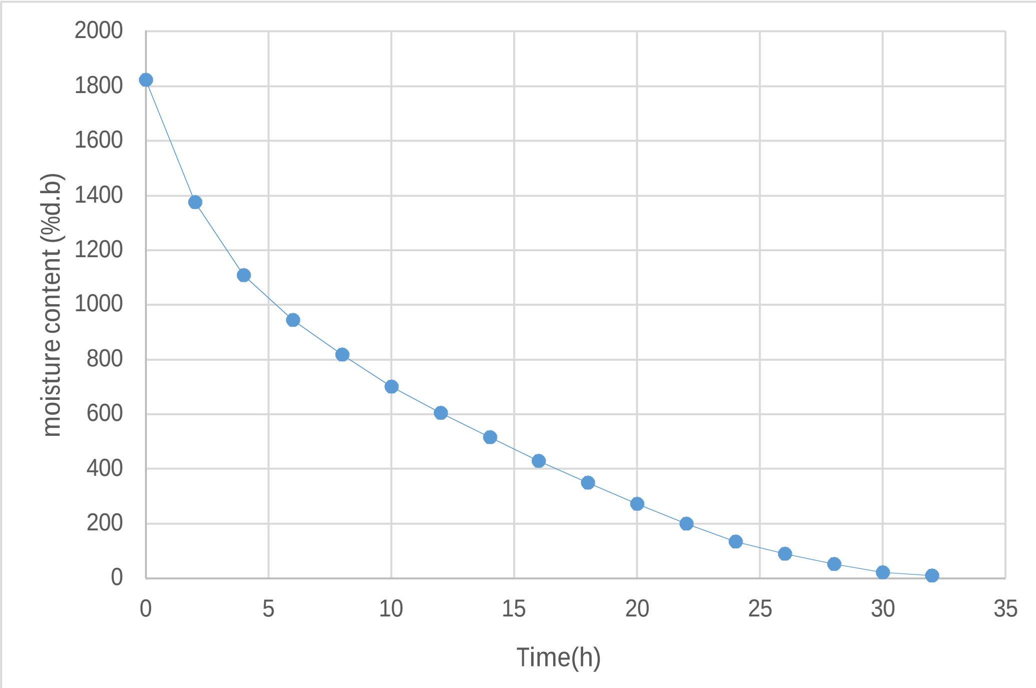

Fig 2b: Variation of Moisture content with time for untreated bottle gourd

B. Drying Rate

The constant drying rate is not found in any set of experimental data during the present research , Fig 3(a) & 3(b). Drying of bottle gourd occurred in the falling rate period as seen in table 2(a) and 2(b).

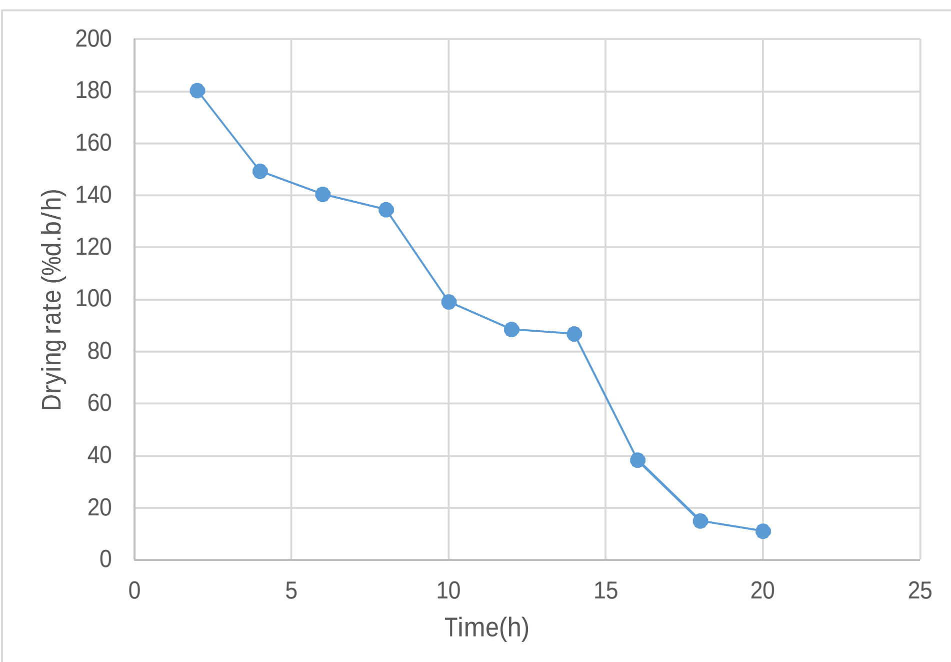

Fig 3a: variation of drying rate with time for treated bottle gourd

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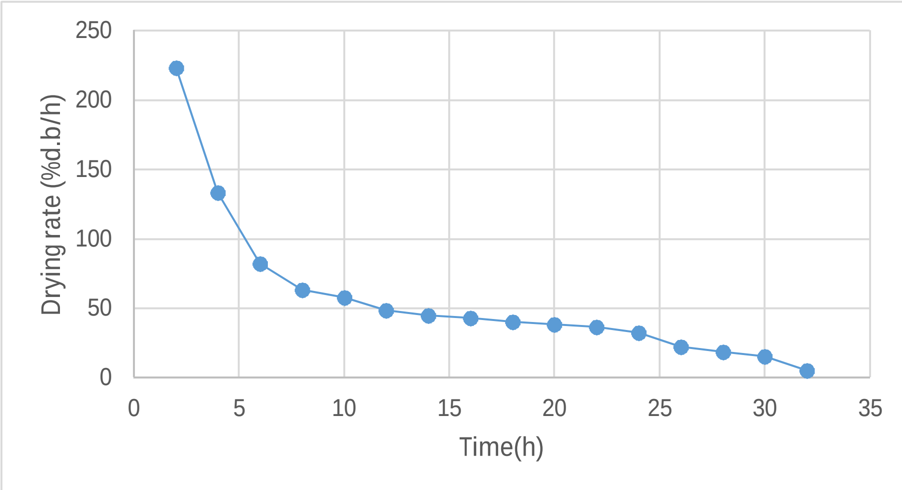


Fig 3b: variation of drying rate with time for untreated bottle gourd

Table 2a, Experimental data of drying treated bottle gourd

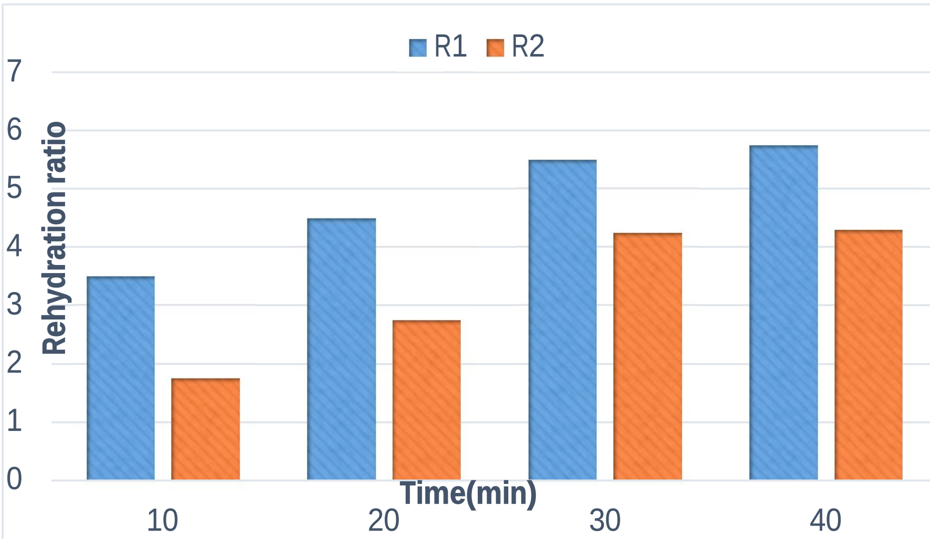
Time (h)	Moisture content (%d.b)	Drying rate(%d.b/h)
0	1823.07	
2	1462.13	180.38
4	1163.3	149.41
6	882.2	140.55
8	613	134.6
10	414.7	99.15
12	237.2	88.75
14	136.6	50.3
16	59.76	38.42
18	29.5	15.13
20	8.87	10.31

Table 2b, Experimental data of drying untreated bottle gourd

Time (h)	Moisture content (%d.b)	Drying rate(%d.b/h)
0	1823.07	
2	1376.1	223.48
4	1108.7	133.7
6	943.8	82.45
8	817.5	63.15
10	702.1	57.7
12	605.1	48.5
14	515.3	44.9
16	429.6	42.85
18	349.4	40.1
20	272.5	38.45
22	199.2	36.65
24	134.4	32.4
26	89.3	22.55
28	52.0	18.65
30	20.8	15.6
32	9.8	5.5

C. Rehydration Ratio

During the drying process cell rupture and dislocation takes place due to which the tissue integrity is lost and the capillaries shrink. It results in the reduced imbibitions of the water and leaves the unfilled pores (Krokida,2000). The rehydration ratios of pre-treated sample is found to be 3.5,4.5,5.5,5.75 and rehydration ratios of untreated sample are 1.75,2.75, 4.25,4.3 as seen in table 2c. It is observed that pre-treated samples resulted in highest rehydration(fig. 4)



R1= Rehydration ratio of treated sample
R2 = Rehydration ratio of untreated sample

Fig 4: variation of rehydration ratio with time

Table 2c, Rehydration data of untreated and treated dried bottle gourd

Time(min)	Rehydration ratio R1 (treated sample)	Rehydration ratio R2(untreated sample)
10	3.5	1.75
20	4.5	2.75
30	5.5	4.25
40	5.75	4.3

V. DRYER EVALUATION TESTS

The evaluation of the dryer is conducted under two distinct conditions ; the “no load” condition and “loading” condition.

A. No Load Condition

In the “no load” scenario, the dryers performance is assessed by monitoring the temperature and humidity levels both inside(without fan) and outside the dryer .Data logger is used inside and outside the dryer to monitor temperature and humidity as seen in table 3a. This assessment aimed to determine the suitability of the dryer for effectively drying bottle gourd .

B. Loading Condition

A quantity of 525g (un-treated) and 325 g(treated) of bottle gourd is loaded inside the dryer in separate trials and subjected to the drying process. Temperature and humidity levels are analyzed as seen in table 3(b) to 3(f). This analysis provided valuable insights into how the dryer functioned when actively drying a load, helping to guage its efficiency and effectiveness in reducing moisture from the loaded product. Moisture reduction, drying rate ,rehydration ratio are computed, and a comprehensive understanding of the dryers performance characteristics could be obtained , aiding in optimizing its operation for bottle gourd drying processes.

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VI. TEMPERATURE AND HUMIDITY DATA

Table 3a, variation of temperature and relative humidity during no load conditions
(date: 22/06/23)

Time	Ambient temperature (°C)	Temperature inside dryer(°C)	RH% inside dryer	RH% outside dryer
9:00 am	26	26	70	70
11:00 am	27	45	75	65
1:00 pm	28	52	79	67
3:00 pm	29	59	78	71
5:00 pm	30	60	79.8	63

Table 3b: Temperature and relative humidity under loading conditions (untreated bottle gourd).
Date :01/08/23

Time	Ambient temperature (°C)	Temperature inside dryer(°C)	RH%inside dryer	RH%outside dryer
9:00am	23	40	42	75
11:00am	29.3	48	33	71
1:00pm	32	60	28	69
3:00pm	29	57	30	74
5:00pm	27	43	49	72

Table 3c: Temperature and relative humidity under loading conditions(untreated bottle gourd).
Date :02/08/23

Time	Ambient temperature (°C)	Temperature inside dryer(°C)	RH%inside dryer	RH%outside dryer
9:00am	22	36	50	72
11:00am	27	50	41	76
1:00pm	34	60	28.2	70
3:00pm	30	59	27	69
5:00pm	29.5	60	28	68

Table 3d: Temperature and relative humidity under loading conditions(untreated bottle gourd).
Date :03/08/23

Time	Ambient temperature (°C)	Temperature inside dryer(°C)	RH%inside dryer	RH%outside dryer
9:00am	25	39	40	69
11:00am	27	49	32	70
1:00pm	30	59	28	70
3:00pm	31	60	27	71
5:00pm	30	43	45	70

Table 3e: Temperature and relative humidity under loading conditions(treated bottle gourd).
Date :10/08/23

Time	Ambient temperature (°C)	Temperature inside dryer(°C)	RH%inside dryer	RH%outside dryer
9:00am	24	37	41	75
11:00am	29	45	37	74
1:00pm	34	60	28	75
3:00pm	33	60	29	68
5:00pm	29	46	49	72

Table 3f; Temperature and relative humidity under loading conditions(treated bottle gourd).
Date :11/08/23

Time	Ambient temperature (°C)	Temperature inside dryer(°C)	RH%inside dryer	RH%outside dryer
9:00am	22	40	40.5	69
11:00am	31	53	49	71
1:00pm	32	60	27	76
3:00pm	30	60	29	70
5:00pm	28	50	43	73

VII. DRYER COST

The cost of the solar dryer is detailed in table 4. It includes various elements required for the construction of solar dryer , each with its respective quantity and unit price.The operational efficiency of the solar dryer relies on a wide range of factors and the advantages it offers. Importantly , the dryer does not entail any maintenance expenses during or after its operation.

Table 4 Cost of the dryer

S.no	Name of the component	Quantity	Unit price(Rs)
1	PPR pipes	3 pipes	240/pc
2	PPR fitting elbow 25 mm	10 pcs	12/pc
3	PPR fitting tee 25 mm	10 pcs	25/pc
4	Polyethylene sheet	1.3m^2	82/m^2
5	Aluminium sheet	2'×3'	50/ft
6	Temperature humidity controller	1	465
7	Exhaust fan DC (12 V)	-	120
8	Battery (12 V, 7 Ah)	-	950
9	Solar panel (10 W)	-	1200
10	Solar charge controller (12 V)	-	354
11	Connecting Wires	-	60
	Total cost		~4700/=

VIII. CONCLUSION

The study involved a two-fold investigation, focusing on both the drying process itself and the efficacy of the solar dryer in facilitating this process. The initial phase of the research involved the assessment of bottle gourd drying characteristics. Through experimental trials, the moisture content and drying rate are tracked at regular intervals during the drying process. The study revealed valuable insights into the drying behaviour of bottle gourd, shedding light on its moisture reduction patterns and the interplay of various process variables.

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It is observed that temperature inside the dryer increased upto 60°C and relative humidity is reduced upto 27%, The treated bottle gourd took 35.48% less time to dry compared to the untreated bottle gourd. The moisture content in %d.b of untreated bottle gourd is reduced to 9.8% while as in pre-treated bottle gourd , moisture content is reduced to 8.8%. Cost of the dryer can further be reduced as there is no need of battery during daytime and the whole system can function directly from solar panel.

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