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Performance of Evacuated Tube Collector Solar Dryer with and Without Heat Sources

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Abstract: The objective of present study is to design and fabricate a solar dryer with evacuated tube collector with and without heat storage material (gravel). The performance of solar dryerfor drying chilli under the meteorological condition of Thanjavur, Tamilnadu, India was investigated. The designed dryer compared with natural sun drying. Drying of chilli in the designed dryer reduced the average initial moisture content from87.36% to a final moisture content of 3.4% in10hours with heat storage material against 12 hours in the dryer without heat storage material and 32 hours in natural sun drying.The designed dryer reduced the duration of drying period up to 66%. The efficiency of the dryerwith heat storage material, without heat storage material and natural sun drying are found to be 34.23, 22.03 and 9.32%, respectively. The specific moisture extraction ratio of the designed dryer with heat storage material is 0.345 kg/kWh.The quality of the dried chilli in the designed solar dryer is high in terms of colour, odour and flavour. From the performance, quality and quick rate of drying it is evident that solar dryer with evacuated tube collector assisted with heat storage materialis more compatible than other modes of drying.

Key words: Solar dryer · Evacuated tube collector · Chilli · Moisture content · Specific moisture extraction ratio · Efficiency

INTRODUCTION

Agriculture is considered to be the backbone of Indian economy as 65-70%of the population depend on agriculture for employment and livelihood. But, yet the national food production could not meet the needs of the population. It is found that, post harvest loss of fruits and vegetables are high. Improper preservation of seasonal agricultural products and depleting energy reserves cause considerable loss, thereby reducing the food supply significantly.

At the time of harvesting, most of the agricultural products have high moisture content. Agricultural products, if left as such will biologically degrade due to the growth of microorganisms. So, to preserve them for future purpose and to make it available throughout the year proper preserving technique is to be adopted.

Drying is a method of food preservation which can improve the shelf life of agricultural products mainly fruits and vegetables. Drying reduces moisture content of a product to a level below which deterioration does not occur and thus prevents fermentation or growth of moulds[1].Products after drying process fetch a better market price. Thus, drying helps the farmers to secure a greater economic return which in turn enhance the economy of the nation [2].

The disadvantages of traditional sun drying are contamination by dirt, insects, dust, rain etc [3-5]. Also, it requires continuous monitoring throughout the drying period, to safeguard the product when the weather becomes worse and to protect it from domestic animals. Also, the product dried is found to be unhygienic and the quality of the product is very poor [6].

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Several attempts to improve sun drying have introduced solar dryers for agricultural applications as a promising alternatethat shows increased dryer efficiency [7-10]. Several research and performance studies on solar dryer with flat plate collectors [11, 12] andheat storage material [13-16] have been reported aiming at the improvement of the traditional drying systems.

From the literature, it is found that solar dryer with collector is one of the best type of drying techniques to dry fruits and vegetables. Also, it is observed that most of the dryers use only flat plate collectors. But the evacuated tube collector has many advantages in compare to flat plate collectors such as high efficiency and performance even in bad weather [17-19].A few experimental studies have been conducted on solar evacuated tube dryers; thus, in this research work, an attempt has been made to design and develop a novel solar dryer with evacuated tube collector. The performance of fabricated dryer forchilliwith and without heat storage material (gravel) were compared to natural sun drying in Thanjavur, Tamilnadu, India. Experiments were performed in 3 months (from March to May 2013) and the drying characteristics of chilli are discussed in present study.

MATERIALS AND METHODS

Experimental Set-up: The designed solar dryer consists of a drying chamber, evacuated tube solar collector, a blower and a chimney. The schematic diagram of the solar dryer is shown in Fig. 1. The cubical drying chamber with dimensions of45x45x45 cm is made of stainless steel sheets of thickness 25mm and insulated on all sides with rockwool slab of thickness 50mm compressed to 40mm to prevent heat loss. Dryer consists of three perforated trays made of aluminiumto place the sample. The dryer is capable of drying 1.5 kg of chilli per batch.

The solar dryer consists of six evacuated tube solar collector with a copper header for heat exchange. This evacuated tube solar collector which is used as air heater is connected to the drying chamber with the help of EPDM (Ethylene Propylene Diene Monomer) rubber hose. The twin glass evacuated tube collector is made of borosilicate of 1.6mm thickness and the gap between the glass tubes is evacuated. The inner tube of the collector is coated with a three layer magnetron sputter coating (SS - Al N/Cu). With application of present drying technology the heat losses due to convection, conduction and radiation are minimized and also it can withstand high temperature. The length, inner diameter and outer diameter of each tube are found to be1500, 37 and 47mm, respectively. The collector is placed at optimum angle in accordance with the latitude of Thanjavur district (10°45’ N), Tamilnadu along N-S direction, facing south so as to track maximum solar radiation throughout the day.

A blower motor of 0.335 KW, 1300rpm with a regulator to control the air flow rateinstalled at inlet of the solar collector to blow air into the collector.

A chimney of 100cm height made of standard wire gauge (SWG) galvanised (Gl) sheet is used at the top of the chamber which increases the air flow rate inside the chamber under the convective principle of rising hot air.

Single layer rock bed (gravel) which is used as heat storage material is uniformly spread on the lower part of the drying chamber. The measurements of the design parameters of the designed solar dryer are summarized in Table 1.

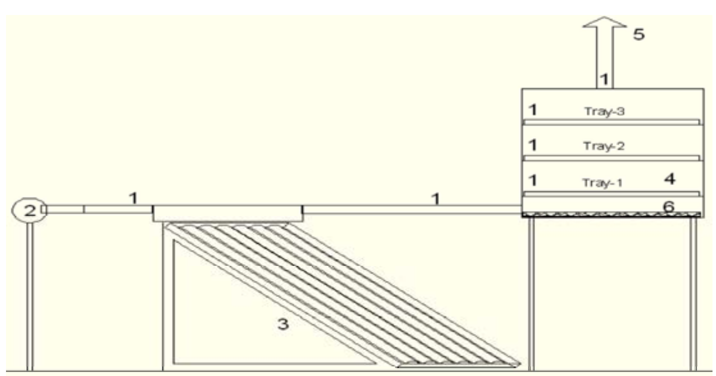

Fig. 1: Schematic diagram of the experimental set-up 1. Temperature sensors; 2. Blower; 3. Evacuated tube collector; 4. Drying chamber; 5.Chimney; 6. Gravel

Table 1: The measurements of the design parameters of the fabricated solar dryer

Design Parameter of the Solar Drying System	Measurement
Surface area of the evacuated tube collector	$0.409m^2$
Volume of the Drying Chamber	$0.091m^3$
Surface Area / Volume Ratio	4.48
Latitude of Thanjavur	10°45'N
Collector slope (Latitude of the location +15°)	25°45'

Instrumentations and Devices: Temperature at various locations (Inlet and outlet temperature of the collector, temperature of all the trays inside the chamber, temperature of the chimney) is measured with the help of RTD (Resistance Temperature Detector) PT100 sensor (6 nos.) connected to SELEC 303 temperature controller and display unit. The ambient temperature, relative humidity and wind speed are measured using a digital anemometer (MASTECH MS 6252B). A humidity meter is used to measure the humidity at the entry and exit of the dryer (± 1% accuracy). Solar insulation is measured using a solar power meter (TES-1333). A digital electronic balance is used for weighing the samples (D-Sonic Digital scale: ± 0.1g accuracy).

Experimental Procedure: Solar drying with and without heat storage material and natural sun drying experiments were carried out for drying chilli under the meteorological conditions of Thanjavur, Tamilnadu (India).

A 200g of fresh and good quality chilli is taken and maintained at a temperature of 105°C for 24 hours in hot air oven and its initial moisture content is determined.

When the blower motor is switched on the air is passed through the evacuated tube solar collector and heated up. This hot air is made to flow into the drying chamber.

Initially, from 8.00am to 9.00am the blower motor is switched on without any load so that the rock bed (gravel) gains heat. At 9.00am the chilli is loaded uniformly over the trays of the drying chamber and the blower motor is switched on. During the sunshine period (9.00am to 5.00pm) the rock bed (gravel) stores the heat energy and during off sunshine period (5.00pm to 7.00pm) the stored heat energy is used to remove the moisture of the sample. During inactive period (7.00pm to 9.00am) the sample is kept in an air tight packet to avoid gain of moisture from surroundings.

During the experiment, ambient temperature, relative humidity and wind velocity, solar insulation, inlet and outlet temperatures of the collector, temperature of all the trays inside the chamber, temperature of the chimney were recorded on hourly basis from 9.00am to 5.00pm. During the experiment, all the drying trays are weighed on hourly basis until the product acquires constant weight that is equilibrium moisture content.

The entire experiment is also performed without heat storage material and under natural sun drying.

Determination of Moisture Content: The initial mass (m_i) and the final mass (m_f) of the sample were recorded at an interval of 1hour till the end of drying using a reliable balance. The moisture content on wet basis (M_{wb}) is given as follows [3, 7, 9]:

$$M_{wb} = \frac{m_i - m_t}{m_i} \quad (1)$$

Determination of Moisture Ratio: The moisture ratio is given as follows[5]:

$$MR = \frac{M - M_e}{M_O - M_e} \quad (2)$$

Where:

M is the moisture content at any time, M_e is the equilibrium moisture content M_0 is the initial moisture content of chilli.

Determination of Moisture Loss: The moisture loss is given as follows [5]:

$$ML = M_i - M_f \quad (3)$$

where,M_i is the mass of the sample before drying and M_f is the mass of the sample after drying.

Determination of Specific Moisture Extraction Ratio: The specific moisture extraction ratio which is the energy required to remove one kg of water is given as follows [13]:

$$SMER = \frac{m_d}{p_d} \quad (4)$$

Where: m_d is the final mass of the sample at any time and P_d is the blower power (kWh).

Determinationof Dryer Efficiency: Efficiency of a solar dryer is calculated as follows [3, 7]:

$$SMER = \frac{m_d}{p_d} \quad (5)$$

Where: M is the mass of the water evaporated from the crop, L is the latent heat of vaporization of water,I is the solar insulation, t is the time of drying and A is the effective area of the collector.

RESULT AND DISCUSSION

The initial moisture content of the ginger is 83.25% (wb), is determined by keeping 200gm of the sample in hot air oven at 105°C for 24 hours.

At first, the designed solar dryer is tested without any load. It is observed that the temperature inside the drying chamber is uniform under unloaded condition.

Variation of solar insulation, ambient temperature (Amb), inlet and outlet temperatures of the Evacuated Tube Collector (ETC in and ETC out), Temperatures of lower tray, middle tray and upper tray are recorded on hourly basis during the entire experimental period (Tables 2 and 3).

During the experimental period, the solar insulation varied from 225.2 to 1084W/m^2; the ambient temperature and the outlet temperature of the evacuated tube collector varied from 31 to 36°C and 44 to 142°C, respectively. From Tables 2 and 3, it was found that temperature from the outlet of evacuated tube collector (ETC out) was very high in compared to ambient temperature. This indicates that the performance of solar dryer is much better than the performance of natural drying. It is also found that the temperature of lower tray is slightly higher than middle tray and upper tray. Also, it was found that the solar insulation is high during mid-noon and the dryer is hot during this period when the sun is overhead.

Fig. 2 shows the variation of moisture loss vs. drying time for solar drying of chilli with and without heat storage material. From the figure it is clear that as moisture loss is more for dryer with heat storage material, the performance of the dryer would be better if heat storage material is used.

Variation of moisture content (%wb) with respect to drying time for sun drying and solar drying of chilli with and without heat storage material is shown in Fig. 3. It is seen that moisture removal is initially high and then gets reduced exponentially. This is because of the removal of moisture from the surface first followed by the movement of moisture from internal part of the product to its surface.

The average initial moisture content of chilli is about 87.36% and the average final moisture content is about 3.4%. The drying time required to reach equilibrium moisture content is 10 hours for solar dryer with heat storage material, 12 hours without heat storage material and 32 hours for natural sun drying. The designed dryer reduces the drying period up to 66%.

Table 2: Hourly variation of solar insulation, wind velocity, relative humidity and temperature at different points recorded for solar drying of chilli with heat storage material

				Temperature (°C)						
Time	Solar Insulation W/m^2	Wind velocity m/s	RH %	Amb. T0	ETC in T1	ETC out T2	Tray 1 T3	Tray2 T4	Tray3 T5	Chim. T6
Day 1 9.00	363.3	2.04	47.5	33.5	49	56	46	45	45	44
10.00	414.4	2.44	47	33.5	50	72	53	53	53	51
11.00	538.9	2.08	44.7	34.2	51	89	61	60	60	58
12.00	681	1.28	43.2	34.5	52	99	65	64	64	63
13.00	752	1.85	43.7	35	53	108	69	68	67	67
14.00	690	1.33	37.7	35.5	54	105	70	70	69	67
15.00	618	1.42	23.5	35.7	56	105	71	70	70	68
16.00	334.5	1.9	38.7	35.5	54	92	64	63	63	61
17.00	228.6	1.61	52.5	35.7	51	82	58	57	57	55
Day 2 9.00	230.1	0.36	48.7	36	42	65	39	38	39	38
10.00	364.5	2	48.5	33.7	56	73	54	53	53	52
11.00	602.4	0.9	45.7	34.5	58	91	65	63	64	63
12.00	707.2	0.09	46	34.7	59	100	67	65	66	65
13.00	720	0.27	42	35.5	60	107	72	71	70	70
14.00	736.5	0.36	52	35.5	62	108	72	72	72	71

Table 3: Hourly variation of solar insulation, wind velocity, relative humidity and temperature at different points recorded for solar drying of chilli without heat storage material

				Temperature (°C)						
Time	Solar Insulation W/m^2	Wind velocity m/s	RH %	Amb. T0	ETC in T1	ETC out T2	Tray 1 T3	Tray2 T4	Tray3 T5	Chim. T6
Day 1 9.00	225.2	2.98	41.2	33	44	58	41	40	41	41
10.00	357.9	1.04	48	34.5	47	99	62	61	61	60
11.00	532.5	0.36	53.6	32.7	50	105	64	60	61	62
12.00	611.2	0.18	52	31	52	115	67	61	63	64
13.00	886	1.76	50	33.2	53	119	76	75	73	73
14.00	1002	1	46.2	34.7	57	131	81	80	78	78
15.00	889.1	1.9	47.5	33.7	57	109	74	72	70	71
16.00	610.9	1.8	47.2	33.7	50	108	69	64	65	65
17.00	363.8	0.36	47.7	33.7	49	91	63	62	61	60
Day 2 9.00	382.4	1.76	52.6	34.7	41	44	37	36	37	38
10.00	422.1	0.36	54.5	33.2	46	89	57	56	56	56
11.00	821.2	0.36	54	33.2	54	110	73	72	71	70
12.00	1026	1.61	52.7	33.7	55	126	77	78	76	75
13.00	1084	1.47	50	34.5	57	139	85	79	81	81
14.00	1067	0.18	43.7	35	54	142	84	81	79	81
15.00	935.4	0.09	45	34.5	52	142	81	76	76	79
16.00	746.2	2	44.2	35	50	123	75	70	71	72
17.00	438.3	1	51	34.5	53	97	67	66	64	64

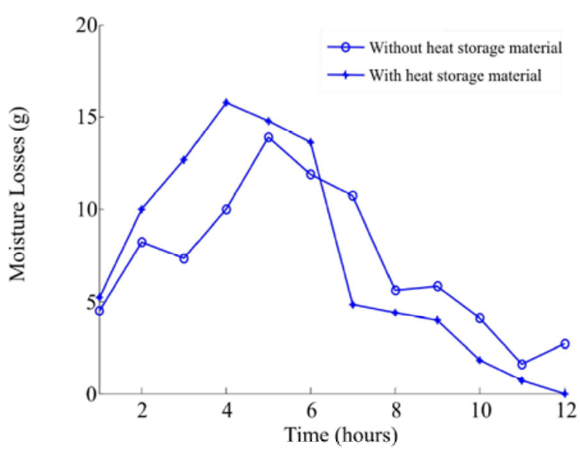

Fig. 2: Variation of moisture loss vs. drying time for solar drying of chilli with and without heat storage material

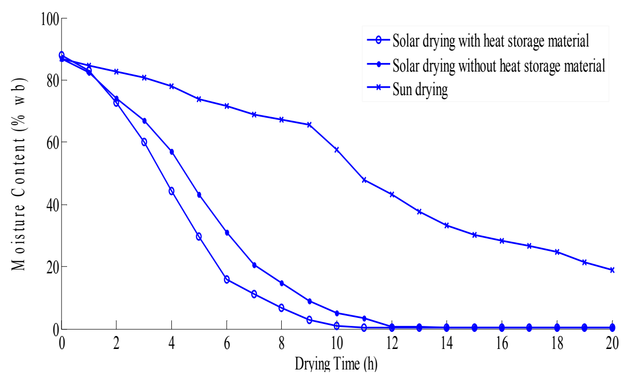

Fig. 3: Variation of moisture content (%wb) with respect to drying time for sun drying and solar drying of chilli with and without heat storage material

The specific moisture extraction ratio for sun drying, solar drying without heat storage material and solar drying with heat storage material are found to be 0.108, 0.288 and 0.345 kg/kWh, respectively.

Comparison of efficiency of the dryer for three different modes of solar drying of chilli is shown in Fig.4. The average efficiency of the dryer with heat storage material, without heat storage material and natural sun drying are found to be 34.23, 22.03 and 9.32% respectively.

As solar drying is free from dust, contamination and is protected against rain, birds and insects, the quality of the solar dried chilli is higher than the natural sun dried one. The labour required in solar drying is also less as compared to sun drying. The natural colour and the appearance of chilli are maintained more when dried in a solar dryer as compared to the sun dried one. Also, the odour and flavour of the solar dried chilli is more satisfactory than the natural sun dried chilli.

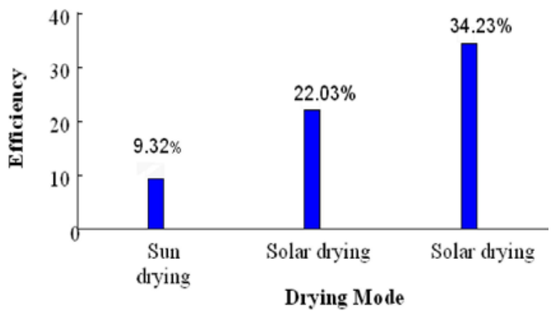

Fig. 4: Comparison of efficiency of the dryerfor three different modes for solar drying of chilli

CONCLUSION

The newly designed solar dryer with evacuated tube collector considerably reduces the drying period of chilli. The use of heat storage material still reduces the drying period of the newly designed dryer. The time taken by the solar dryer is one-thirdof the time taken by natural sun drying. The efficiency of the solar dryerwith heat storage material is higher than the efficiency of the solar dryer without heat storage material.Similarly, the moisture loss and specific moisture extraction ratio are higher for the designed solar dryer with heat storage material than without heat storage material. The quality of the solar dried chilli using the designed dryer is high in terms of colour, flavour and appearance as compared to the natural sun dried one. As the dryer makes use of evacuated tube collector, it can perform better during winter season and off-sunshine period than the dryer that makes use of flat plate collector. The drying process can be controlled in the designed dryer.It is also evident that the thermal storage material helps in improving the performance of the solar dryer with evacuated tube collector. This dryer can be used to dry any agricultural product and product that cannot be dried under natural sun drying.Solar dried product meets the standard of exporting and farmers can make a good profit. This type of solar dryers can play a major role in improving the economic growth of a nation.

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Persian Abstract

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چکیده

هدف این تحقیق طراحی و ساخت یک خشک کن خورشیدی مجهز به کولکتور لوله‌ای خلا با و بدون مواد ذخیره سازی انرژی حرارتی (سنگریزه) می باشد. عملکرد خشک کن خورشیدی برای خشک کردن ادویه جات در شرایط آب و هوایی هند (تنجاور، تامیلنادو) بررسی شد. خشک کن طراحی شده با خشک کردن تحت شرایط نور خورشید مقایسه شد. برای خشک کردن ادویه جات در خشک کن طراحی شده با میانگین رطوبت اولیه ۸۷/۳۶ درصد و رطوبت نهایی ۳/۴ درصد، با مواد ذخیره سازی انرژی حرارتی برای مدت زمان ۱۰ ساعت و در حالت بدون مواد ذخیره سازی انرژی حرارتی مدت ۱۲ ساعت و تحت نور خورشید به مدت ۳۲ ساعت به طول انجامید. خشک کن طراحی شده موفق به کاهش زمان خشک کردن به میزان ۶۶ درصد گردید. راندمان خشک کن با مواد ذخیره سازی انرژی حرارتی (۳۴/۲۳ درصد) و بدون مواد ذخیره سازی انرژی حرارتی (۲۲/۰۳ درصد) و تحت شرایط نور خورشید (۹/۳۲ درصد) گزارش گردید. نسبت استخراج رطوبت ویژه برای خشک کن با مواد ذخیره سازی انرژی حرارتی ۰/۳۴۵ kg/kWh بوده است. کیفیت ادویه جات خشک شده در خشک کن خورشیدی طراحی شده از نظر رنگ، بو و طعم بالا بود. عملکرد، کیفیت و سرعت بالای خشک کردن نشان داد که خشک کن خورشیدی مجهز به کولکتور لوله‌ای خلا با استفاده از مواد ذخیره سازی انرژی حرارتی نسبت به روش های دیگر خشک کردن برتری قابل ملاحظه‌ای دارد.