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INVESTIGATION ON DRYING KINETICS AND TECHNO-ECONOMICS OF SOLAR-BIOMASS HYBRID DRYING SYSTEM

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Abstract

A solar-biomass hybrid dryer was designed and fabricated in the Dept. of UCES & EE, Dr. PDKV, Akola. A biomass combustor was retrofitted to natural convection solar tunnel dryer utilized solar energy for drying of turmeric slices during day time and *Prosopis juliflora* as fuel in biomass combustor cum hot air generator during off sunshine hours and thus extended the working time of the dryer. The results indicated that drying was faster and took less time in SBHD as compared to the OSD (Open Sun Drying). The maximum efficiency of biomass combustor and solar-biomass hybrid dryer was found to be 79.79 and 14.00 per cent, respectively. On the basis of economic analysis it is revealed that drying of 5 mm processed and unprocessed turmeric slices seems to be economical in SBHD. It was found that the system could generate an adequate and continuous flow of hot air in the temperature range of 50 to 60 °C required for drying. In drying kinetic study, Modified Henderson and Pabis model was found best fitted for blanched and peeled turmeric slices of 5 mm thickness (SBP3) and Page model was found to be best fitted for blanched and unpeeled turmeric slices (SBN3) with higher R^2 in comparison with other mathematical drying models. The best ranked thin layer drying model for the blanched and peeled turmeric slices (HBP3) dried in solar biomass hybrid dryer was Two term model. The best ranked thin layer drying model for the unblanched and peeled turmeric slices (HBN3) dried in solar biomass hybrid dryer was Logarithmic model. The drying of turmeric slices in SBHD gave better quality powder in terms of color (higher L*, a* and b* value) than open sun drying.

Keywords : Solar tunnel dryer, solar biomass hybrid dryer, biomass combustor, drying efficiency, curcumin.

Introduction

Turmeric is the dried rhizome of *Curcuma longa* L. of the ginger family. It is one of the extensively used spices in the Indian subcontinent (Sarker and Nahar, 2007). Curcumin, demethoxycurcumin, bis-demethoxycurcumin, and ar-turmerone are four major active components of turmeric (Chopra and Simon, 2000). Mostly it is used as a condiment and only a small quantity is used in pharmaceuticals and cosmetics (Chattopadhyay *et al*., 2004; Chirangini *et al*., 2004; Sarker and Nahar, 2007; Rouhani *et al*., 2009). Antioxidant activity and free radical scavenging potential are the most important characteristics (Nagarajan *et al*., 2010). The most valued constituent of turmeric is yellow pigment i.e. curcumin (Rakhunde *et al*., 1998) as it is an important factor in sensory and consumer acceptance of products (Wang *et al*., 2009).

Driers in general can be easily classified into different types, depending on mode of heat supply, design case, operating pressure, handling of the feedstock etc. The natural convection solar tunnel dryer is one of the designs that has achieved some level of acceptance. The design is suitable for small-scale industries because it is easy and inexpensive to construct, simple to run and can produce a good quality of products under favorable climatic conditions. One significant disadvantages of this drier is that it works in the sunlight only. For commercial producers, this factor limits its ability to dry a produce when there is not adequate solar radiation. Drying time also extends as drying takes place during daytime only. Prasad J. *et al.* (2006) indicated that there have been a few attempts made to overcome this limitation in simple natural convection solar driers. There are industrial scale driers operated on electricity. Leis *et al.* (1999) reported a drier, which used a biomass burner for air heating and running blower through electricity correspond to a thermal output of 112 kW. This paper evaluates the techno economic performance of the solar biomass hybrid dryer for drying of turmeric on both solar and biomass mode and open sun drying, for comparison.

Material and Methods

Indian cultivars Salem of turmeric were procured from local farmers of Akola districts of Maharashtra State (India). Following samples were used during the test run in OSD and SBHD. The code and nomenclature was given to the turmeric samples for their drying in Table 1.

Table 1 : Code and nomenclature of the turmeric samples.

S.N.	Open sun drying samples	Solar-Biomass hybrid dryer samples	Nomenclature
1	SBP 3	HBP 3	0.5 cm slice blanched peeled
2	SBN 3	HBN 3	0.5 cm slice blanched unpeeled
3	SUP 3	HUP 3	0.5 cm slice unblanched peeled
4	SUN 3	HUN 3	0.5 cm slice unblanched unpeeled

Solar-biomass hybrid system was consisting of solar tunnel dryer and biomass combustor. Solar tunnel dryer of size 3×6×2m was used for experimentation purpose. Biomass combustor cum hot air generator for producing hot air retrofitted to the solar tunnel dryer was used during test run as shown in Fig. 1. During day time the SBHD uses sunlight for drying the turmeric samples and during night time the hot air was introduced in dryer by using the biomass combustor.

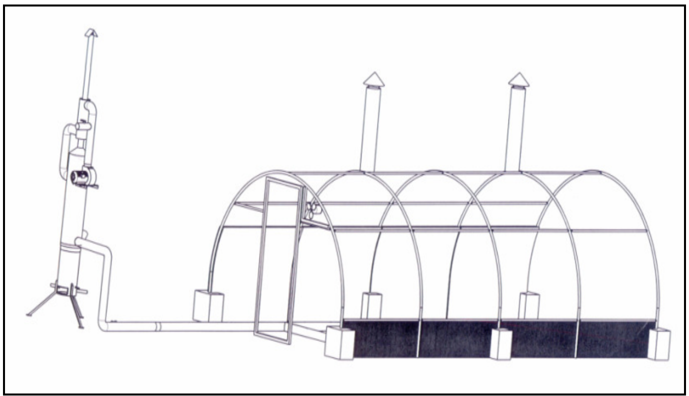

Fig. 1 : Details of Isometric view of solar-biomass hybrid dryer

(A) Mathematical modelling of drying data

Moisture loss was recorded during the drying process in order to determine the drying curves. For calculating the drying rate of turmeric slices in both drying methods, initial moisture content (Mi) and equilibrium moisture content (Me) were determined.

Table 2 : Mathematical models applied to the solar drying and solar biomass hybrid drying curve

S.N.	Model Name	Model
1.	Lewis	M.R. = $exp(-a.x)$
2.	Page	M.R. = $exp(-a.x^b)$
3.	Henderson-Pabis	M.R. = $a.exp(-b.x)$
4.	Logarithmic	M.R. = $a.exp(-b.x)+c$
5.	Two term	M.R. = $a.exp(-b.x) +c. exp(-d.x)$
6.	Modified Henderson and Pabis	M.R.= $a.exp(-b.x) +c. exp(-d.x)+e.exp(-f.x)$
7.	Wang and Singh	M.R. = $1+a.x+b.x^2$

Result and Discussions

The data presented in Fig.2 and 3 showed that the average temperature variation inside solar tunnel during was found in between 31.28 to 52.47° C during day time and 30.52 to 51.42° C during night time during winter season (up to 12.00 h). This temperature goes up to 58.62° C during day time and 54° C during night time in summer season (up to 12.00 h).

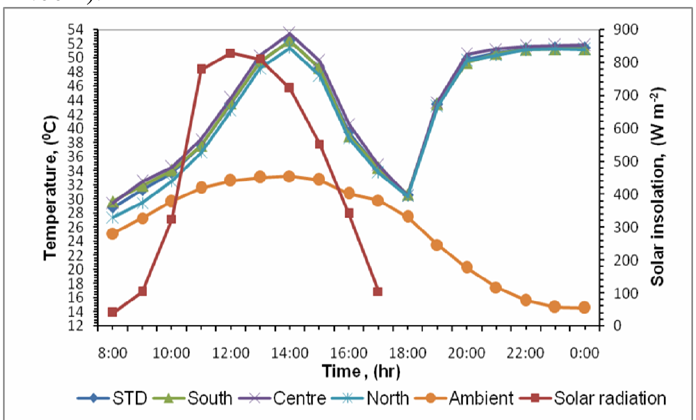

Fig.2 Average temperature variation during in SBHD of winter season (Dec. 2012)

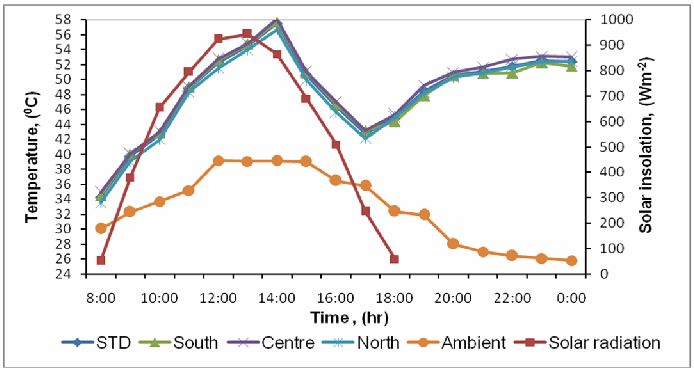

Fig.3 Average temperature variation during full load test in SBHD of summer season (March, 2013)

A. Overall efficiency of solar biomass hybrid dryer

Table 3 revealed that blanched turmeric slices required less drying time than the unblanched (HUP3 & HUN3) turmeric slices. The overall efficiency of solar biomass hybrid drying system for drying of turmeric slices was found to be in the range of 13-14 percent.

Table 3 : Overall efficiency of solar-biomass hybrid dryer samples

S.N.	Sample	Total drying hours	Total moisture evaporated (kg)	Heat gain, (MJ)	Heat input, (MJ)	Efficiency, (%)
1	HBP 3	26	35.43	82.56	575.26	14.35
2	HBN 3	27	35.82	83.98	621.58	13.51
3	HUP 3	26	35.52	83.78	575.26	14.56
4	HUN 3	27	33.85	82.93	621.59	13.34

Table 4 : Total drying hours required to dry turmeric samples in SBHD and OSD

S.N.	Turmeric dried in SBHD	No. of drying hours	No. of days	Turmeric dried in OSD	No. of drying hours	No. of days
1	HBP 3	27	1.5	SBP 3	29	4
2	HBN 3	28	1.5	SBN 3	30	4
3	HUP 3	27	2	SUP 3	30	4
4	HUN 3	28	2	SUN 3	38	5

B. Thin layer drying model for drying of turmeric in OSD and SBHD

It is revealed from the obtained results that all the models showed the best fit having R^2 values more than 0.9. Modified Henderson and Pabis model was best fitted for blanched and peeled turmeric samples SBP3. Page model was found to be best fitted for blanched and unpeeled turmeric slices SBN3 dried in open sun drying. Variation of moisture content with drying time and variation of drying rate with drying time in OSD for SBP3 and SBN3 is depicted in Figs. 4, & 5. Also same was depicted for SBHD in Figs. 6 & 7 respectively. The turmeric samples dried in open sun drying and is represented thin layer drying behaviour and fitted to thin layer drying models. The drying of 5 mm turmeric slices followed falling rate drying behaviour.

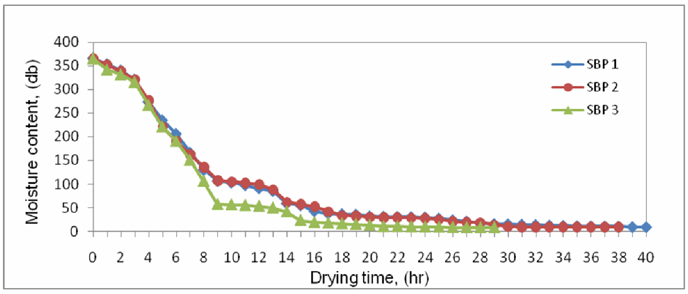

Fig. 4 : Variation of moisture content of turmeric in OSD

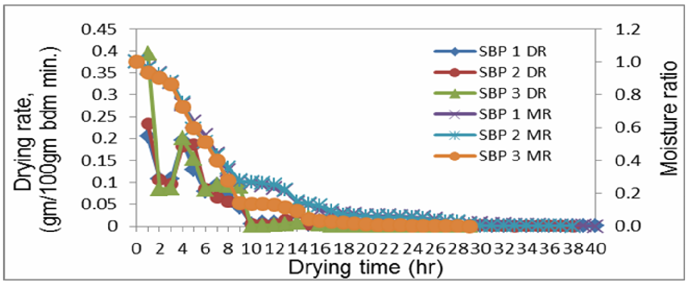

Fig. 5 : Variation of drying rate with drying time in OSD

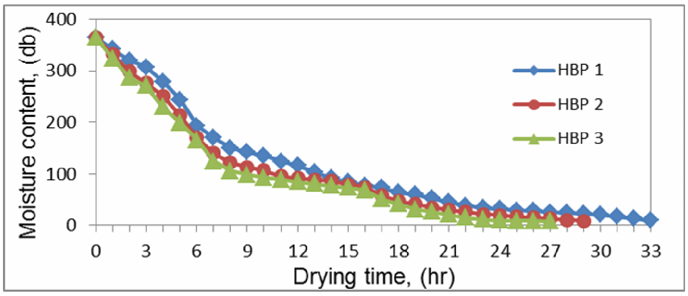

Fig. 6 : Variation of moisture content with drying time in SBHD

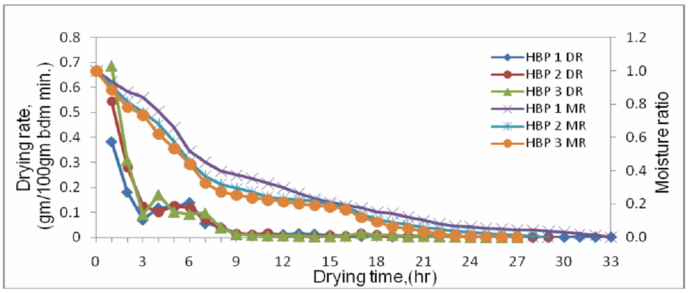

Fig. 7 : Variation of drying rate and moisture ratio in SBHD

C. Effect of drying condition on color value. (L*, a* and b*) of dried turmeric powder

Hunter CIE L* a* b* characteristics were determined using a Hunter lab color flex E2. The color value lightness (L*), redness (a*) and Yellowness (b*) were detected. Samples were placed in 1 cm path length optical glass cell and color parameters were measured under total transmission mode using illuminant D 65 and 10 degree observer angle. Also blanched, peeled and sliced turmeric samples showed more L* a* b* values. The results indicated in table revealed that cooking the sample prior to dehydration is important to obtain a product with higher intensity of yellow and red as compared to unblanched samples. It is concluded that blanching and peeling caused a pigments and higher Hunter CIE L*, a* and b* values and the samples dried in SBHD was obtained higher value of yellow and red color than dried in OSD.

Table 5 : Effect of drying condition on color value of turmeric

Open Sun Dried			
Turmeric samples	**L***	**a***	**b***
SBP3	49.08	23.43	58.51
SBN3	48.10	23.01	58.81
Solar Biomass Hybrid Dried			
HBP3	58.68	26.51	70.11
HBN3	53.78	24.15	65.11

D. Economics of solar biomass hybrid dryer for drying of turmeric

Economics of SBHD for drying of turmeric the different economic parameter of SBHD are summarized in Table 9. The details of cash inflow and outflow up to 15 years were calculated.

Table 6 : Computation of cost of operation of different turmeric samples in solar-biomass hybrid drier.

S.N.	**Description**	**Fresh slice (0.5cm)**	**Processed slice (0.5cm)**
		Amount (Rs.)	**Amount (Rs.)**
I	**Fixed cost**		
i	Solar-biomass hybrid drier	90,700.00	90,700.00
II	**Operating cost Rs/year**		
i	Raw material cost	100,125.00	100,125.00
ii	Labour cost	36,000.00	36,000.00
iii	Repair and maintenance cost	2,600.00	2,600.00
iv	Fuel wood cost, yr-1	9,720.00	9,720.00
iv	Cost of grinding	14,020.00	14,020.00
v	Electricity charges	4,500.00	4,500.00
	Total	**1,66,965.00**	**1,66,965.00**
	Economic indicators		
a	Net present worth, Rs	345546.69	345546.69
b	Benefit- cost ratio	1.25	1.25
c	Payback period	4 month & 26 days	4 month & 26 days

The present worth of total cash inflow and outflow for drying of 0.5 cm processed and fresh turmeric slices in SBHD were found to be Rs. 345546.69 and 345546.69, respectively. Based on NPW it could be concluded that the drying of 0.5 cm turmeric slices in fresh and processed forms seems to be economical.

The benefit cost ratio of 0.5 cm processed and fresh slices turmeric dried in SBHD and found to be 1.25 and 1.25 respectively. Thus, it is concluded that investment is justified and drying of processed and fresh 0.5cm slice is economically viable. Payback period for drying of 0.5 cm turmeric slices in fresh and processed form was found to be 4 month and 26 days. From all the above economic indicators it was concluded that drying of processed and fresh slices, turmeric seems to be economical drying operation in SBHD.

Conclusion

The overall efficiency of biomass combustor for hot air generation was found to be 79.79 per cent at average ambient air flow rate (650.45 kg h^{-1}), fuel wood consumption (2.70 kg h^{-1}) and heat input (11070 kcal h^{-1}). It is revealed that biomass combustor was able to produce sufficient hot air for drying of turmeric slices. It is revealed that the overall efficiency for peeled turmeric slices achieved more efficiency of drying than unpeeled slices since more surface area was available for moisture removal in turmeric slices during thin layer drying. On the basis of economic analysis it is revealed that drying of 0.5 cm processed and fresh slice, 3 cm cut and whole processed turmeric seems to be economical in SBHD. Considerable reduction in drying time is the major advantage reported with this hybrid dryer. While overcoming the limitations of solar drying during cloudy days, the solar-biomass hybrid dryer also enables drying during night-time. It is concluded that drying rate of turmeric slices in solar biomass hybrid dryer was faster than open sun drying. In drying kinetic study, Modified Henderson and Pabis model was best fitted for blanched and peeled turmeric slices (SBP3) and Page model was found to be best fitted for blanched and unpeeled turmeric slices (SBN3) with higher R^2 in comparison with other models in open sun drying method. The best ranked thin layer drying model for the blanched and peeled turmeric slices (HBP3) dried in solar biomass hybrid dryer was two term model. The best ranked thin layer drying model for the unblanched and peeled turmeric slices (HBN3) dried in solar biomass hybrid dryer was Logarithmic model. The drying of turmeric slices in SBHD gave better quality powder in terms of color (higher L*, a* and b* value) than OSD.

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