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Study of Drying characteristics of *Terminalia bellirica* and feasibility analysis of locally built solar dryer

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Abstract

The present article is focused on the evaluation of economic and efficiency feasibility of solar dryer for drying *Terminalia bellirica*. In addition total useful energy required for drying *Terminalia Bellirica* (bahera) is also evaluated. In this perspective a lab scale, low cost natural convective solar dryer was locally fabricated. Different parameters viz. amount of moisture content, total energy required for drying, the annual costs of drying per kg and efficiency of dryer was evaluated. The initial and final moisture content was found to be 61% and 1% respectively on wet basis. The total useful energy required for the drying the product was found 0.73 MJ. The annual costs of drying per kg and unit cost of useful energy was evaluated to be Rs.14.57 and the efficiency of drying of dryer has been found to be 7.44% for *Terminalia Bellirica*.

Keywords: **N**atural convective solar dryer, Moisture content, Efficiency, Annual cost, Total energy required.

INTRODUCTION

Drying is an essential process used to remove moisture from the agricultural, medicinal products etc. to preserve for long term duration. Due to the lack of knowledge of suitable drying methods open sun drying is still most popular method among the farmers of the India. The influence of rain, storms, microorganisms, long drying time and most important reduction of products quality etc. are some disadvantages of open sun drying. However, solar dryers protect the products from the contaminations, reduce drying time, helpful to dry the products in control manner and it maintains the product quality, etc. Significant work has been carried out by different researchers from last two decades to design, development, efficiencies and economic viability for different types of solar dryers (Clark, 1981; El-Sebaii, 1981; Exell and Kornsakoo 1978; Fuller, 1998; Sarkar and Sakeh, 2002). The higher efficiency, maintained quality of the dried products in comparison to open sun drying and usefulness of cabinet type solar dryer for domestic application has been published (Sodha et al., 1995). The evaluations of technical, analytical and economical aspects of solar dryers have also been reported by other researchers (Lutz et al., 1987 and Mahpatra et al., 1990).

The study has been carried out in northern part (Himalayan region) of India which is blessed with thousands of species of plants; however, about 320 species have been identified in terms of their medicinal value. The product *Terminalia bellirica* is well known for its medicinal values and found up-to 4000 ft. altitude in the Himalayan region. *Terminalia bellirica* is useful in acsites, asthma, bleeding and ulceration of gum, blood pressure, burns, cooling wash of eye, cough, dysentery, diarrhoea and worm etc.

The present study is focused on the evaluation of efficiency and economic feasibility of locally built natural convective cabinet type solar dryer by drying the locally grown medicinal product. The aim of present study is also to find the total energy required for drying the same product.

MATERIALS AND METHODS

Samples

For experimental purpose *Terminalia bellirica* is collected from Tungnath region of Uttarakhand Himalaya at an altitude 2000 ft. The fruit part of the plant was cut into small pieces and 0.5 kg of sample was taken in the dryer as well as in open sun. The entire sample was taken as a single layer for proper drying.

Drying Methods

The experiments have been carried out during the cultivation periods of the product. To maximize the solar radiation intensity incident on the collector, the dryer was installed at south facing.

Open sun drying

The traditional way of drying follows the spreading of the product over the rough surface under the sun. Similar methodology has been adopted under the present study. The products were spread over a plane paper and periodically stirred to ensure uniform drying. The dried products have been weighed after intervals of one hour.

Cabinet type solar dryer

A natural convection cabinet type solar dryer of wooden frame was fabricated locally for the present study and shown in Figure 1. It consists of a single-layered transparent cover (glazing) of thickness 0.60 mm at the top and is covered with three sides by thermocole sheet of thickness 1.5 cm. Thermocole sheet is used for insulation and is sandwiched between wooden frame and aluminum sheet of thickness 0.2mm. The aperture area of collector (glass) is 0.936 m^2 and the tilt angle of the glass surface was taken as 29^o. The cabinet has a bed area of 120 cm x 78 cm and the heights of front and back panel are l0 cm and 26 cm respectively. The inside surfaces (aluminium sheet) of the dryer are painted with black paint. Ventilation holes are provided at the bottom and upper sides of the dryer to ensure natural air circulation under and around the product. The dryer is placed on the stand made up of steel having dimensions 123 cm x 79 cm x 58 cm. A tray of quadrilateral shaped having wooden frame of equal height of 3.5cm with metallic mesh at the base is taken to contain the product. The spacing between the tray and base of dryer was taken 5cm.

Figure 1. Natural convection type solar dryer.

Measurements

Thermal performance of solar thermal device depends upon the construction/design parameters as well as the climatic/operating conditions. The climatic parameters viz. solar radiation intensity, inside and ambient temperatures, wind speed and relative humidity were measured during the experiments. All these parameters were measured at regular interval of one hour. Intensity was measured at south facing by SM-201 Sunshine recorder (CEL- India) of least count $1mW/cm^2$. Laboratory type mercury bulb thermometers (of least count 1^oC) was used to measure the temperature inside dryer, ambient temperature & relative humidity were measured by HN-CH series temperature/humidity meter (China) and prevailing wind speed by AM-4201 anemometer (Taiwan). Thermometers were fixed at different place inside the cabinet dryer and their average value has been taken. Digital balance of least count 0.5 gm. was used for weighing the dried products.

METHODOLOGY

The effectiveness of the cabinet type solar dryer has analysed on the basis of widely adopted thermal performance parameters:

Moisture content

The percentage of moisture content on wet weight basis has been calculated using the following relations (*Ekechukwu, 1999*).

$$M_{(wet)} = \frac{(m-d)\times 100}{m}$$

where, *m* and *d*, are the initial and final weights of the product respectively.

Loading density

The term loading density signifies the amount of product can be dry per batch in the system and can be expressed as (Augustus, et al. 2002).

Loading density (LD) = weight of fresh product loaded in dryer (Kg)/total solar aperture area (m^2)

Efficiency of drying system and total useful energy required for drying

The efficiency of drying system was evaluated by the expression (Augustus et al, 2002).

$$\eta = \frac{m_w \times L \times 100}{S_\infty}$$

where, L is the latent heat of vaporization (Kcal/kg), S_∞ is the solar intensity (KWh/m^2/day) at a particular instant and m_w is the amount of water to be evaporated (kg) calculated by the following relation (*Purohit and Kandpal, 2005*).

$$m_w = \frac{(M_{ci} - M_{cf})\times M_{sd}}{(1-M_{ci})}$$

where, M_{ci} and M_{cf} represents the initial and final moisture contents of the product (in fraction) to be dried respectively and M_{sd} is the amount of solar dried product (kg).

The useful energy required raising the temperature of the product to be dried from initial temperature (T_a) to the drying temperature (T_d):

$$q_{sens} = \left[\left(\frac{(1-M_{cf})}{(1-M_{ci})}\right) C_p (T_d - T_a)\right] M_{sd}$$

where, C_p represents the specific heat of the crop and can be estimated (in MJ/kg^0C) from Siebel's formula (*Purohit & Kandpal, 2005*):

$C_p = [0.80 M_{ci} + 0.20]\ 4.1868 \times 10^{-3}$

The useful energy required for evaporation of moisture from the product can be expressed as:

$$q_{evap} = \left[\frac{(M_{ci} - M_{cf})}{1-M_{ci})}\right] M_{sd}\, h_{fg}$$

where, h_{fg} represents the enthalpy of evaporation of water (Kcal/kg) at the drying temperature. Thus the total useful energy required for drying the product can be expressed as (*Purohit and Kandpal, 2005*):

$$UE_d = q_{sens} + q_{evap} = M_{sd}\left[\left(\frac{(1-M_{cf})}{(1-M_{ci})}\right)C_p\,(T_d - T_a) + \left(\frac{(M_{ci}-M_{cf})}{(1-M_{ci})}\right)h_{fg}\right]$$

The first term on the right side of equation represents the useful energy required for sensible heating of wet crop from the ambient temperature (T_a) to the drying temperature (T_d) and the second term represents the useful energy required for evaporation of moisture in the crop.

Economic analyses

The annual cost method has been considered for the economic analysis (*Vasanthi et al., 2005*). The initial capital investment (ICI) of the locally fabricated cabinet dryer was taken 2000 Rs. The expected useful life time of the dryer is assumed 10 year and maintenance cost to be 10% of the initial investment and considered to be constant throughout the lifetime. The harvesting period of dried product is taken 150 days. The selling price of *Terminalia bellirica* was 10 Rs/kg. The salvage value (SV) of the system for *Terminalia bellirica* was taken 3.7% of the initial investment.

Annual cost method

Annual cost = first annual cost/m^2 + annual maintenance cost – annual salvage value

First annual cost/m^2 = capital recovery factor (CRF) x initial capital investment (ICI)

Capital recovery factor (CRF) $= \dfrac{i(1+i)^n}{(1+i)^n - 1}$

where, 'i' represents rate of interest and 'n' useful life-time of the dryer.

First annual salvage value = sinking fund factor (SFF) x salvage value (SV)

Sinking fund factor (SFF) for a system is given =

$$\frac{i}{(1+i)^n - 1}$$

Annual product yield (APY)

= mass of the product dried (M_{sd}) x harvesting time (T) / drying time (t)

Annual cost of drying per kg of product =

annual cost / annual product yield

RESULTS AND DISCUSSION

The fabricated dryer was tested before the experiment in sunny day and results are shown in Figure 2. The results obtained can be helpful to understand and to control the temperature of the dryer with solar radiation availability.

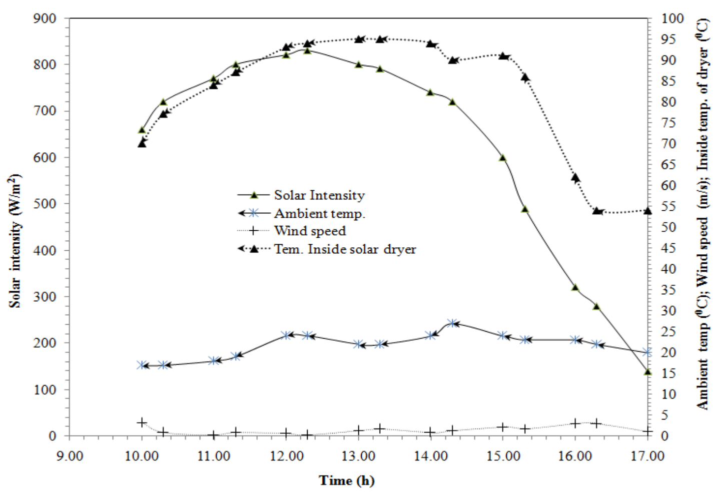

Figure 2 Testing of locally fabricated non-convective cabinet type solar dryer

The variation of moisture content with time of selected dried product in a cabinet type solar dryer and open sun were evaluated and shown in Figure 3. From figure 3 one can depicts that for the product open sun drying is slower process than in cabinet dryer. The evaporation of moisture from the product as usual depends upon climatic conditions of the surrounding medium. The fluctuating portion in some places in the drying curves obtained during the variation of solar radiation intensity. The variation of solar radiation effect on the movement process of the moisture from the inner part to the surface and thus evaporation of moisture may be effected due to the change of surround temperature of the product.

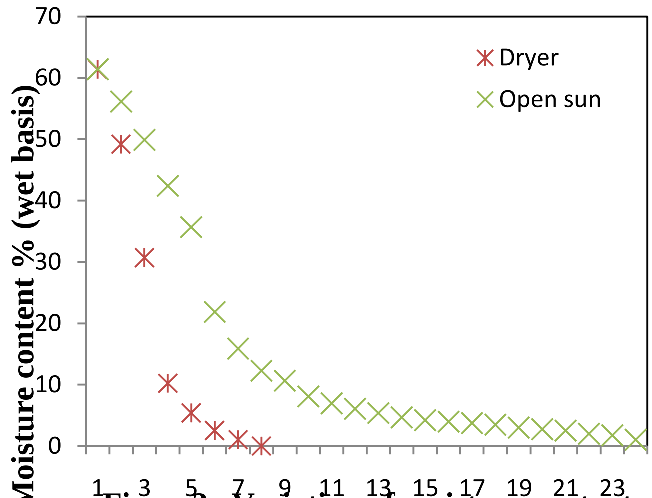

Figure3. Variation of moisture content with drying time .

Different parameters used for the evaluation of efficiency of the dryer are given in Table 1. The efficiency of dryer was found to be attractive in comparison to open sun drying. The efficiency of dryer was found to be 67.44%. The initial and final moisture content on wet basis for the dried product is also given in Table 1. Initial and final moisture content on wet basis has been found to be 61% and 1% respectively. The drying time for *Terminalia bellirica* was found 1 day.

Table 1 also shows the total useful energy required for drying this product. Total useful energy required for drying was found to be 0.73MJ. For total useful energy, useful energy required to raise the temperature of the products from initial to drying temperature and useful energy required for evaporation of moisture from the products were calculated and results are also given in Table 1. The significance of total energy analysis is the amount of energy which can be saved without any pollution by the use of such kind of dryer.

Different parameters used for economic analysis of the dryer are given in Table 2. The values of maintenance cost/m^2 and annual cost of the dryer are much attractive. These values can be in affordable range to poor farmers in comparison to electricity-backup and other conventional fuels operated dryers.

In addition, the cost of the dryer can be reduced by making them by the farmer themselves. The evaluated value of annual cost of drying per kg of *Terminalia bellirica* has found Rs 14.57.

Table 1. Efficiency of drying system and total useful energy required for drying Terminalia bellirica

Parameters	Symbol	Unit	Results
Initial weight of the product	m	kg	0.5
Final weight of the product	d	kg	0.193
Aperture area of dryer		m^2	0.936
Loading density	LD	Kg/m^2	0.53
Amount of water evaporated	m_w	kg	0.30
Latent heat of vaporization	L	Kcal/kg	2.26
Average intensity on tilted surface	S_∞	$KWh/m^2/day$	5.82
Average intensity on horizontal surface	S_∞	$KWh/m^2/day$	17.87
Drying time in dryer		hour	7
Drying time in open sun		hour	27
Initial moisture content	M_{ci}	fraction	0.61
Final moisture content	M_{cf}	Fraction	0.01
Efficiency of dryer	η	%	67.44
Specific heat of the crop	C_p	MJ/kg^0C	0.0029
Temperature inside the dryer	T_a	^0C	73.38
Ambient temperature	T_d	^0C	32.38
Useful energy required to raise the temperature of the product from initial to drying temperature	q_{sens}	MJ	0.06
Enthalpy of evaporation of water	h_{fg}	Kcal/kg	2.26
Useful energy required for evaporation of moisture from the product	q_{evp}	MJ	0.67
Total useful energy required for dying the product	UE_d	MJ	0.73

CONCLUSION

The efficiency of dryer for *Terminalia bellirica* have found much more attractive than open sun drying. The advantage of such kind of dryer is of very low cost and requires low maintenance and annual cost. The maintenance cost/m^2 of the dryer has been found in affordable range and in addition the low values of annual cost of drying/kg of the dried products for the selected products. Annual cost of drying/kg of product can be reduced by saving transport and labour cost by making such kind of dryer locally. Drying effects of product extracts should be further studied.

Table 2. Economic feasibility of fabricated dryer of drying Terminalia bellirica

Parameters	*Symbol*	*Unit*	*Results*
Rate of interest	*i*	*fraction*	*0.14*
Useful life-time of dryer	*n*	*Year*	*10*
Initial capital investment	*ICI*	*Rs*	*2000*
Maintenance cost		*Rs/m²*	*38.34*
Capital recovery factor	*CRF*	*fraction*	*0.19*
Sinking fund factor	*SFF*	*fraction*	*0.05*
First annual cost		*Rs/m²*	*383.43*
First annual salvage value	*SV*	*fraction*	*0.05*
Annual cost of dryer		*Rs*	*421.72*
Annual product yield	*APY*	*kg*	*28.95*
Harvesting period	*T*	*days*	*150*
Drying time	*t*	*days*	*01*
Selling price		*Rs/kg*	*10*
Annual cost of dryer		*Rs/kg*	*14.57*

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