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Drying Characteristics of Oil Palm Frond Particles in a Spouted Bed Dryer

Yie Hua Tan[1,*], Siti Masrinda Tasirin[2], Agus Saptoro[1], Cirilo Nolasco-Hipolito[3]

[1]Department of Chemical Engineering, Faculty of Engineering and Science, Curtin University Malaysia, Miri, Malaysia.
[2]Department of Chemical & Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Selangor, Malaysia.
[3]Instituto of Biotechnology. Universidad del Papaloapan. Circuito Central #200, Col. Parque Industrial, CP. 68301. Tuxtepec, Oaxaca. Mexico.

*Corresponding author: tanyiehua@curtin.edu.my

Abstract. The large quantity of oil palm fronds is generated by the oil palm plantation. This biomass has been seen as a promising raw material for paper production, biomass fuel and animal feed. Nevertheless, before its utilization, oil palm fronds require proper pre-treatments including drying. The present study aims to study the drying kinetics and characteristics of oil palm frond particles in a spouted bed dryer. In this research, inlet air temperature, air velocity and bed height were varied to obtain the optimal operating conditions for drying. Experimental results indicated that the drying rate is proportional with the inlet air temperature and air velocity, however, it is in reverse relationship with the bed height. The drying kinetic of oil palm frond particles in spouted bed was analyzed via drying curve. The attained drying rate curve shows the drying progressing with an initial drying period and two falling periods. On the other hand, no significant constant rate period could be observed. Combined effects of the parameters which can yield the highest quality product and consuming the least energy were also investigated. It was found that the optimum operating conditions were as follows: hot air temperature at 90°C, air velocity at 1.34 m/s and bed height equal to 10 cm. It is evident that compared to sun drying, a spouted bed drying has resulted in better qualities of dried oil palm frond particles in terms of colour and aroma.

1.0 Introduction

Malaysia is one of the largest producers of palm oil in the world with plantations covering an area of 4,487,957 hectares in 2017 [1]. Oil palm industries generate at least 30 million tonnes of lignocellulosic biomass annually in the form of oil palm trunks (OPT), empty fruit bunches (EFB), oil palm fronds (OPF) and palm pressed fibres (PPF) [2]. OPF can be found abundantly in Malaysia since the fronds are cutting off during the harvesting season which happens throughout the year. As a result, they are able to become one of the most reliable raw materials for papermaking, fiber boards, mattresses, cushions, cattle feed, fertilizer and can also be converted to bio-fuel such as bio-ethanol. These have proven that OPF has the greatest potential to be transformed to different commercial products and used in various industries [4]. In fact, OPF has been used as animal feedstock due to their low cost, especially in terms of cropping practice, collection and storage [5]. Hence, OPF is playing a significant role in the economics of Malaysia.

If the wet chopped oil palm frond is exposed to the atmosphere for a long period of time, it will degrade within 1 day due to the fungal attack. Thus, the colour of OPF will turn into brownish immediately followed by a black colour and subsequently emit an unpleasant foul odour. It is, therefore a crucial step, i.e. drying oil palm fronds is needed to be done as soon as possible in order to bring the moisture content to about 15 % dry basic. 15 % dry basic is chosen due to the moist content requirement of the cattle feedstock market in Malaysia [6]. According to [7], the cost of drying process occupied about 30 % of the total production cost, thus pre-drying of the chopped oil palm frond using solar is necessary for cost reduction purpose. Unfortunately, solar drying is highly dependent on daily weather which has significantly affected the production of ruminant feed. Also, the artificial heater which using hot air produced from combustion of fossil fuel is costly [8].

In this study proposed the spouted bed technique as the drying method for oil palm frond. This study was performed to study the drying kinetics in the spouted bed to show it is more effective and able to produce good quality dried oil palm frond in large quantities. The chosen material in this study is oil palm frond, i.e., the by-product and waste from the oil palm industry [9]. Thus, the objectives of this study were to obtain the drying kinetics of oil palm frond in spouted bed dryer and to review the drying performance of oil palm fronds up to 15% moisture content dry basis. The spouted bed was originally developed as a substitute for a fluidized bed for the coarse and uniformly sized particles in order to overcome the poor quality of gas fluidization. Some of its unique characteristics, especially the cyclic recirculation of the solids, have proven the spouted bed mechanism is capable to perform more effective drying operations than fluidized bed mechanism via the random solids spouted motion [10]. The main advantage of spouted bed dryer is able to handle the Group D particles (Geldart) effectively [11]. Moisture content was calculated based on a dry base (db) basis using the following Eq. (1) [12]:

$$X(db) = \frac{W_t - W_k}{W_k} \qquad (1)$$

where X (dry basis) is a fraction of moisture content; Wt is the sample weight at a specific time; Wk is the sample dry weight (g).

The investigation of the drying kinetic and characteristics of the chopped OPF using the spouted bed dryer, batch experiments were conducted by varying the superficial velocity of hot air (1.34 m/s, 1.46 m/s, and 1.58 m/s), temperature of hot air (50ºC, 60ºC, 70ºC, 80ºC and 90ºC) and two different bed height (10 cm and 15 cm). Optimization on the energy and the quality of the final OPF products have been analysed in this paper as well.

2.0 Materials and methods

2.1. Equipment

Figure 1 shows the schematic diagram of the experimental apparatus used in this study. Air entered the filter before it was flowing to the air blower. Air was supplied by an air blower and passed through an electric heater with a temperature control. The air humidity was measured by Hygroflex, Rotronic AG before it entered the spouted bed unit. The spouted bed column unit consists of a stainless steel column of 30 cm diameter and 1.5 m long. At the conical bottom of the unit is a spouting nozzle of 75 mm diameter. The material can be withdrawn through a spout arrangement at the bottom.

Table 1. Operation parameters for oil palm frond drying experiment in spouted bed

Set	Temperature (ºC)	Bed height (cm)	Air velocity (m/s)
A1	50	10	1.34
A2	60	10	1.34
A3	70	10	1.34
A4	80	10	1.34
A5	90	10	1.34
A6	80	10	1.46
A7	50	10	1.46
A8	50	15	1.46
A9	50	15	1.58
A10	60	15	1.46

A11	60	10	1.46
A12	60	15	1.58
A13	70	15	1.46
A14	70	15	1.58
A15	70	10	1.46

2.2. Preparation of oil palm frond sample
Fresh oil palm fronds used in this work were obtained from Bangi, Selangor Darul Ehsan, Malaysia. After removing the leaves, the oil palm fronds were subsequently cut into smaller pieces (2 cm) and ran through a mechanical shredder (Cheso Cresher Model LCT 10 HP). The chopped oil palm fronds were then crushed and the particles size was measured and determined as the type – D in Geldart's classification of particles (9.3 mm).

2.3. Drying Experiment
Initial moisture content of the samples was determined by placing the samples in an oven (Venticell, MMM Medcenter Gmbh, Germany) overnight at 100ºC [13]. The fresh crushed oil palm frond samples were then placed into the spouted bed column. The height of the layer was measured with a ruler. After a several readings were obtained, samples were taken out from the bed column. The air blower was switched on in order to let the air circulated in the bed column for about 15 mins until it achieved a steady state of operation. Next, the electric heater was switched on and the desire temperature was adjusted. The hot air circulated for about 10 min before the drying experiment. This is to reduce the heat loss through the bed's wall [14]. The oil palm frond samples were placed into the spouted bed through the feeder and the initial weight of a scoop of the oil palm frond sample was weighted. A scoop of the sample was taken out every 5 mins interval until 80 mins and the moisture content was then calculated. Different operating parameters for oil palm frond drying experiment in spouted bed are summarized in the Table 1.

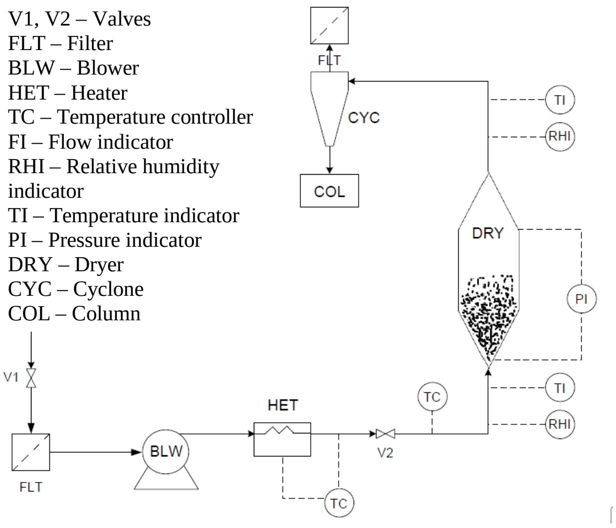

Figure 1. Schematic diagram of spouted bed dryer.

2.4. Sample result studies
For the comparison study, the oil palm fronds were dried under the sun. This was done by placing 500 g of chopped oil palm frond samples on a steel tray in thin layering. This sun drying was conducted in a span of 3 days. Observation on the changes of the dried oil palm fronds samples were jotted throughout the experiment.

3.0 Results and discussion

3.1. Drying rate against time curve

The drying kinetics were observed from the drying rate curve, dX/dt against drying time, t. Figure 2 shows the changes in drying rate in dry base with drying time at different temperature situations. In general, it can be observed that drying rate declines with time or with the reduction of moisture content. The drying rate curve indicated that there were two falling rate periods throughout the drying process. No constant drying rate period was observed and this may indicate that the drying was mainly controlled by the internal heat and mass transfer rate [15].

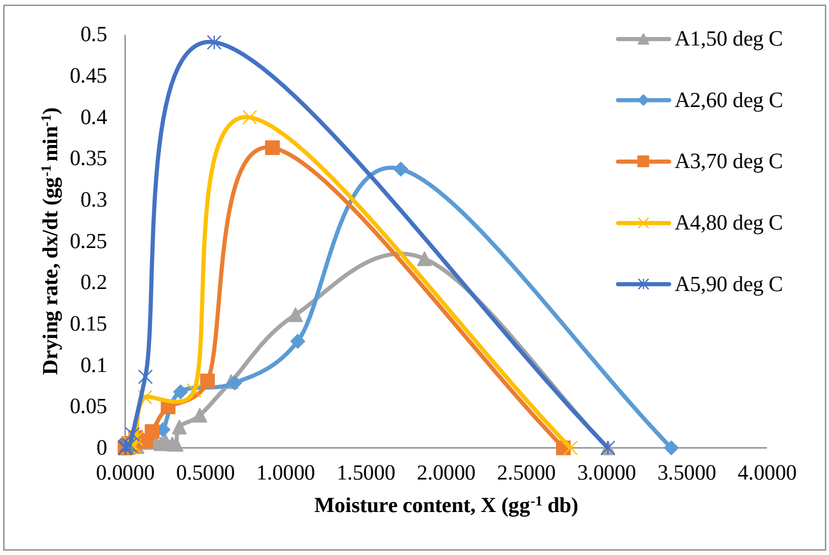

Figure 2. First drying rate at different temperature with fixed bed height (10 cm) and air velocity (1.34 m/s)

3.2. Energy consumption in drying process

Total energy requirement in each drying cycle using the dryer and energy needed for drying wet oil palm fronds were measured by using Eq. (2) and (3). The energy consumption in each period was estimated using Eq. (2) [16]:

$$E_t = Au\rho_a C_a \Delta T\, D_t \qquad (2)$$

E_t: total energy consumption in each drying (kWh), A: cross section area of column (m^2), u: air velocity (m/s), ρ_a: air density (kg/m^3), C_a: specific air heat (kJ/kg ^{o}C), ΔT: temperature difference (^{o}C), D_t: total drying time of each sample (hr)

The energy consumed for drying 1 kg of wet oil palm fronds was calculated using Eq. (3).

$$E_{kg} = \frac{E_t}{W_0} \qquad (3)$$

E_{kg}: Specific Energy Required (kW h/kg), W_0: initial weight of the sample. The total energy requirement for a charge of the dryer and energy needed for drying 1 kg of oil palm frond can be seen from Figure 3 and 4.

From Figure 3 and 4, it was observed that set A5 consumed the least energy (0.5050 kW h/kg) for drying 1 kg oil palm fronds at temperature 90^{o}C and air velocity of 1.34 m/s. Meanwhile, the maximum energy consumed during the drying process was set A1 (1.3059 kW h/kg) at 50^{o}C and 1.34 m/s. It can be concluded that the energy requirement decreases with increasing drying temperature and air velocity. Therefore, through optimization study, the parameters in set A5 were selected for drying oil palm fronds because it consumed the least energy in comparison to the others.

The lowest ratio value represents the optimal set of parameters since the most economical operation is defined as producing the largest amount of products using the smallest energy requirement.

Set A5 was observed having the smallest value of ratio of parameter as shown in Table 2. This means that set A5 have the most optimal operating conditions associated with the least energy consumption and high drying economy.

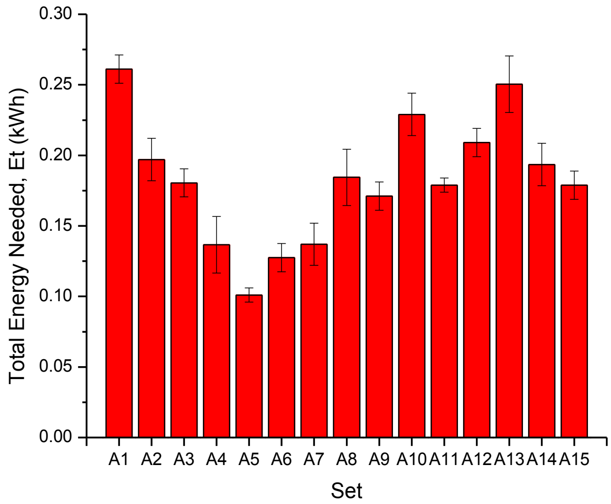

Figure 3. Total energy requirement for a charge of the dryer at different set parameter.

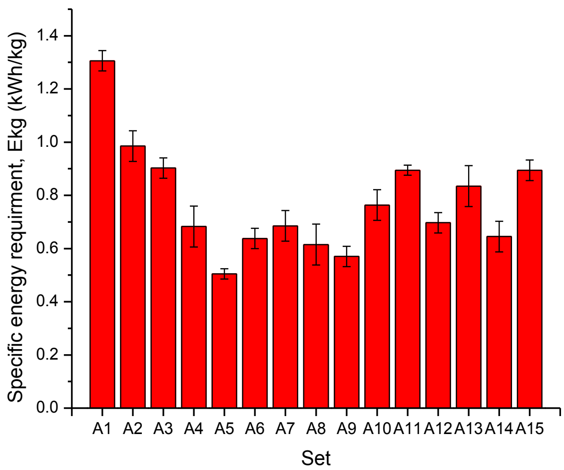

Figure 4. Specific energy requirement for different set parameter.

Table 2. Ratio of parameter at different operation parameters

Set	Air temperature, T (°C)	Air velocity, u (m/s)	Drying time, t (min)	Weight ,W (g)	Ratio of parameter (m.°C/g)
A1	50	1.34	54	200	1085.40
A2	60	1.34	30	200	723.60
A3	70	1.34	22	200	619.08
A4	80	1.34	14	200	450.24
A5	90	1.34	9	200	325.62

A6	80	1.46	12	200	420.48
A7	50	1.46	26	200	569.40
A8	50	1.46	35	300	511.00
A9	50	1.58	30	300	474.00
A10	60	1.46	32	300	560.64
A11	60	1.46	25	200	657.00
A12	60	1.58	27	300	511.92
A13	70	1.46	28	300	572.32
A14	70	1.58	20	300	442.40
A15	70	1.46	20	200	613.20

Table 3. The optimal parameter of the set A5

Air temperature, T (°C)	Air velocity, u (m/s)	Bed height (cm)	Weight, W (g)
90	1.34	10	200

3.3. Comparison between spouted bed and direct sunlight drying

A comparison between drying oil palm fronds using spouted bed and direct sunlight were studied. It was observed that solar drying is highly dependent on daily weather. If the weather was good, the drying time to achieve 15% (dry base) was observed around 3 days. If the weather was bad (rainy day), longer drying time (~5 days) to achieve the desired moisture content was noticed. While, spouted bed method only required approximately 15 mins to dry the oil palm frond chips. Figure 5 shows the quality comparison between the spouted bed and direct sunlight drying.

Figure 5. Quality comparison of oil palm frond using (a) Spouted bed (b) direct sunlight.

Dried oil palm frond from the spouted bed has a white greenish colour, whereas, the oil palm frond which dried by direct sunlight appeared as yellowish-light brown chips is due to the serious fungus attack on the surface of oil palm fronds. The quantitative data of colour test was conducted using colorimeter (chromameter CR-400, Konica Minolta). CIE 'Lab' colour space is independent device and can serve as an absolute colour reference (Sharma, 2003). Furthermore, it represents all colour visible to the human eyes and similar colours can be found in close proximity within the colour space. The CIE 'Lab' co-ordinate system is shown in Figure 6, which separates the ambient lighting or luminosity ('L'), into the vertical axis and the chromaticity into the horizontal axis. The chromaticity is represented by two parameters 'a' and 'b'. The 'a' represents the green–red colour component and the 'b' represents the blue–yellow component [17].

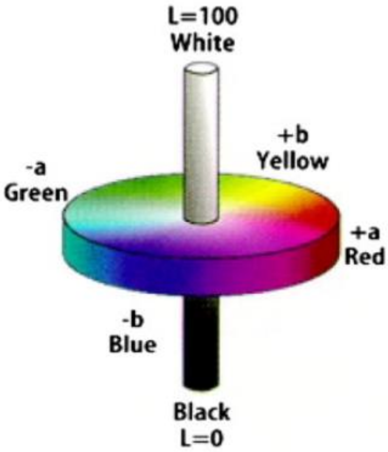

Figure 6. CIE 'Lab' colour space [18].

The difference in colour was measured using the following Eq. (5),

$$\Delta E*_{ab} = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \quad (5)$$

Table 4 shows the L*, a* and b* readings for dried oil palm frond from spouted bed and direct sunlight drying. While, Table 5 shows the colour difference in dried oil palm frond chips between spouted bed and direct sunlight drying.

Table 4. L*, a* and b* readings for dried oil palm frond spouted bed and direct sunlight drying

Reading	L*	a*	b*
Fresh oil palm frond chips	72.25	2.12	17.82
Dried oil palm frond chips by spouted bed	78.11	0.90	15.08
Dried oil palm frond chips by sunlight drying	55.30	2.61	16.58

Table 5. Colour difference in dried oil palm frond chips between spouted bed and direct sunlight drying

	Spouted bed	Sunlight
ΔL*	5.86	-16.95
Δa*	-3.02	0.49
Δb*	-2.74	-1.24
ΔE	7.1351	17.0054

The smallest value of ΔE for the spouted bed indicated that there is insignificant colour difference between dried oil palm frond chips via spouted bed and fresh oil palm frond chips. The colour of dried oil palm frond chips via spouted bed method is lighter, greenish and blue than fresh oil palm frond chips. On the other hand, the colour of the dried oil palms frond chips by the way of sun drying is darker, reddish and blue than fresh oil palm frond chips.

Aroma wise, the dried oil palm frond chips via spouted bed gave out a fresh grass and sugar cane scent whereas the sun dried oil palm frond chips produced a 'sour' smell and lack of freshness aroma. In terms of shape, the dried oil palm frond chips via spouted bed had a smoother surface. While, the sun dried oil palm frond, however, a lot of tiny fibres and agglomerated particles can be found on the surface of the chips. Thus, it can be concluded that spouted bed oil palm fronds possess better quality compared to sun dried ones.

4.0 Conclusions

The drying characteristics of oil palm frond particles via spouted bed dryer were investigated at various operating conditions. The drying rate increases with the increase in hot air temperature and hot air velocity; decreases with an increase in bed height. The drying curve identified that the drying progressed with two falling periods. No constant drying rate period was observed. The obtained optimum operating conditions that yield the best final quality and used the least energy were hot air temperature at 90°C, air velocity 1.34 m/s and height of bed 10 cm. Additionally, a comparison between two drying methods: spouted bed and sun dried oil palm frond was investigated. It is apparent that spouted bed drying method is being able to produce a better quality dried oil palm frond chips in a shorter period of time.

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