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Performance of forced convection type solar drier with thermal storage for ginger drying

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■ **ABSTRACT :** Thermal energy storage is one of the most efficient ways to store solar energy for heating air by energy collected from sun. An indirect forced convection solar drier with thermal storage has been developed and tested its performance for drying ginger under the metrological conditions of Udaipur, India. Agricultural food materials can be dried at late evening, while late evening drying was not possible with a normal solar dryer. So that, solar dryer with storage unit is very beneficial for the humans and as well as for the energy conservation. The system consisted of a flat plate solar air collector, heat storage unit, a drying chamber and a DC fan. Drying experiments have been performed at an air flow rate of 0.0025 kg/s. Drying of ginger rhizomes in a forced convection solar drier reduces the moisture content from around 84 per cent (wet basis) to the final moisture content about 9.63 per cent in 36 h. Average drier efficiency was estimated to be about 30 per cent.

■ **KEY WORDS :** Solar drier, Ginger drying, Heat storage material

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In India, sun drying is the most commonly used method to dry the agricultural materials like grains, fruits and vegetables. In sun drying, the crop is spread in a thin layer on the ground and exposed directly to solar radiation and other ambient conditions. The rate of drying depends on various parameters such as solar radiation, ambient temperature, wind velocity, relative humidity, initial moisture content, type of crops, crop absorptivity and mass of product per unit exposed area. This form of drying has many drawbacks such as degradation by wind blown, debris, rain, insect infestation, human and animal interference that will result in contamination of the product. Drying rate will reduce due to intermittent sunshine, interruption and wetting by rain (Jain *et al.,* 2004).

Solar thermal technologies have been used in various applications either, as natural convection type dryer, or with forced convection type dryer (Das and Sarma, 2001). For commercial applications, the ability of the drier to process continuously throughout the day is very important to dry the products to its safe storage level and to maintain the quality. Normally thermal storage systems are employed to store thermal energy, which includes sensible heat storage, chemical energy storage and latent heat storage.

The solar drier is an energy efficient option in the drying processes. Many experimental studies reported the various methods used for drying of agricultural materials using solar drier for copra drying, for onion drying, and for pineapple drying. Use of forced convection solar driers with thermal storage seems to be an advantage compared to traditional methods and improves the quality of the product considerably. Normally thermal storage systems are employed to store the heat, which includes sensible and latent heat storage. Common sensible heat storage materials used to store the sensible heat are water, gravel bed, sand, clay, concrete, etc.

The objective of the present work is to develop a forced convection solar drier with thermal storage for drying of ginger under the metrological conditions of Udaipur, India. The experiment was conducted in April 2012. The performance of a forced convection solar drier with rock as heat storage material and drying characteristics of ginger rhizomes are discussed in this paper.

■ METHODOLOGY

Fabrication and dimensional features of dryer (Fig. A and B):

Frame structure :

The frame structure consisted of legs, base frame and supporting frame. MS angle of 30 x 30 x 5 mm was used to

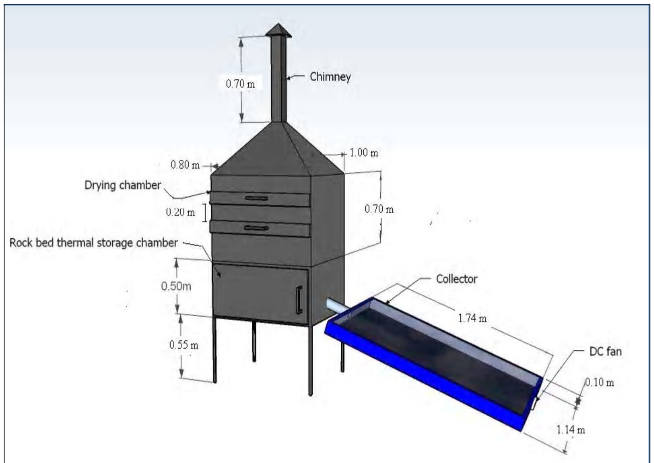

Fig. A: Schematic diagram of forced convective dryer with thermal storage

Fig. B: Pictorial view of experimental set up

fabricate the legs, base frame and supporting frame. This frame structure was mounted on four legs of 0.55 m height.

Insulation :

The sides of dryer (Heat storage) is insulated with 2.5 cm thick glass wool sandwiched between 24 swg GI sheet and MS Sheet.

Rock bed thermal storage :

The rock bed of 0.15 m^3 was used as thermal storage for supplying the energy for 2 hours. The rock bed was placed below the drying chamber and connected to collector. The main purpose of storage was to supply the energy after noon when the insolation starts decreasing and when there is cloud cover for short period. The bed got charged by the hot air from collector during 8 hours of operation. The dimension of thermal storage chamber was 1.0×0.8×0.5 m.

Drying chamber :

The drying chamber consisted of the trays *i.e.* product

Table A : Design conditions and assumptions

Items	Condition or assumptions
Location	Udaipur (27°42' N, 75°33' E)
Capacity	20 kg fresh ginger
Loading rate (L_r) in each tray	10 kg
No. of trays	2
Initial moisture content (m_i)	84%
Final moisture content (m_f)	10%
Ambient temperature (T_a)	30°C
Ambient relative humidity (RH)	25%
Drying temperature (T_d)	60°C
Sunshine hours	10 h
Drying time (t_d)	8 h
Storage backup time	2 h
Solar insolation (I_t)	853 W/m^2
Dryer efficiency (η)	30 %
Density of ambient air, ρ_a	1.252 kg/ m^3
Density of product, ρ	500 kg/m^3
Density of rock, ρ_r	2500 kg/m^3
Specific heat of rock, C_{pr}	0.84 kJ/kg° c
Specific heat of ambient air, C_{pa}	1.005 kJ/kg° c
Height of chimney (H)	0.70 m

holder made of wire mesh fitted in aluminum angle frame of 50 x 50 x 3 mm. There were 2 trays each having 10 kg capacity. The heated air supplied by thermal storage from solar collector and exhausted at another end. Thus, the air is circulated within the product. The dimension of drying chamber was 1.0 x 0.8×0.7 m and the height of product holder was kept 5 cm.

Air circulation unit :

The air circulation unit consisted of fan. The fan was placed at the collector inlet to increase the air flow rate and pass through collector to the drying chamber. Therefore, DC fan of 12 V, 0.25 A with flow rate of 120-180 m^3/h was selected. It was operated on 10 W_p SPV panel to avoid the dependence on electricity.

Design procedure :

Mass of water to be removed during drying, M_w (kg)

$$M_w = \frac{m_i - m_f}{100 - m_f} \times W$$

Mass of water removed per hour, m_w (kg/h)

$$m_w = \frac{M_w}{t_d}$$

Total energy required, Q (kJ)

$$Q = W \times C_p \times (T_d - T_a) + (M_w \times \lambda)$$

Energy required per hour, Q_t (kJ/h)

$$Q_t = \frac{Q}{t_d}$$

Design of thermal storage

The amount of energy to store in packed bed, Q_s (kJ)

$$Q_s = Q_t \times t_s$$

where,

Q_t= Energy required per hour, kJ/h

t_s =Storage back up time, hour

The volume of storage bed, V_s (m^3)

$$V_s = \frac{Q_s}{\rho_r \times C_{pr} \times (T_d - T_a)}$$

Design of chimney :

Rate of air needed to absorb m_w kg of water, per hour

$$Q_a = \frac{m_w \times \lambda}{C_{pa} \times \rho_a \times (T_e - T_a)}$$

Now, Q_a (m^3) amount of moist air is needed to be removed in 8 hours. Therefore, the rate at which moist air is to be removed is given by q_a

$$q_a = Q_a / (8 \times 60 \times 60), m^3/s$$

Draft produced if we assume height of chimney, H by 0.70 m

$$D_i = H_g (\rho_a - \rho_e)$$

But actual araft D_a =0.40 x D_i

Velocity of exit air, $v = \sqrt{\frac{2D_a}{\rho_e}}, m/s$

Thus, if assumed this exit air is being carried out by one chimney

$$Q_c = q_a$$

Area of chimney

$$A = \frac{Q_c}{V \times k}$$

Instrumentation and experiments :

For drying ginger rhizomes at commercial level experiments were conducted during the typical day of summer months of 2012. The system is oriented to face south to maximize the solar radiation incident on the dryer. The global solar radiation incident on a horizontal surface is measured using a Digital Solarimeter. Wind speed and exit air velocity at chimney outlet are measured by using Lutron Anemometer Model no. AM-4822 and hot wire anemometer Model no. LM-4204, respectively. Calibrated NiCr–Ni thermocouples connected to a multi-channel Emcon—Digital Solar Data Monitor (Environmental Measurement and control, Cochin) were used to measure the temperatures at different locations of dryer, e.g. dryer inlet, dryer outlet and ambient. The temperatures of the different parts of the system were measured after every one hour. The ambient temperatures were also recorded; the moisture contents of product during drying are measured on the dry basis.

■ RESULTS AND DISCUSSION

The results of the present study as well as relevant discussions have been presented under following sub heads:

Performance of the dryer :

The testing on no load and full load were made for summer seasons. The average temperature inside the dryer was 18–20^{0}C higher than the ambient temperature. The moisture content of the ginger was reduced to around 10 per cent from an initial value of 84 per cent in four day. Temperature variation during no load testing in forced convection solar dryer with thermal storage on a typical day of month (11 April 2012) at different locations inside the dryer and the outside is graphically illustrated in Fig.1, respectively.

It is observed from the Fig.1that the maximum temperature inside the solar dryer on a typical day was 69.5^{0}C at 13:00 h while the minimum temperature was 36.7^{0}C at 9.00 h. The maximum ambient temperature recorded was 38^{0}C at 13.00 h, while minimum ambient temperature was 27.8^{0}C at 9.00 h.

In full load test the maximum temperature inside the solar dryer was 71.2^{0}C at 13.00 h while the minimum temperature was 36.3^{0}C at 9.00 h (16 April 2012) as illustrated in Fig. 2. The maximum ambient temperature recorded on this day was 38.2^0 C at 13.00 h and minimum ambient temperature was 27.8^{0}C at 9.00 h.

It was observed that the drying chamber outlet temperature was lower than that of drying chamber inlet temperature and the relative humidity of drying chamber outlet was more than drying chamber inlet. This was due to addition of water vapors into heated air. In the last hours of drying the

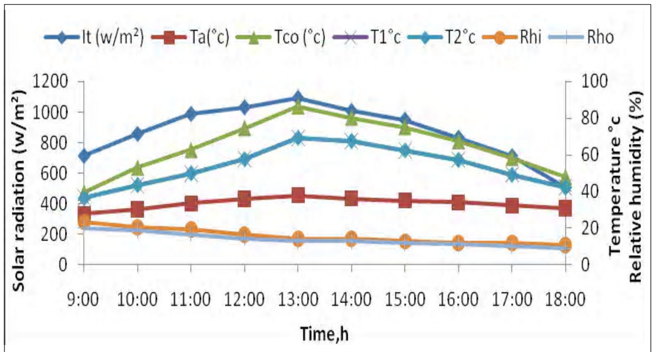

Fig. 1: Temperature variation at no load

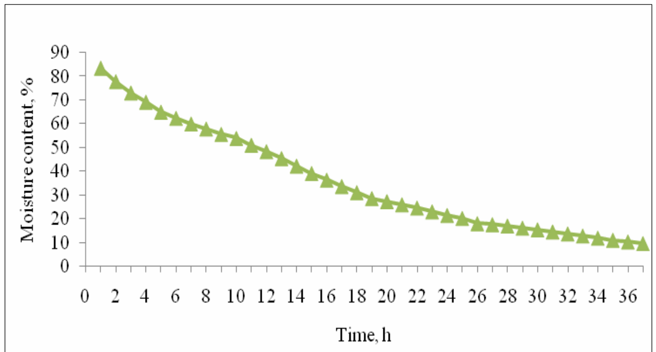

Fig. 3: Variation of moisture content against drying time

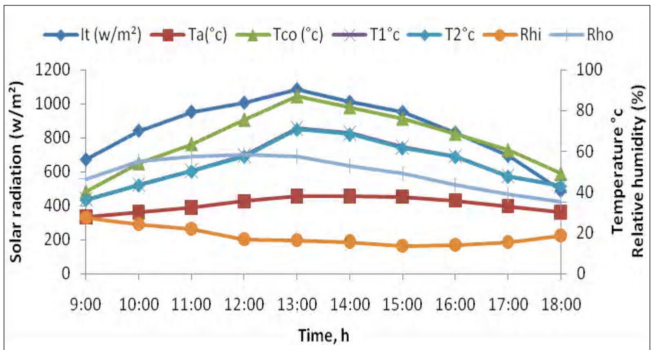

Fig. 2: Temperature variation at full load

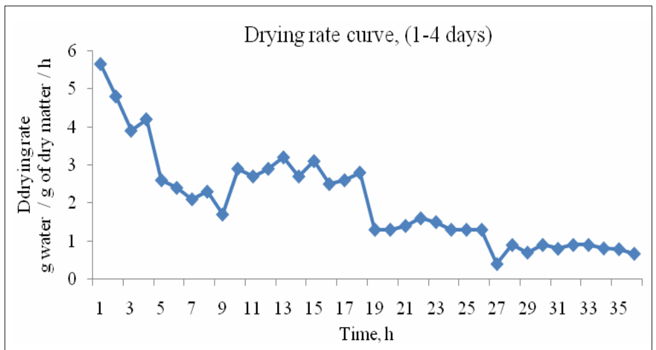

Fig. 4: Variation of drying rate against drying time

Table 1 : Dimensions of solar dryer

So. No.	Description	Result obtained	Unit
1.	Total quantity of water in product	16.8	kg
2.	Bone dry weight of material	3.27	kg
3.	Quantity of water to be evaporated	16.36	kg
4.	Drying area	0.8	m^2
5.	Velocity of exit air	0.4	m/s
6.	Diameter of chimney	0.10	m
7.	Height of chimney	0.70	m

Table 2 : Economic indicator for forced convection type solar drying system

Sr. No.	Economic indicator	Value
1.	Net present worth	2,47,120
2.	B/C ratio	1.78
3.	Payback period	5 month
4.	IRR	36.5 %

difference between drying chamber inlet and outlet temperature and relative humidity was decreased. It was an indication of drying of ginger rhizomes.

Fig. 2 shows the variation of solar intensity and ambient relative humidity during experimentation. Maximum solar intensity recorded was about 1085 W/m^2 during peak sunshine hours. In the drying chamber outlet, a high relative humidity of about 58 per cent was recorded during initial stages of drying and gradually reduced to about 35 per cent at the end of drying.

The result of moisture content with time is presented graphically in Fig. 3. The initial moisture content of ginger rhizome was 84 per cent (w.b.). At the end of the first day it was reduced to 54 per cent. On second day the moisture content at the end of the day was 29 per cent. On third day moisture content at the end of the day was 17.2 per cent. At the end of fourth day moisture content reduced to 9.63 per cent which is the safe for storage of ginger for about 8 to 10 months.

Fig. 4 shows the variation of drying rate against drying time. High drying rate (of about 5.6 g/g of dry matter/h) was observed during the initial stages of drying. Drying rate gets decreased with increase in drying time.

Economic analysis

- The life of solar dryer is 10 years (n).
- The discount rate is assumed to be 10 %.
- The annual repair and maintenance cost is 2 % of cost.
- The cost of fresh ginger is Rs. 30/ kg.
- The cost of dried ginger rhizomes is Rs. 400/kg.
- Labour cost: One person can be involved to dry ginger rhizomes so labour charges for one person (@ 25 Rs./hr each) will be considered.
- The dryer can be operated 300 days in a year.

Cost for material and construction of the solar dryer for drying 20 kg of ginger rhizome in a dryer was estimated as around 14,500.

Conclusion :

The performance of an indirect forced convection solar drier with thermal storage was designed, fabricated and investigated for ginger drying. The drier with thermal storage material enables to maintain consistent air temperature inside the drier. The inclusion of heat storage material also increases the drying time by about 2 h per day. The ginger was dried from initial moisture content 84 per cent to the final moisture content about 9.63 per cent. It could be concluded that, forced convection solar drier is more suitable for producing high quality dried ginger for small holders. Thermal efficiency of the solar drier was estimated to be about 24 per cent.

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