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Research paper

Mathematical modeling of drying behavior of cashew in a solar biomass hybrid dryer

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Abstract

The main objective of this study is to analyze the drying behavior of cashew nut experimentally in a solar biomass hybrid dryer using mathematical models. Suitability of fifteen different mathematical drying models available in the literature is used to describe the drying characteristics of cashew. Experimental data of moisture ratio, temperature and relative humidity obtained from different dryer conditions were fitted to the various empirical drying models. The performance of the drying model was compared based on their correlation co-efficient (R^2), Root Mean Square Error (RMSE) and Reduced Chi-Square (χ^2) between the observed moisture ratios. The two terms and Midilli models showed the best fit under solar drying. Page model was found to be the best model for describing the thin layer drying behavior of cashew for biomass drying and hybrid drying.

Keywords: Drying models; Solar drying; Biomass drying; Hybrid drying; Cashew kernel moisture ratio

1. Introduction

In many agricultural countries, large quantities of food products are dried to improve shelf life, reduce packing costs, lower weights, enhance appearance, encapsulate original flavor and maintain nutritional values [1]. The main goals of drying process in the food industry may be classified in three groups such as, economic considerations, environmental concerns and product quality. Though the primary objective of food drying is preservation, depending on the drying mechanisms, the raw material may end having significant variation in product quality .Cashew nut processing in India is mostly carried out by small farmers in rural areas [2]. Proper drying of cashew kernel enhances good appearance, original taste and maintains nutritional quality. Conventional based dryers are being used by farmers for drying which are energy intensive. In this context, renewable energy based solar biomass hybrid dryer is considered as an alternative to conventional drying to reduce drying cost and environmental sustainability.

Modeling of the drying process is one of the most important aspects of drying technology. The thin layer drying model has been found to be most suitable for characterizing the drying parameters. Several researches on the mathematical modeling and experimental studies had been conducted on the thin layer drying processes of various agricultural products [3–11].

Aghbashla et al. [3] investigated the modeling of thin layer drying behavior of potato slices in a semi industrial continuous band dryer. In order to describe the drying behavior of potato slices, three drying models were fitted to the drying data. The Page model was selected as the best according to R^2, χ^2 and RMSE. The effective diffusivity varied between 3.17×10^{-7} and 15.45×10^{-7} m^2/s, and the energy of activation was found in the range of 39.49–42.34 KJ/mol.

Kavak Akpinar et al. [4] investigated the mathematical modeling of thin layer drying process of long green pepper in solar drying and under open sun drying. The drying data were fitted to thirteen different mathematical models. Among the models, logarithmic model was found to be most suitable model for describing the drying curve of the thin layer forced solar drying process of long green peppers with R^2 of 0.98815, χ^2 of 0.001742354 and RMSE of 0.040998285.

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Nomenclature

a,b,c	drying constants
exp	experimental
k,g,n	drying constants
k, k_0, k_1	drying velocity constant in drying models
MR	moisture ratio
pre	predicted
P	number of constant
R^2	correlation co-efficient
RH	mean effective relative humidity
RMSE	root mean square error
SEE	standard error of estimate
N	number of observations in drying chamber (%)
T	temperature (°C)
v	air velocity (m/sec)
χ^2	reduced chi-square error
X	moisture content (% db)
X_o	initial moisture content (% db)
X_e	equilibrium moisture content

Waewsak et al. [5] investigated a mathematical modeling study of hot air drying for some agricultural products. Biomass dryer was used to dry some agricultural products such as red chili peppers, lemon grass and leech lime leakers. Among the thirteen different models studied, the Midilli model was found to be the best for describing the drying behavior of red chili peppers and leech lime leaves, where as the Wangh and Singh model was the most suitable for lemon grass.

Hii et al. [6] investigated the thin layer drying model and product quality of cocoa. The drying kinetics and artificial drying process of Cocoa beans were investigated. The dryer was tested with a temperature of 60, 70 and 80°C. The result showed that the new model was best fit for the drying behavior of cocoa beans.

Gunhan et al. [7] studied the mathematical modeling of drying of bay leaves. The experiment was conducted with constant air velocity of 1.5m/sec, relative humidity of 5%, 15% and 25% and different temperatures 40°C, 50°C and 60°C. The drying data were fitted with fifteen different mathematical drying models on the basis of correlation co-efficient (R^2), root mean square error (RMSE), mean bias error (MBE), reduced Chi-square χ^2 and t-statistics method. The result showed that Page model was most suitable for drying of bay leaves.

Zomorodian and Moradi [8] presented mathematical model of forced convection solar drying of Cuminum cyminum using mixed and indirect drying method. Eleven different mathematical models were studied to determine the pertinent coefficients for each model by non-linear regression analysis technique. The best results were found for the diffusion model with $R^2 = 0.995$, $\chi^2 = 0.0023$ and RMSE = 0.0199 in mixed mode and the Midilli model with $R^2 = 0.995$ $\chi^2 = 0.023$ and RMSE = 0.0225 in indirect mode. And finally the best model was selected due to the high pertinent coefficient.

Kaleta et al. [9] formulated three new types of drying model for drying apple. The drying behavior of apple was investigated in fluidized bed dryer. The three developed models were compared with the accuracy of sixteen models available from the literature. Their accuracies were measured on the basis of correlation co-efficient (R^2), root mean square error (RMSE), and reduced chi-square (χ^2). At the end of this study, the Page model and one of the empirical models formulated by the author were considered as the most suitable model with $R^2 > 0.9977$, RMSE = 0.0094–0.0167, $\chi^2 = 0.0001$–0.0002.

Kumar et al. [10] performed the mathematical modeling of thin layer hot air drying carrot Pomace. The experiments were carried out at 60, 65, 70 and 75°C at an air velocity of 0.7m/sec. The average value of effective diffusivity ranged from 2.74×10^{-9} to 4.64×10^{-9} m^2/sec and the activation energy value was 23.05 KJ/mole for drying of carrot Pomace. With increase of temperature, the drying time of the carrot Pomace decreased where as the effective diffusivity increased with increasing drying temperature.

Basunia and Rabbani investigated the best fitted thin-layer re-wetting model for medium – grain rough rice. Around five models, diffusion, page, exponential, and polynomial were compared with experimental data on the basis of standard error of estimate (SEE). The comparison showed that the diffusion and page models had almost the same strength of fit with the average SEE value which was less than 0.0015 [11].

From the vast extensive literature review, very scarce information is available on thin layer drying behavior of cashew kernel. Hence, this study was carried out to fulfill the existing research gaps on thin layer modeling of cashew kernel.

The main objectives of this study are to:

- Investigate drying kinetics of cashew kernel in a solar biomass hybrid dryer.
- Study the most suitable drying models for describing the drying behavior of cashew.
- Find out the size of drying equipment and drying chamber based on the operating condition of the dryer.

2. Materials and methods

2.1. Materials

For the purpose of sample preparation, 80 kg of boiled cashew nut shell was procured from a local farmer in Cuddalore district, Tamil Nadu, India. The outer shell is removed by using hand operated cutter to obtain raw cashew kernel with initial moisture content of 10%. For conducting drying experiments, 40 kg of cashew kernel was loaded in the ten drying trays with 4 kg in each tray. The experiment was conducted from 8:00 am to 5:00 pm in solar mode, biomass mode and hybrid mode.

2.2. Drying equipment

Schematic diagram of solar biomass hybrid dryer is shown in Fig. 1. It consist of a solar collector, drying chamber, biomass backup heater and blower with variable speed control unit [12,13].

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