Development of a Solar-Biomass Integrated Drying System for Spice Crops

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By

Abhijit Borah

DEPARTMENT OF AGRICULTURAL ENGINEERING
TRIGUNA SEN SCHOOL OF TECHNOLOGY
ASSAM UNIVERSITY
SILCHAR – 788 011, INDIA

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CERTIFICATE

This is to certify that the thesis entitled **Development of a Solar-Biomass Integrated Drying System for Spice Crops** submitted by **Abhijit Borah** to the Department of Agricultural Engineering, Assam University, Silchar towards partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy in Agricultural Engineering is a bonafide research work carried out by him under our supervision and guidance. This work has not been submitted previously for any other degree of this or any other University. It is further certified that the candidate complied with all the formalities as per requirements of Assam University. We recommend that the thesis may be placed before the examiners for consideration of award of the degree of this University.

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Dr. S. Sarkar
Associate Professor

Dr. L.N. Sethi
Associate Professor

DECLARATION

I , **Abhijit Borah** bearing registration Number Ph.D/33-110033340/2011-12, hereby declare that the present thesis entitled "***Development of a Solar-Biomass Integrated Drying System for Spice Crops*",** is an original work carried out in the Department of Agricultural Engineering, Assam University, Silchar with acceptations of guidance and suggestions received from my supervisor Dr. L. N. Sethi, Associate Professor and Co-supervisor Dr. S. Sarkar, Associate Professor, Department of Agricultural Engineering, Assam University, Silchar. To the best of knowledge and belief, it contains no material which has been accepted for the award of any other degree or diploma of this University or other Institute of higher learning, except where due acknowledgement has been made in the text. The data and the findings discussed in the thesis are the outcome of my research work. The thesis is being submitted to Assam University, Silchar, for the degree of Doctor of Philosophy (Ph.D) in Agricultural Engineering.

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ASSAM Ph.D/33-110033340/2011-12

DEVELOPMENT OF A SOLAR-BIOMASS INTEGRATED DRYING SYSTEM FOR SPICE CROPS

Abstract

Drying is an essential process used all over the world for the preservation of farm produce. It helps in reducing the water activity of the produce to a level below which deterioration does not occur for a definite duration. Various drying methods/sources are employed to dry different food produce. Each one is having its own advantages and limitations. Conventional fuel operated driers are more efficient than open sun drying, provide uniform high quality dried produce, with many more advantages, but in spite of all these favourable points, such units are beyond the reach of rural people with limited product volume and financial resources. Moreover, the increasing rate of fuel consumption in agriculture has made it necessary, not only to save energy by intensifying the drying process, improving designs etc. but also using renewable energy sources for drying processes. Solar and biomass are the two main renewable sources of energy that is used for drying of agricultural produce. Appropriate use of these sources in drying provide reduction of drying time and specific improvement of the product quality in terms of colour, taste and texture in comparison to open sun drying. In order to increase the energy efficiency, improve the energy quality, and reduce emissions in the energy conversion, integration of biomass and solar drying system is important in the development of the alternative energy systems.

So, the present research was undertaken in design and development of a solar biomass fired integrated drying system (IDS) for drying of ginger and turmeric rhizomes. Functional design of a solar flat plate collector was carried out to harness maximum solar intensity. The collector dimension of 2220 mm x 1230 mm was finalized with an inclination of 15^0 facing south (26.75^0 N and 94.22^0 E) for maximum exposure to insolation. To increase the intensity of solar radiation, a double parabolic concentrator was designed accommodating 6 parabolic concentrators with equal spacing of 15 mm. Horizontal and vertical manual tracking was incorporated to provide tracking by 11.54^0 and 4.68^0 respectively. A bio-waste fired assembly with a detachable grate type husk feeding system, combustion chamber with a horizontal grate for burning of solid biomass of length 1620 mm and diameter 450 mm was also designed. The capacity of the dryer was designed for 100 kg per batch in 6 perforated trays. Total cost involvement of the dryer was Rs.80,000/-. Along with the developed dryer, drying were also carried out simultaneously in a fluidized bed dryer (FBD), electrical oven and open sun drying for comparison.

To understand the drying kinetics, drying experiments on ginger and turmeric rhizomes were carried out by interchanging the trays in a predetermined sequence and time interval for uniform drying. Drying of ginger was accomplished in 16 hour of effective drying time reducing moisture content from 88.8 % to 6 % (wb), when air temperature was maintained at 55 ± 3^0 C using paddy husk as the source of fuel. Drying curves were drawn and moisture ratio (ln MR) against time was computed. While drying turmeric, it was observed that drying was accomplished in 14 hours of effective drying. The moisture content was brought down to 6.26% (wb) from initial level of 89.26% (wb).

Comparative performance of the selected mechanical drying systems was studied considering specific energy consumption (SEC). The highest SEC while drying ginger was by oven drying followed by IDS and FBD. However, in case of turmeric drying minimum SEC was observed in IDS followed by FBD and Oven drying. Cost of drying was compared. In comparison to IDS, cost of drying ginger in FBD and Oven were 5 and 19 times more, respectively. The same in case of turmeric were 14 and 30 times more in FBD and Oven drying, respectively compared to drying in IDS.

Energy utilization efficiency by the IDS was analyzed. After computing overall heat loss coefficient of collector surface area, energy utilization efficiency by the solar collector assembly was found to be 49.27%. Energy utilization efficiency of the bio-waste fired assembly was found to be

62.32%. Considering total heat available in the plenum chamber and latent heat of evaporation, the IDS showed 39.33% of overall energy utilization efficiency.

Attempt was made to simulate a drying process and to identify best suitable model out of six selected thin layer drying models. Moisture content data were converted into the moisture ratio (MR) expressions and curve fitting with drying time for the selected drying models were analyzed. Sigma Plot software was used for nonlinear regression to the data obtained during drying and for modeling of drying curves. The suitability of the equations was evaluated in terms of statistical parameters such as coefficient of determination (R^2), mean percentage error (P) and standard error estimate (SEE). Analyses of overall statistical parameters of drying kinetics validated Page model as the most suitable one among the six models tried for simulation. Experimental and simulated moisture ratio curves when drawn for this model for both the spices, it was observed that the curves were near similar indicating sound drying conditions. The effective moisture diffusivity during drying for different trays was determined using method of slopes for ginger and turmeric separately. The effective moisture diffusivity (D_{eff}) for ginger was found to be, 2.97×10^{-7} m^2s^{-1}, while experimenting with turmeric rhizomes effective moisture diffusivity was found to be 3.747×10^{-7} m^2s^{-1}. It was observed that, diffusivity in IDS was 35.7% more in comparison to diffusivity reported in literature under sun drying. Effective moisture diffusivity in case of turmeric drying was nearly 21% more in comparison to ginger drying. Moisture diffusion was easier in turmeric rhizomes due its less fibrous nature compared to ginger.

The effect of selected drying methods on the quality attributes of dried spices were studied by analysis of different parameters viz. rehydration ratio (RR), oleoresin level, volatile oil content, texture, colour for ginger samples and curcumin content, texture, colour etc. for turmeric samples using standard methods. Results obtained were statistically analyzed using 1-way analysis of variance test (ANOVA). Non uniform exposure to hot air and extreme drying conditions affects the cell structures resulting in poor rehydration, which is a negative quality attribute. The rehydration characteristics of dried ginger were studied in terms of RR and coefficient of rehydration (COR). In case of samples dried in IDS, rehydration ratio values ranged from 1.60 to 2.29 with respect to different time intervals, which was compatible with samples from oven drying (2.32). Better values of COR, which is indicative of good quality attributes was observed in products from IDS than from oven as well as sundried. Oleoresin and volatile oil content in dried ginger from different drying methods were studied as these are the most heat sensitive quality parameters of ginger. Ginger oleoresin was found to be highest in samples from IDS (2.60%) and affected most in FBD (0.84%). Highest amount of volatile oil was found in samples from oven drying (0.95%) and lowest (0.40 %) was found in samples from FBD. Texture studies of dried turmeric from all the four drying methods showed that, turmeric dried in IDS required maximum peak force (8789.006 g) which was an indication of achieving maximum uniform drying whilst positive area under curves was minimum (10745.264 g.sec) amongst all indicating dried turmeric would require minimum energy during size reduction operations. Maximum deviation of colour from raw turmeric (67.354) was in case of oven dried samples. Lowest value of ΔE (52.681) in case of samples obtained from IDS indicated most acceptable characteristics colour of turmeric. However, IDS produced samples with minimum Hue angle (64.87^0). Corresponding Croma value being highest (26.786) indicated comparatively more colour intensity. Taking curcumin content of raw turmeric (6.35%) as base, percent retained in samples after drying was compared for the selected drying methods. It was observed that, variation in retention of curcumin was only 1.31%, varying between 97.13% and 95.82%.

The drying processes were optimized using a nine point Hedonic scale wherein the range was fixed based on maximum and minimum values of drying time, specific energy consumption, texture, colour change, rehydration characteristics, oleoresin and volatile oil content, curcumin content as applicable. IDS scored highest value (47) whereas FBD scored lowest (22).

Key words: Biomass-solar drying system, food quality, ginger, optimization, turmeric

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(Abhijit Borah)

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AOAC	Association of Official Agricultural Chemists
CD	Critical difference
CIE	Commission internationale de l'Eclairage
CIPHET	Central Institute of Post-Harvest Engineering and Technology
COR	Co-Efficient of Rehydration
CPC	Compound Parabolic Collector
CV	Coefficient of variance
db	Dry Bulb
DPSAH	Double Pass Solar Air Heater
FBD	Fluidized Bed Dryer
GI	Galvanized Iron
IDS	Integrated Drying System
IMC	Initial Moisture Content
M. Tech.	Master of Technology
MC	Moisture Content
MNCSCD	Mix Mode Natural Convection Solar Crop Dryer
MS	Mild Steel
N-E	North East
OA	Overall Acceptability
PCM	Phase Change Matter
RR	Rehydration Ratio
SEC	Specific Energy Consumption
Sed	Standard deviation
SEE	Standard Error Estimate
SPDDSAH	Single Pass With Double Duct Solar Air Heater
SPFDSAH	Single Pass With Front Duct Solar Air Heater
SPRDSAH	Single Pass With Rear Duct Solar Air Heater
SS	Stainless Steel
UK	United Kingdom
USA	United States of America
wb	Wet Basis

LIST OF SYMBOLS

ΔE^*	total colour change
ΔT	absolute temperature difference
^0C	degree Celsius
^0K	degree Kelvin
A	Area
a^*	CIE colour scale redness / greenness
$A_{collector}$	surface area of collector
b^*	CIE colour scale yellowness / blueness
CO_2	carbon dioxide
c_p	specific heat at constant pressure
cv	calorific value of fuel
d	Distance
D	Diameter
d_a	draught induced by chimney
d_b	draught loss in bends
d_d	draught loss through the ducts
d_e	draught loss through the chimney
D_{eff}	effective moisture diffusivity
d_k	draught loss due to kinetic energy at exit
d_s	draught loss due to sudden change of sections
d_t	total draught loss
$\varepsilon_{absorber}$	emissivity of absorber
ε_c, ε_{cover}	emissivity of glass cover
f	fanning friction factor, focal length
F_r	collector heat removal factor
g	gravitational acceleration
H	height of chimney
H'	height of hot gas column
H_a'	actual draught
h_{fg}	latent heat of evaporation
h_{p-c}	convective heat transfer co-efficient from plate to cover
h_r	heat transfer co-efficient due to radiation
$h_{r,\ c-a}$	heat transfer co-efficient from cover to sky due to radiation
$h_{wind/air}$	heat transfer co-efficient of air

LIST OF SYMBOLS

I_α	solar intensity
k	thermal conductivity, drying rate constant
K_1	co-efficient of friction
K_2	co-efficient of friction due to sudden change in section
L	length, thickness
L^*	CIE colour scale lightness / darkness
L_1, L_2	arc length
ln	natural logarithms
m	Mass
M	instant material moisture content
m_c	mass flow rate
M_e	equivalent moisture content
m_f	mass of fuel
M_o	initial moisture content
MR	moisture ratio
MR_{exp}	experimental moisture ratio
MR_{pre}	predicted moisture ratio
n	model parameter
N	total number of observations
N_2	Nitrogen
n_i	number of constants
Nu	Nusselt number
P	mean percentage error
p_a	atmospheric pressure
p_g	pressure of flue gas
Q	heat, rate of heat transfer
Q_{actual}	actual rate of heat transfer
Q_c	rate of heat transfer from fuel combustion
Q_i	incident heat energy
Q_o	rate of heat loss
Q_u	rate of useful heat extracted by collector
Q_v	volume flow rate
R	gas constant,
r	Radius

LIST OF SYMBOLS

R^2	co-efficient of determination
R_a	Rayleigh number
R_{eD}	Reynolds's number
S	area of parabola
T	absolute temperature
t	Time
T_{abs}	absolute temperature of absorber
T_{air}	absolute temperature of air
$T_{ambient}$	ambient temperature absolute value
T_c, T_{cover}	absolute temperature of cover
T_{dp}	product temperature
T_{inlet}, T_i	absolute temperature at inlet
T_{outlet}, T_o	absolute temperature at outlet
T_s	absolute surface temperature
U_b	bottom heat loss co-efficient
U_e	edge heat loss co-efficient
U_L	overall heat loss co-efficient
U_t	top heat loss co-efficient
V	Velocity
w	weight of air required to burn the fuel
Z	cylindrical co-ordinates
α	dynamic viscosity of air
β	thermal expansion co-efficient
η	instant thermal efficiency
η_c	efficiency of the bio-waste fired assembly
η_o	overall efficiency
μ	dynamic viscosity
ρ	Density
ρ_a	density of air
ρ_g	density of flue gas
σ	Stefen Boltzmann constant
υ	kinematic viscosity of air
Θ	Slope