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Drying kinetics of oil palm trunk waste in control atmosphere and open air convection drying

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ABSTRACT

The oil palm trunk chips were dried in a laboratory scale convective drying at two different operating conditions; open air fan drying and control atmosphere drying (25 °C and 80% relative humidity). The experimental drying data were used to estimate the drying kinetics and to select the suitable form of drying curves. Six different mathematical models such as Henderson–Pabis, Logarithmic, Midilli–Kucuk, Newton, Page, Wang–Singh models and the newly introduced modified Midilli–Kucuk model were applied to the experimental data and their co-efficient of regression, root mean square errors and sum of square error, were compared and predicted by non-linear regression analysis using the MATLAB R2011b (7.13.0.564) software. It was found that the proposed modified Midilli–Kucuk model could predict the drying rate curve when compared with the experimental data point for the drying of oil palm trunk chips.

1. Introduction

Oil palm plantation is the major agricultural plant in Malaysia. It is one of the main agricultural activities in Malaysia which contributed around 76.9% of the total plantation. According to the Malaysian Palm Oil Board 2012 statistical report, 5,037959 hectares area was used for the oil palm plantation [1]. The productive age of oil palm tree is around 25 years. After this age, the oil palm tree needs to be replaced through replantation [2]. The replantation produces around 2.29 million cubic meter of waste in the form of oil palm trunk [3]. Fresh oil palm trunk contains high moisture content that could reach as high as 500% based oven dry weight and when degraded could pollute the surrounding environment [4]. However these oil palm trunk wastes could be further utilized as raw materials for wood panel products. Before the oil palm trunks could be used as raw materials for panel products, the oil palm trunks were normally reduced to smaller sizes in chips form and dried to moisture content around 7–10% [5]. This can be done by air drying or kiln drying. Hashim et al. [5] explored the useable of OPT chips after air drying process for the production of environmentally and sustainable products such as compressed lumber, fibreboard and binderless particleboards.

Due to high moisture content, the oil palm trunk is very prone to fungal attack and will degrade easily. Thus drying the oil palm trunk to acceptable moisture content should be done as soon as possible. The properties and quality of the product produced are also highly influenced by the moisture content. The primary objective of drying is to reduce the moisture to a certain level at which on further drying, no remarkable change in volume and weight of the material will take place. In addition, low moisture content will allow the materials to be kept at longer time without any fungal attack. Many types of drying techniques had been used to dry resources such as wood. These techniques can be classified as convective or direct drying with air flows at different temperatures, indirect or contact drying using hot plates, dielectric drying, natural air drying and microwave drying. Out of these techniques the convective drying is the most prevalently used technique for drying of biomasses because it prevents burning of the surface. Convective drying is affected by air velocity, air temperature, air humidity, steady and uniform air flow, turbulence level of air flow etc. A controlled atmosphere chamber of drying facilitates well-controlled experiment with greater accuracy and reproducibility [6].

Drying of biomass like oil palm trunk (OPT) is a complex process of heat and mass transfer. The mass loss during drying mostly following the falling rate curves. The water loss from the bulk of the fibrous material is generally controlled by the capillary action and internal diffusion of water molecules [7]. This loss of water caused the shrinkage of the biomass. The effect of shrinkage during drying was analyzed experimentally by Wang and Brennan (1993) [8], they found the decrease in thickness, length and width of the potato samples during drying decreased linearly with decrease in moisture content. The modeling of shrinkage during convective

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Nomenclature

M_t	moisture content at any time	q	heat of vaporization (2260 J/g)
M_0	initial moisture content	M	moisture content
M_e	moisture content at equilibrium	ρ_0	initial density
N	number of observations	V_0	initial volume
V_v	void volume	V_s	volume of solid (dry matter)
g	specific gravity	V_w	volume of water
E_{mv}	energy	ρ_w	water density
a, b, k, n	models parameters	ρ	density
ε	total porosity	RH	relative humidity of air
V_a	volume of air		
Mr	moisture in gram		

drying for different food items can be classified into two categories such as empirical and fundamental [9]. Many researchers tried to study the influence of different drying conditions on drying characteristics of the biomass materials during dehydration. Mcminn and Magee [10] reported that the shrinkage of potato volume was influenced by temperature; Ratti [11] studied the effect of relative humidity on the shrinkage of potato, apple and carrot and Lang and Sokhansanj [12] reported effect of relative humidity on the wheat and canola kernel.

The kinetics of the drying period is one of the important study to explore the time taken to dry the biomass at certain moisture level and the rate of water removal from the biomass. The drying characteristics of biomass open a new window of information for designing new and improved drying system [13]. In recent past, some studies were reported on the convective drying characteristics of the biomass hygroscopic non-porous materials such as potato, carrot core and carrot cortex [14], tomato under different isothermal drying [15] and potato slices [6]. These convective isothermal drying data were applied to different empirical mathematical models and based on the best of fit model they were selected to determine the kinetic rate constant of drying.

Few researchers had addressed the drying kinetics for different biomasses for isothermal conditions [6,14,15], as well as non-isothermal conditions [16,17]. Up to now the literature surveyed by the authors did not find any published results on isothermal convective drying characteristics of OPT in open air desk type fan drying and controlled atmosphere for temperature and humidity test chamber drying. These results are important in providing information to the researcher and drying technologist concerning the energy consumed, shrinkage occurred in the OPT and rate of water transported from the OPT to the atmosphere, both in open air and controlled atmosphere conditions. This is due to the fact that drying of biomass can cause shrinkage in the volume of the biomass materials and it may adversely affect on the properties of the final products. The objectives of this study were to find the suitable model for drying kinetics, drying rate and volume shrinkage of OPT chips under open fan and controlled atmosphere drying. The fitting of the experimental data to the isothermal drying models are verified and the obtained results are reported.

2. Materials and methods

2.1. Materials preparation and drying procedures

Approximately 25 years old fresh oil palm trunks were cut from a local plantation in Northern Malaysia. After debarking, the oil palm trunk was cut into small pieces of dimension of $44.43 \pm 0.2 \times 25.06 \pm 0.2 \times 17.90 \pm 0.2$ mm and weight 18.4200 ± 0.0050 g. The initial moisture content of oil palm trunks samples were determined by using the oven dry method at 105 °C for 24 h. The average initial moisture content was found to be 63.65% wet basis. The drying processes were carried out in the laboratory of Division of Bioresource, Paper and Coatings Technology, School of Industrial Technology, Universiti Sains Malaysia, Penang, Malaysia. These experiments were run at two different conditions for comparison between open air fan drying and controlled atmosphere. Five replicates of oil palm trunk samples were taken for each drying condition.

A table fan (35 watt table fan model Mistral-MBF-300) was used for open air drying; the samples were kept in the tray with single layer. The average relative humidity (RH) of the laboratory during sample drying period was 70–90% ± 2% with temperature around 23–27 ± 1 °C and the fan's air speed was approximately 1.5 ms^{-1}.

The RH chamber made of Gotech Testing Machine Desk type model GT-7005-T was used for controlled atmosphere drying. The relative humidity and temperature of the RH chamber was fixed at 80.0% ± 1.0% and 25 ± 0.5 °C, respectively. The samples were placed in a tray in single layer inside the RH chamber. The maximum deviation in relative humidity was recorded within 1% and in temperature increment of 0.5 °C during drying respectively.

2.2. Mathematical modeling

In this research, the nonlinear regression analysis had been performed using the MATLAB R2011b (7.13.0.564), together with the values of the drying parameters and the corresponding statistical data were also evaluated. All fitting calculations were done by using six isothermal drying kinetics models and the newly modified Midilli–Kucuk as listed in Table 1. Initially, all data were fitted with the models such as modified Midilli–Kucuk, Henderson–Pabis, Logaritnmic, Midilli–Kucuk, Newton, Page, and Wang–Singh model and than the constant parameter of each drying kinetic model was calculated. The non-dimensional moisture ratio (MR) [6] of oil palm trunk was calculated by using the following Eq. (1):

$$MR = \frac{(M_t - M_e)}{(M_0 - M_e)} \quad (1)$$

where M_t is the moisture content at any time (g water/g dry solid), M_o is the initial moisture content (g water/g dry solid), and M_e is the equilibrium moisture content of sample (g water/g dry solid). The models parameters were determined using a non-linear regression analysis. The indicator used to evaluate goodness of the tested models to the experimental data is the coefficient of determination (R^2). For fitting the non-directional moisture ratio data to the isothermal drying rate models the determination of the model parameters are essential. This task was performed using MATLAB R2011b (7.13.0.564) software.