Drying Kinetics of Oil Palm Frond Waste Using Simple Batch Oven Dryer

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Article Info	Abstract
	Drying phenomena of oil palm frond waste as agriculture waste was observed using simple batch oven dryer. The operation temperatures were 50, 80 and 120 °C. The sample of oil palm frond was weighed periodically every 30 minutes. Moisture content, shrinkage phenomena and drying kinetic model were investigated to the difference operation temperature. Experimental result exhibited that temperature influent significantly to the drying rate. The water transport controlled by diffuse mechanism. Shrinkage occurred in radial direction and decreased the size to almost 65% from initial size. In longitudinal direction almost is not change of size. The drying kinetic was $X = exp[-382697.447\ e^{(-7355.8/T)}\ t^n]$ for Page model and equation for MQSM (Modified Quasi-Stationary Method) model was $X = 1/\{1 + [t/(1206.7 - 3.1089T)]^n\}$.

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INTRODUCTION

As a largest exported oil palm in the world, Indonesia has about 10.1333 and about 10.5865 million Ha plantation in 2012 and 2013 respectively (Badan Pusat Statistik, 2015). Palm oil tree has many agriculture waste such as empty fruit bunch (EFB), palm pressed fibre (PPF), oil palm trunk (OPT), oil palm (shell) and oil palm frond (OPF). Every Ha of plantation area result about 10.88 tons oil palm frond every year that mean about 302055.6274 and 315564.7123 tons oil palm frond waste every day in 2012 and 2013 respectively (Kelly-Yong et al., 2011). This waste usually is abandoned or burned in plantation area due to the difficulty of transportation. Oil palm frond is a biomass that containing high holocellulose concentration so that can be utilized as cellulose source in pulp and paper industry (Zainuddin et al., 2011; Hussin et al., 2014), bioethanol (Goh et al., 2010; Ofori-Boateng & Lee, 2014), forage (Rahman et al., 2011) and bio-plastic (Zahari et al., 2015). Oil palm frond contains water content almost 70% wet based (Mohideen et al., 2011). For pulp and paper industry, water content of feed material influents significantly to the properties of final product because high water content can invite the microorganism such as brown rot fungi that decreasing the mechanical properties by consuming the cellulose. The other hand, low water content increase the chromophore formed from polyphenolic compound (Ressel, 2006; Singh & Singh, 2014). High chromophore cause high bleaching need. Thus, the drying step of feed materials is important step that determine the final product quality, cost effectiveness and environmental aspect.

Several researchers have been investigated the drying technologies to control water content of oil palm frond. Fudholi et al. (2015) observed the drying mechanism of OPF using solar assisted drying. Solar energy was used to heat air. Heated air then was sprayed to the chopped oil palm frond. Drying time was 22 hours (more than one day because one day 8 hours solar drying). Water content decreased from 60% to 10%. Mohideen et al. (2011) used swirling fluidized bed dryer to dry stem and leaves of OPF. The experimental result exhibited that stem and leaves could not be fluidized together due to difference hydrodynamic characteristic. Puspasari et al. (2012) used fluidized bed drying using heated air. OPF chopped to form noodle like form and hot air sprayed from the bottom of fluidized tank. Several drying model were fitted to the experimental result. However, the drying characteristic in batch drying method has not investigated. This paper observed moisture content, shrinkage and drying kinetics of OPF with different temperatures in batch oven drying. Several drying models were tested. The drying kinetic coefficient of drying models was calculated to find the drying kinetics model.

EXPERIMENTAL

OPF was collected from plantation around ITSB campus Cikarang, Indonesia then isolated with plastic wrap to keep the moisture content is not change while transportation. The chemical content of plant diverse depend on age, species, plant parts and usually chemical content of plant reported in range. OPF composed of stem and leave that have difference moisture content. Mohideen et. al. (2011) suggested that the stem and the leave have to dry in different reactor because they have difference initial moisture content and geometry. The diffusion depth of leaves smaller than stem so that the moisture loose faster. In this experiment, oil palm frond stem was used. The stem then chopped then dried using domestic batch oven (Kirin, China, Model KBO-90 M 9 L) at 50, 80 and 120 °C as shown in Fig 1. Moisture content then measured periodically every 30 minutes by weighting the OPF sample using digital weighing balance (OHAUS-Adveturer, NJ, USA) of accuracy 0.0001 g.

The experimental results were fitted with theoretical model shown in Table 1. where, X is normalized moisture content defined as.

$$X = \frac{X - X_e}{X_0 - X_e} \qquad (1)$$

t is time, a, k, b and σ are free parameters regard to each equation model. X, X_e and X_0 are moisture content in dry based (g water/g dry mass), equilibrium moisture content and initial moisture content, respectively. Free parameters were tried using Microsoft Excel using SOLVER tool by minimizing the residual mean square sum (RMSS) and calculated using Eqs. (2). SOLVER tool of Microsoft Excel have been used by Puspitasari et al (2012) get the drying parameter for OPF with fluidized bed dryer and show a good result.
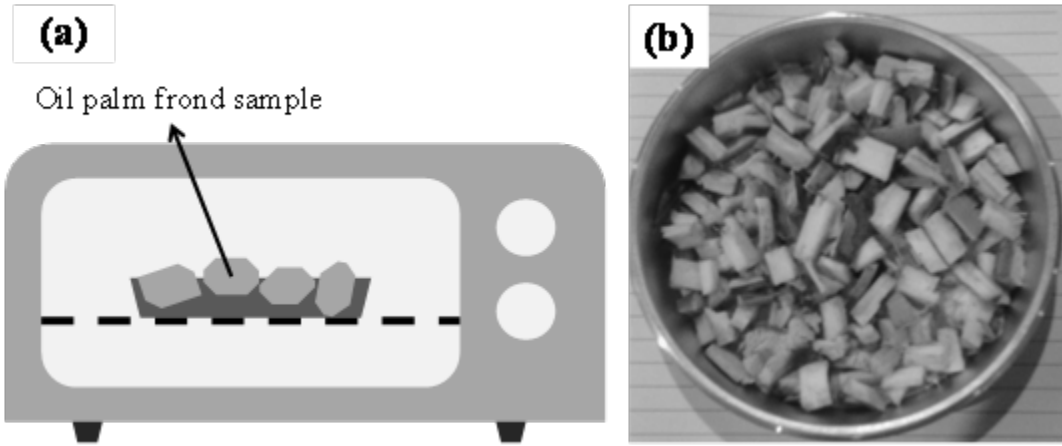
Figure 1. Schematic diagram of experimental apparatus (a) and chopped stem OPF (b)

Table 1. Theoretical kinetic model of drying.

No	Model	Equation	Reference
1	Page Model	$X = \exp(-kt^n)$	Puspasari et. al. (2012)
2	MQSM (Modified Quasi-Stationary Method) Model	$X = \dfrac{1}{1 + (t/\sigma)^n}$	Puspasari et. al. (2012)
3	Henderson & Pabis	$X = a\exp(-kt)$	Ayadi et. al. (2014)
4	Newton	$X = \exp(-kt)$	Ayadi et. al. (2014)
5	Wang & Singh	$X = 1 + at + bt^2$	Ayadi et. al. (2014)
6	Two Term Exponential	$X = a\exp(-kt) + (1 - a)\exp(-kat)$	Ayadi et. al. (2014)

$$RMSS = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{N - p}} \qquad (2)$$

where y_i, $\hat{y}_i$, N and p are experimental moisture, calculation moisture, number of data and number of drying parameter each model respectively. The shrinkage percentage was calculated based on the following equation

$$S = \frac{PZ}{IZ} \times 100\% \qquad (3)$$

with S, PZ and IZ are shrinkage percentage, present size and initial size respectively. The size of oil palm frond was measured by Image MIF free software using two dimensional image (Rahaman, 2003).

RESULT AND DISCUSSION

Fig. 2 and 3 show the photograph of oil palm frond for several drying condition. The surface of oil palm frond is crumpled 30 minutes after drying although the equilibrium moisture content is still far to be reach. This phenomenon indicates that the diffusivity of water inside the porous of oil palm frond and between cellulose fiber is much slower than the mass transfer of water in the interface to the bulk atmosphere. From the figure, oil palm frond undergo shrinkage several minutes after drying depend on drying condition. Shrinkage in the radial direction more significant than in the longitudinal direction as shown in Fig 4a. The percentage of decrease to about 65% in radial direction and almost constant in longitudinal direction. While the drying occurred, the water inside the porous in a pipe form, diffuse in the longitudinal direction that cause decreasing of inside pressure. This mechanism is shown in Fig. 4b. The result agree with Mohideen et al. (2011) that drying mechanism of stem oil palm frond controlled by diffusion. The decreasing pressure cause collapse the porous and shrinkage will be occurred. The increasing size after drying to higher than initial size more caused by human error calculation when measurement of oil palm frond. Several shrinkage phenomena found in organic material such as grape (Azzouz et. al., 2002) and potatoes (Bacelos and Almeida, 2011, Hassini et. al, 2007).

Drying rate is tightly related to the moisture content of materials and can be represented by moisture content change. Kemp et.
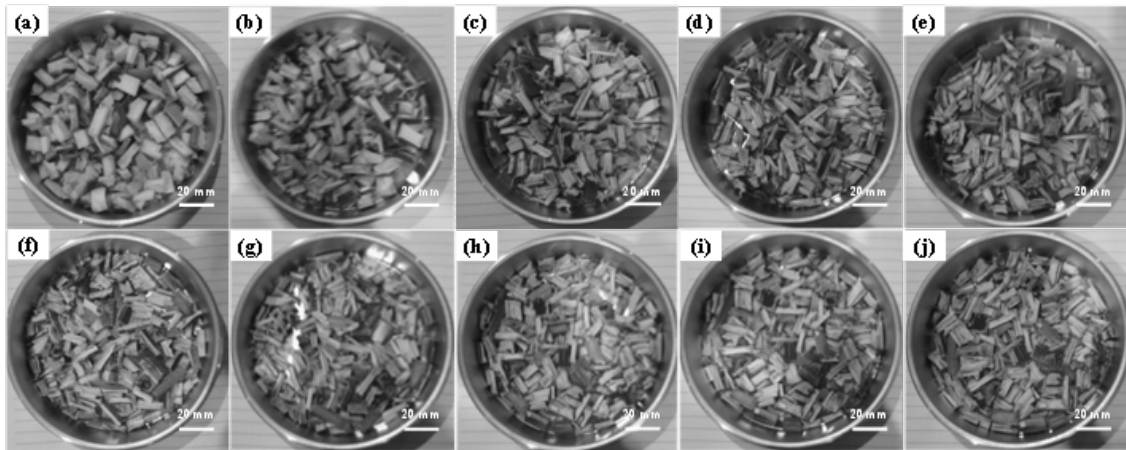
Figure 2. Photograph of chopped OPF with medium size after drying period 0 (a), 30 (b), 60 (c), 90 (d), 120 (e), 150 (f), 180 (g), 210 (h), 240 (i) and 270 min (j) at drying temperature 120 °C
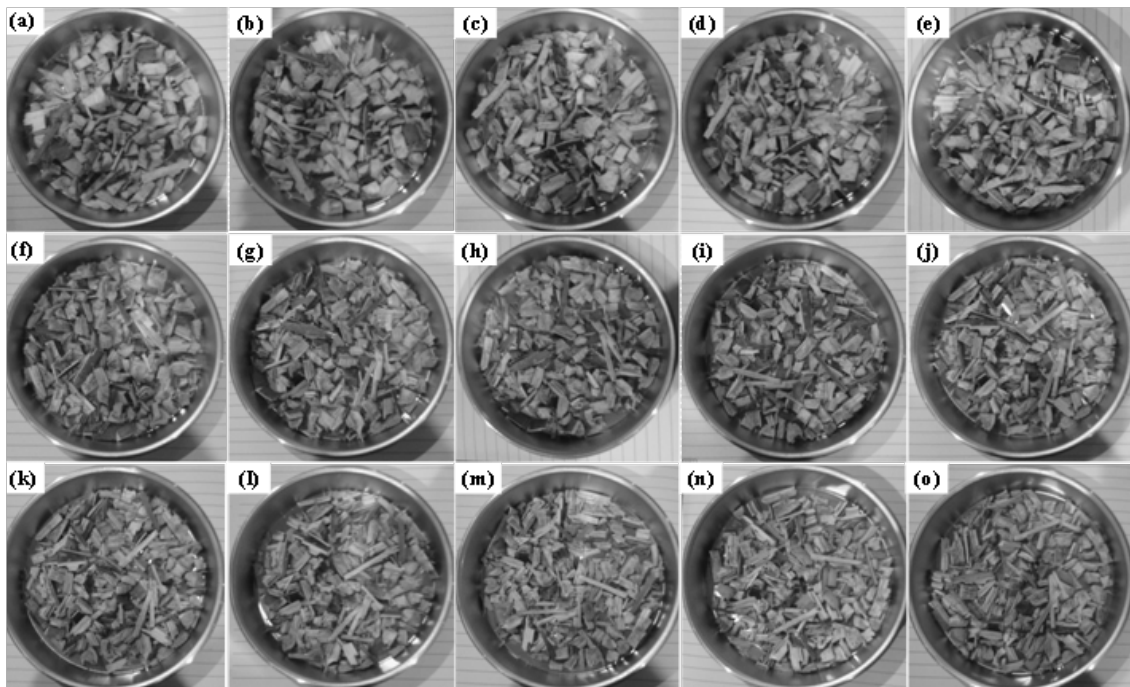

Figure 3. Photograph of chopped OPF with medium size after drying period 0 (a), 30 (b), 60 (c), 90 (d), 120 (e), 150 (f), 180 (g), 210 (h), 240 (i), 270 (j), 300 (k), 330 (l), 360 (m), 450 (n) and 540 min (o) at drying temperature 50 °C.

al. (2001) said that the drying rate of the material can be obtained by dividing the difference of weight of two point along the time interval. However, for periodic sampling and weighing give a few data point and not good enough to result the good drying curve (curve is not shown). Fig.5a exhibits the change of moisture content every 30 minutes. The experimental results reveal that the temperature of drying shows the significant effect to the drying rate. Higher temperature will cause lower humidity. Lower humidity that mean lower

water concentration in the surrounding air will enhance the driving force of drying rate. In addition, higher temperature just not influence the humidity of surrounding air but also increase the density difference of surrounding air so that increase the convective drying. The moisture content is about 337 % dry based or 77% wet based agrees with previous investigation done by Mohideen et. al. (2011).

Fig. 5b-d exhibits the plotting between experimental results and theoretical models. Page
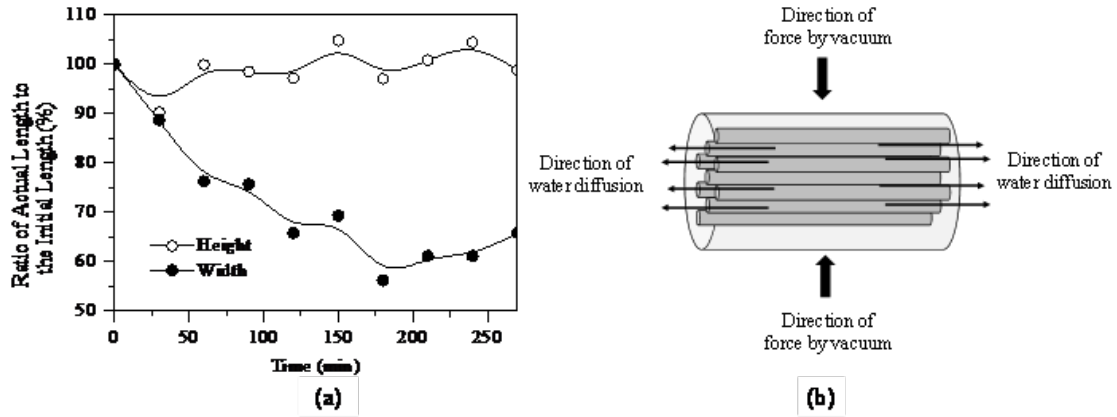
Figure 4. Change of length of chopped OPF to the time at operation temperature 120 °C (a) and the shrinkage mechanism (b)
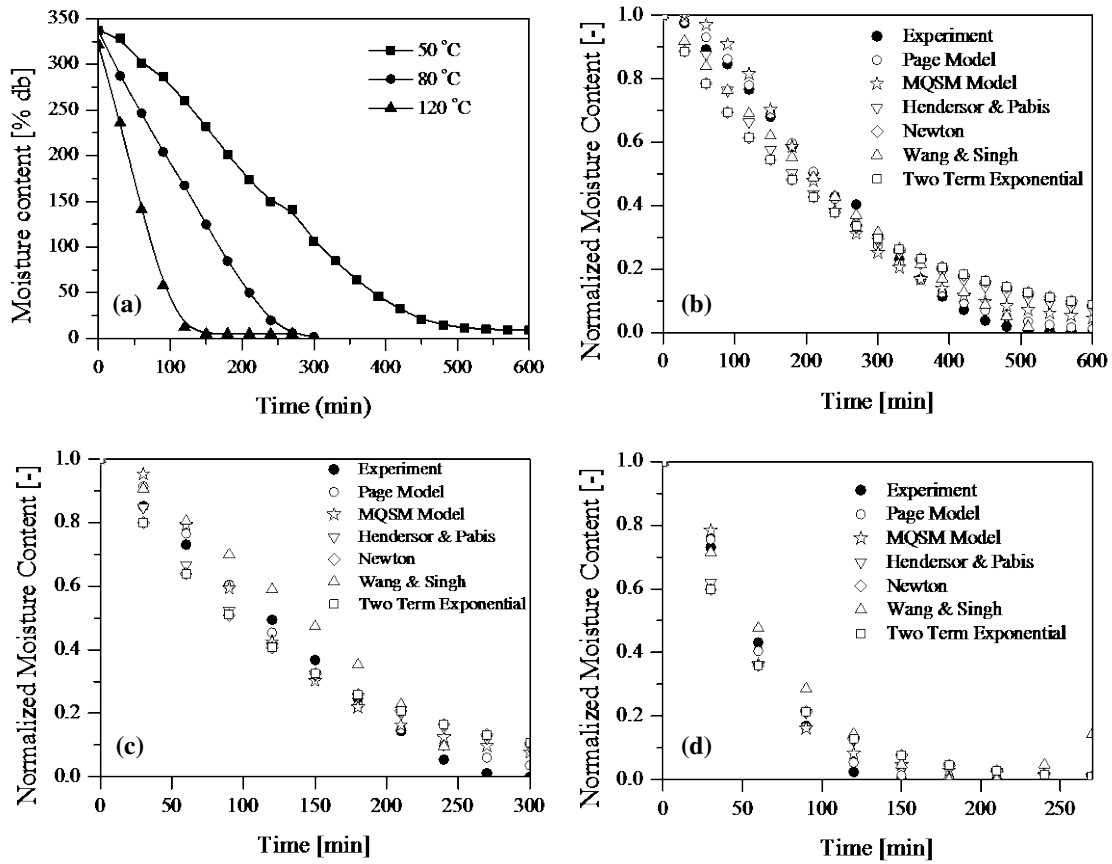

Figure 5. Moisture content to the time at several operation temperatures (a) and normalized moisture content to time at drying temperature 50 (b), 80 (c), 120 °C (d)

model show the smallest RMSS as shown in Table 2. Page model also reported shown best fitting result for several agriculture drying such as chestnuts (Correia et. al., 2013), soybeans (Mariani et. al., 2015) for several difference drying system. MQSM was used by Kudra and Efremov (2003) to model the drying kinetic of celery, wheat, cranberry and polystyrene. High index n in

MQSM model reveals that the drying mechanism internally controlled mass transfer (diffusion) as discussed before. In MQSM model is based on mass transfer in solid bulk in the diffusivity given by effective diffusivity resulting semi theoretical model.

The parameter for every equation is shown in Table 3. The drying kinetic coefficient of
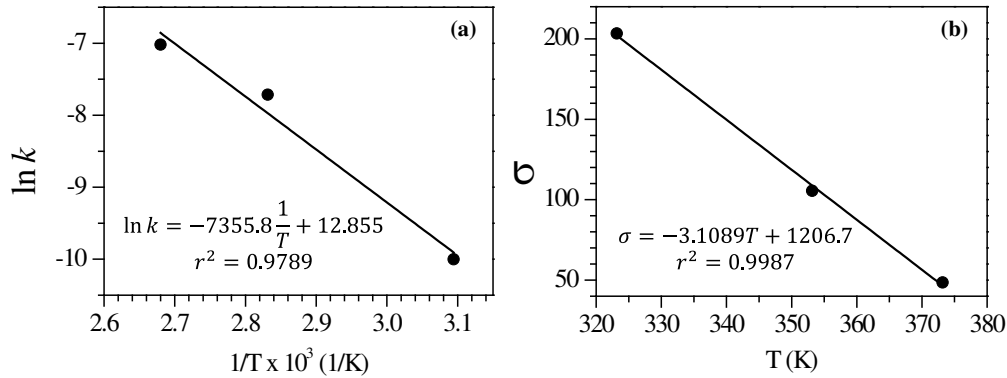
Figure 6. Graphical plot of Page (a) and MQMS (b) drying kinetic coefficient

Table 2. Error value of several models at several operation temperatures

Model	50 °C	80 °C	120 °C
Page Model	0.023787	0.039941	0.017434
MQSM Model	0.050743	0.068594	0.042668
Henderson &Pabis	0.086886	0.082211	0.070871
Newton	0.101836	0.084620	0.070437
Wang & Singh	0.048443	0.101521	0.082841
Two Term Exponential	0.104485	0.089255	0.074712

Table 3. Parameters of several models

Temperature (°C)	Page Model		MQSM Model		Henderson &Pabis	
	$k \times 10^4$	N	n	σ	A	$k \times 10^2$
50	0.4534	1.7988	2.8067	203.3676	1.1573	0.4641
80	4.4612	1.5623	2.3755	105.4833	1.0799	0.8064
120	8.9325	1.6904	2.6723	48.5835	1.0610	1.7919
	Newton	Wang & Singh		Two Term Exponential		
	$k \times 10^2$	$a \times 10^2$	$b \times 10^6$	$a \times 10^{-5}$	k	
50	0.4057	-0.2793	1.6976	1.6711	242.7783	
80	0.7492	-0.3088	-2.8210	33.3247	22.4548	
120	1.7128	-1.0317	26.4550	1.5948	1073.8306	

page and MQSM model is function of temperature. For page model, the drying kinetic coefficient obey Arrhenius equation

$$k = k_0 e^{\frac{-E}{RT}} \qquad (4)$$

Eq. (4) can be arrange in logarithmic form as shown in eq. and plotted linearly $\ln k$ to the $1/T$.

$$\ln k = -\frac{E}{R}\frac{1}{T} + \ln k_0 \qquad (5)$$

and drying kinetic coefficient for MQSM model is formulated as

$$\sigma = a + bT \qquad (6)$$

From the Fig. 6, E and k_0 are 61158.622 $kJ/(kgmol\,K)$ and 382697.447 respectively and a and b are 1206.7 and -3.1089 respectively. The kinetic model for Page model is

$X = \exp[-382697.447 e^{(-7355.8/T)} t^n]$ and $X = 1/\{1 + [t/(1206.7 - 3.1089T)]^n\}$ for MQSM model.

CONCLUSION

Drying mechanism of chopped OPF controlled by diffusion mechanism. Shrinkage phenomena was found in radial direction and decrease the size about 65% of initial size. In longitudinal direction the shrinkage did not appear. Operation temperature significantly affects the drying rate. Increasing temperature will increase drying rate. Moisture content is about 337% dry based. Page model followed by MQSM model exhibits best fitted model to the experimental result. The kinetic model is $X = \exp\left[-382697.447 e^{-\frac{7355.8}{T}} t^n\right]$ for

Page model and model for MQSM is $X = 1/\{1 + [t/(1206.7 - 3.1089T)]^n\}$.

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