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Spouted Bed Drying of Oil Palm Frond Particles

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***Abstract*— Oil palm frond has been used for many applications especially as a source of industrial fibers. Drying of oil palm frond particles is essential before the material could be used for subsequent applications. This research aimed to study the drying kinetics of oil palm frond particles in a spouted bed dryer. Spouted bed dryer has been used by various industries because of its ability to dry large size and irregular shape particles. In this research, experiments were conducted to study the effect of various operating variables on the drying kinetics of oil palm frond particles in a spouted bed dryer. The manipulated variables were hot air temperature, superficial air velocity and bed height. Batch drying experiments of oil palm frond particles were performed by varying the hot air superficial velocity (1.3 m/s, 1.5 m/s and 1.6 m/s), temperature of hot air (50°C, 60°C and 70°C) and bed height (10 cm and 15 cm). For comparison purposes, samples of oil palm fronds were also dried under the sun. The fiber color changes subjected to two different drying methods were also observed. Drying kinetic results from the spouted bed drying experiments indicated that the drying duration decreased with an increased in air temperature and air velocity and a decreased in bed height. The color of the fiber from spouted bed dryer was less deteriorated compared to that dried by direct sun drying. Drying of oil palm fronds in a spouted bed dryer produced fibers that were lighter in color than the product dried by sun drying.**

***Keywords*— drying kinetics; fibrous material; spouted bed; oil palm frond; quality of product.**

I. INTRODUCTION

The most generated oil palm biomass is oil palm frond (OPF), which estimated up to 46.53 MT in 2012 [1]. Thus, the opportunity of utilizing this oil palm waste is promising. Many current research have reported the utilization of OPF for other purpose particularly as source of industrial fibers or cellulose [2] in various products such as pulp and paper [2], compressed boards [3], filler in composites [4], food ingredients/xylose [5], and animal feed meal [6]. It also composed of lignocellulosic materials that can be utilized to produce bio-ethanol [7]. The high carbohydrate content in OPF also potential for the production of bio-succinate [8], [9]. Recently, Mastuli et al. [10] reported the utilization of oil palm frond for hydrogen production through catalytic gasification process.

Normally, oil palm frond has about 60-70% moisture content based on wet basis (wb), therefore, it must be dried to at least 15% moisture content in order to prevent microorganism growth [11]. Solar drying and conveyor type dryer have been used by the industry to dry oil palm fibers [12]. However, the final product moisture content from these dryers may not be uniform because of the uneven contact between the gas and the fiber in the dryers. Puspasari et al. [13], [14] reported the application of fluidized bed dryer assisted with mechanical agitation to dry the oil palm frond fibers. They showed that agitation helped to assist the fluidization of the fibrous material and hence homogeneous mixing in the bed was achieved. Effects of inlet air temperature from 50-80 ºC, superficial air velocity from 0.6-1.0 m/s, bed load from 200-300 g, and agitation speed from 300-500 rpm on the drying characteristics were investigated. Their results showed that the most important parameter affecting the drying rate was air temperature, followed by air velocity and bed load. They also stated that agitation speed only showed small effect on the drying rate. Mohideen et al. [11] have also utilized the fluidized bed dryer for the drying of oil palm fronds. Both the leaves and stems were successfully dried in a swirling fluidized bed dryer at air velocities of 1.25 and 2.0 m/s and temperatures of 45 and 60 ºC. They concluded that the average time to reduce the moisture content to 15% was 60 minutes and 90 minutes for the leaves and stems, respectively.

Spouted bed dryers have been widely used to dry various materials with irregular shapes and sizes [15]. Although several publications have reported the applications of spouted bed drying, information about OPF drying is very limited. The purpose of this paper is to determine the effects of various drying variables, namely air velocity, air temperature and layer height, on drying kinetics of oil palm frond particles in a spouted bed dryer. The fiber color changes were also investigated.

II. Materials and Methods

A. Spouted Bed Dryer

Fig. 1 shows the schematic diagram of the spouted bed dryer in Drying Technology Laboratory, Department of Chemical and Process Engineering, Universiti Kebangsaan Malaysia. The bottom part of the dryer (i.e. the cone) is connected to a blower and heater whereas the upper part of the dryer is the outlet exhaust gas and dust to the cyclone and bag filters. The spouted bed dryer is made of stainless steel with overall height (including cyclone) of about 4 m from the floor. The blower is driven by a motor of 20 hp while the electric heater controls the temperature with thermostat. The cylinder column height is 75 cm and the cone (the gas inlet) height is 30.5 cm. The cylinder has a diameter of 30 cm whereas the nozzle cone has a diameter of 7.5 cm. The nozzle cone has an angle of 40º.

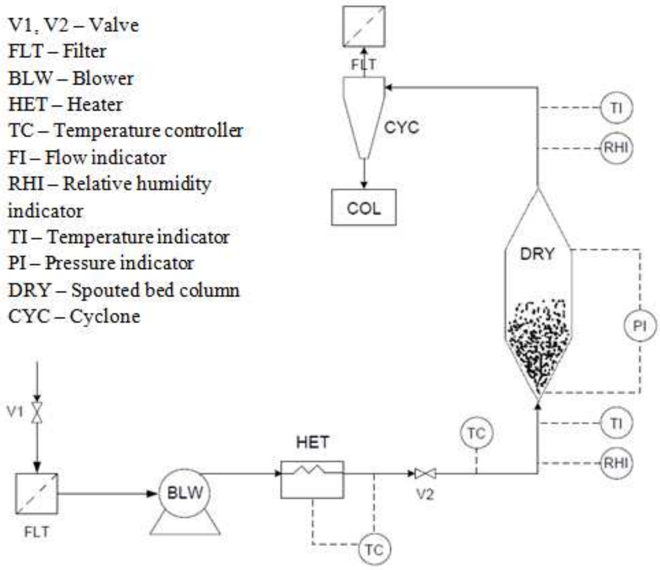


Fig. 1 Schematic diagram of spouted bed dryer

B. Materials

The fresh oil palm fronds were obtained from Bangi, Selangor Darul Ehsan, Malaysia. After the leaves have been removed, then the frond was cut into 2 cm pieces and further crushed in a mechanical shredder (Cheso Cresher Model LCT 10 HP). The crushed oil palm frond is shown in Fig. 2. The average initial moisture content of oil palm fronds used in this work was 74.9 ± 19.6% wb.

Fig. 2 Crushed oil palm fronds

C. Drying Experimental Procedures

In this study, the drying kinetics of oil palm fronds in spouted bed dryer was investigated at different drying parameters. The drying parameters used were air velocity, air temperature and bed height of oil palm fronds. Experiments were conducted at: air velocities of 1.3, 1.5 and 1.6 m/s; air temperatures of 50, 60 and 70 ºC; bed heights of 10 and 15 cm (which corresponds to bed weights of 200 and 300 g, respectively). Table I shows the experimental run performed in this study. During each experiment, oil palm frond was sampled every 5 min to analyze its moisture content. The desired final moisture content of oil palm frond was about 15% (w.b.). For comparison purposes, samples of oil palm fronds were also dried using sun drying method. In this case, the drying experiment was terminated when the moisture content of the sample reached 15% wet basis.

TABLE I
Experimental Run for Drying of Oil Palm Fronds in Spouted Bed Dryer

Run	Temperature (ºC)	Air velocity (m/s)	Bed height (cm)
R1	50	1.3	10
R2	60	1.3	10
R3	70	1.3	10
R4	50	1.5	10
R5	60	1.5	10
R6	70	1.5	10
R7	50	1.5	15
R8	60	1.5	15
R9	70	1.5	15
R10	50	1.6	15
R11	60	1.6	15
R12	70	1.6	15

Moisture content (dry basis) of oil palm fronds is calculated using [16]:

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

D. Color Analysis of Dried Sample

The color analysis was conducted using Minolta Chromaticity Meter CR-200 (Konica Minolta, Osaka, Japan). CIE-$L^*a^*b^*$ method was used as the color testing method. L^* stands for lightness, while a^* and b^* are for chromaticity. The color direction is indicated by the sign of a and b, i.e.: $+a^*$ shows the direction to red, $-a^*$ shows the direction to green, $+b^*$ shows the direction to yellow and $-b^*$ shows the direction to blue. The color change, ΔE^*, is given by:

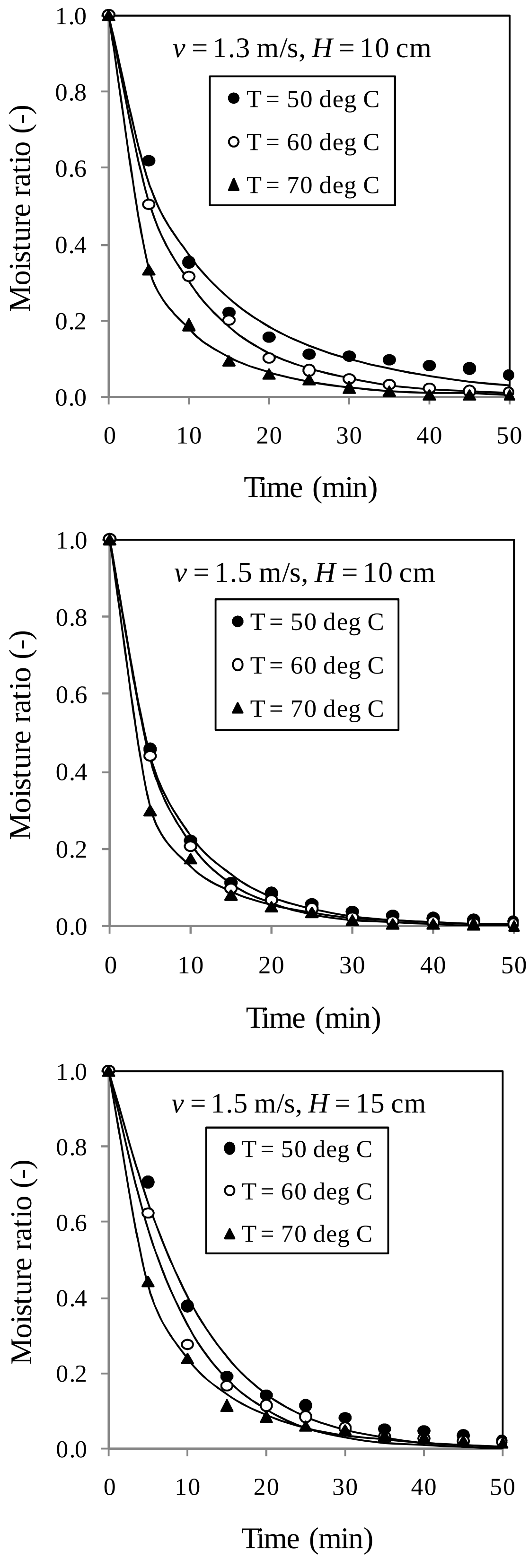
$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (2)$$

III. Results and Discussion

A. Drying Kinetics of Oil Palm Fronds

Fig. 3 shows the effect of varying the inlet air temperature on the drying kinetics of oil palm fronds in a spouted bed dryer. As expected, drying at the highest air temperature (70 ºC) resulted in the shortest drying time and hence, the highest drying rate. It was observed that the drying time required to dry the oil palm fronds to 15% moisture content (wb) at inlet air temperature of 50, 60 and 70 ºC is 48, 29 and 20 min, respectively, with air velocity of 1.3 m/s and bed height of 10 cm. Increasing hot air temperature causes a reduction in the drying time, showing that the rate of drying increases with air temperature. Air temperature increase causes the increase in temperature gradient inside the solid. Thus, the amount of heat transferred is also increases. Aghbashlo et al. [17] explains that the increase in temperature causes an increase in the slope of the drying curve showing that the effective moisture diffusivity increases with temperature. Fig. 3 also shows that the effect of inlet air temperature in enhancing the rate of drying was less pronounced at a higher inlet air velocity. The enhancement of drying rate at higher air velocity (1.5 m/s) was lower than that at lower air velocity (1.3 m/s), as observed when the drying process of oil palm fronds was performed at different temperatures and fixed bed height of 10 cm. However, with the increase of bed height to 15 cm and air velocities to 1.5 and 1.6 m/s, no noticeable difference on the drying rate was observed.

Fig. 4 shows effect of different air velocities on the drying kinetics of oil palm fronds. As can be seen in Fig. 4, using a higher air velocity resulted in a shorter drying time or in other words a higher drying rate than that obtained at lower inlet superficial air velocity. The bed of oil palm fronds was much better stirred at higher inlet air velocity due to the greater bulk air movement and hence, a higher drying rate was achieved. The shorter drying time with higher air velocity was also reported by a lot of investigators includes Reyes et al. [18] for the drying of carrot slices in an agitated fluidized bed dryer. However, it was also observed from Fig. 4 that, for a fixed bed height of 10 cm, the effect of superficial air velocity was less obvious at higher inlet air temperature. The difference on the drying rate caused by the increase in inlet air velocity was larger for lower air temperature. According to Wachiraphansakul and Devahastin [19], the effect of air velocity was greater when drying at low temperatures because the driving force for heat transfer was not large enough to exceed the effect of stronger agitation in the bed at higher air velocity. The difference on the rate of drying induced by increasing the air velocity diminished with deeper bed.



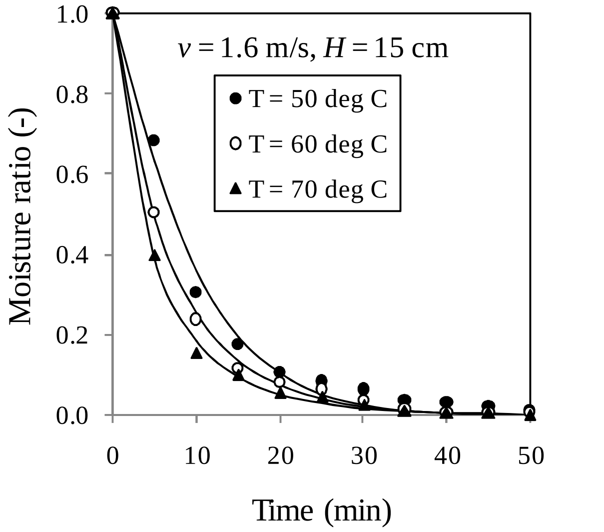
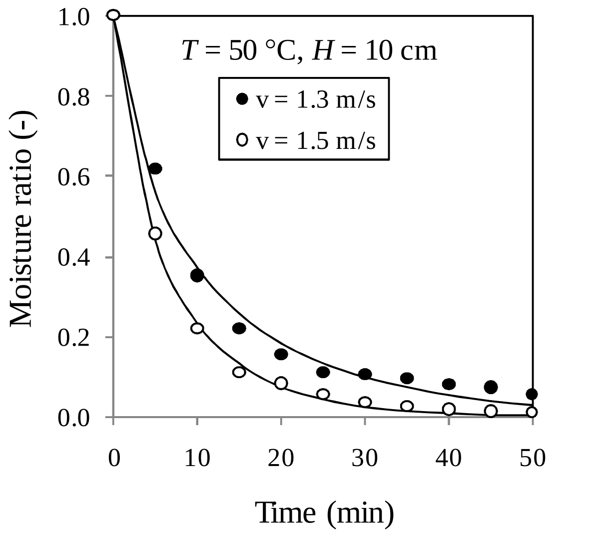
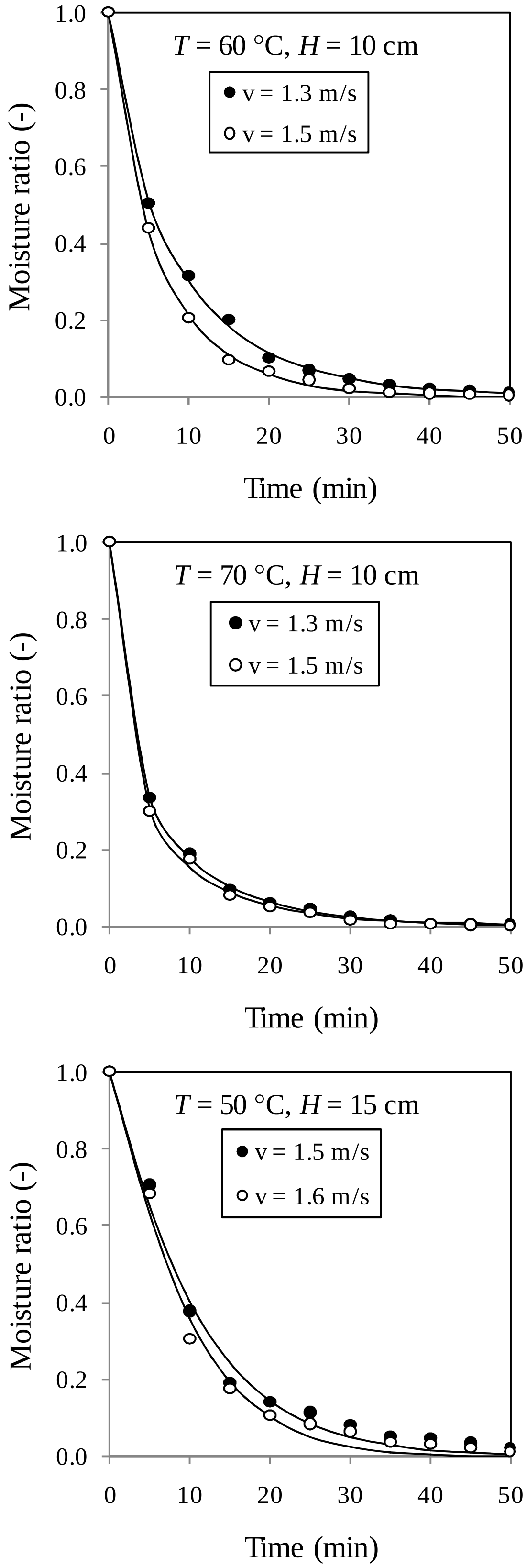


Fig. 3 Effect of inlet air temperature on drying kinetics of oil palm fronds

The effect of different initial bed heights on the drying kinetics of oil palm frond is shown in Fig. 5. It can be observed from Fig. 5 that operating with lower bed height (10 cm) resulted in a higher drying rate compared to that with a deeper bed of oil palm fronds (15 cm). As stated by Srinivasakannan and Balasubramanian [20], when the bed height of the solid decreases, the amount of moisture diffusing from the solid to the gas also decreases. As a result, the bed temperature increases and moisture diffusivity also increases. This causes an increase in the drying rate. It was also observed from Fig. 5 that for a fixed superficial air velocity, the effect of bed height was less pronounced at higher air temperature. This means that the reduction of drying rate by the increase in bed height was lower for higher drying air temperature.





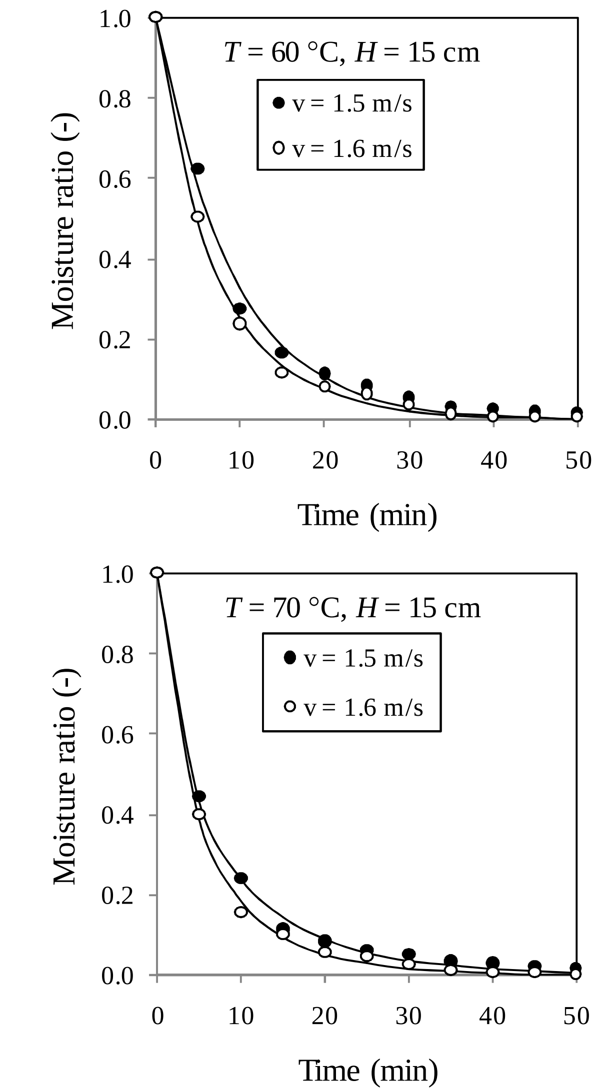


Fig. 4 Effect of inlet air velocity on drying kinetics of oil palm fronds

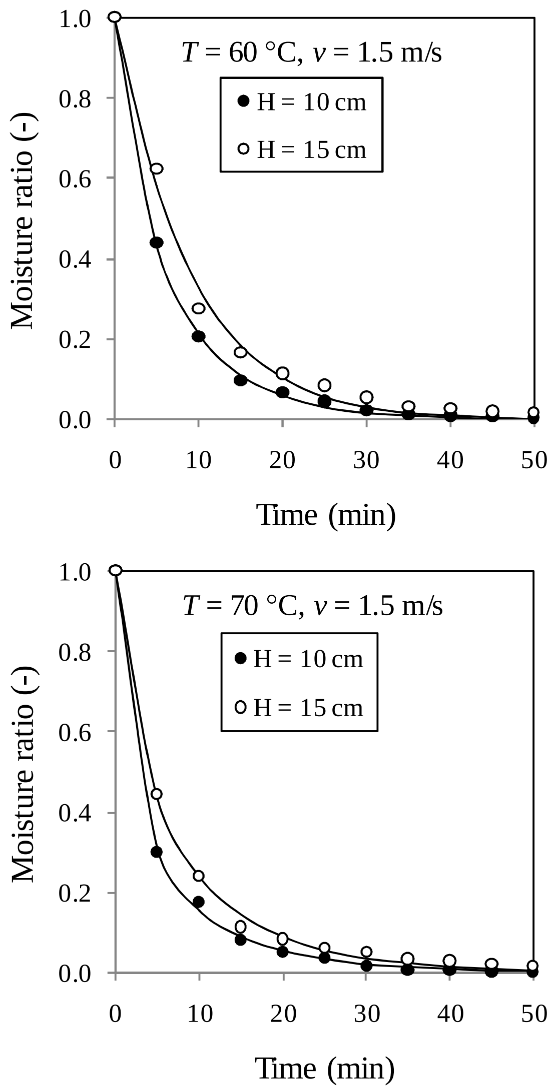
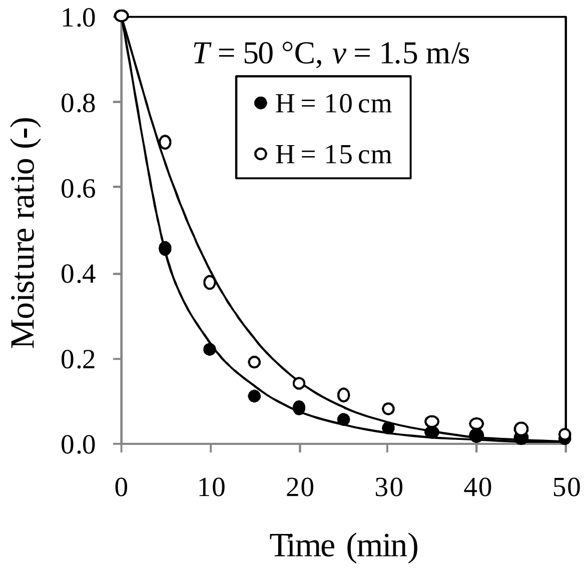


Fig. 5 Effect of initial bed height on drying kinetics of oil palm fronds



B. Comparison using Different Methods

Fig. 6 shows the photograph of the products dried in spouted bed dryer (a) and drying under the sun (b). It is clear that dried fronds in the spouted bed dryer preserved its natural color while the dried product from sun drying appeared darker in color and tend to be brownish. Table II lists the color difference of oil palm fronds underwent different drying methods. It can be seen that the value of *L** (lightness) of dried oil palm fronds had the largest change compared to the other color values. The largest difference of *L** value occurred when drying the oil palm fronds under the sun. The oil palm frond dried by sun drying was darker than fresh oil palm frond. The color change of *b** was between 1.24 and 2.74. The negative values imply that the yellowness of dried oil palm frond was lower than that of fresh oil palm frond. The drying method which gave the largest change in the value of *b** was spouted bed drying. The redness of dried oil palm fronds changed between 0.49 and 3.02 compared to the redness of fresh oil palm fronds. Oil palm frond which was dried using spouted bed dryer had a largest change of the *a** value which was 3.02. Overall, from the value of color change ΔE^*, it is clear that drying of oil palm fronds in spouted bed dryer produced fibers with less color deterioration compared to the fibers produced from direct sun drying indicated by the lower value of ΔE^*.

Fig. 6 Photograph of dried oil palm frond using: (a) Spouted bed (b) Direct sunlight

TABLE II
EXPERIMENTAL RUN FOR DRYING OF OIL PALM FRONDS IN SPOUTED BED DRYER

Drying method	L^*	a^*	b^*	ΔL^*	Δa^*	Δb^*	ΔE^*
Fresh	72.25	2.12	17.82	0	0	0	0
Spouted bed	78.11	-0.90	15.08	5.86	-3.02	-2.74	7.14
Sun	55.30	2.61	16.58	-16.95	0.49	-1.24	17.00

IV. CONCLUSION

The drying characteristics of oil palm frond particles in a spouted bed dryer were investigated at various operating conditions, i.e. superficial velocity of hot air (1.3 m/s, 1.5 m/s and 1.6 m/s), temperature of hot air (50 ºC, 60 ºC and 70 ºC) and bed height (10 cm and 15 cm). The shortest drying duration was obtained at the highest hot air temperature and hot air velocity and the lowest bed height. It was observed that the drying time required to dry the oil palm fronds to 15% moisture content (wb) at inlet air temperature of 50, 60 and 70 ºC was 48, 29 and 20 min, respectively, at air velocity of 1.3 m/s and bed height of 10 cm. However, for a bed height of 10 cm, the effect of superficial air velocity was less obvious at higher inlet air temperature. The difference on the drying rate caused by the increase in inlet air velocity was larger for lower air temperature. It was also observed that for a fixed superficial air velocity, the effect of bed height was less pronounced at higher inlet air temperature. It can be concluded in this case that the reduction of drying rate by the increase in bed height was lower for higher drying air temperature. A comparison between fibers that were dried using direct sunlight and those dried using spouted bed dryer showed that drying of oil palm fronds in the spouted bed dryer preserved its natural color. Drying under direct sunlight caused considerable reduction in the lightness of dried oil palm fronds.

NOMENCLATURE

L^*, a^*, b^*	Color parameters
v	Air velocity (m/s)
W_o	Initial weight of sample (kg)
W_k	Dry weight of sample (kg)
W_t	Weight of sample at a specific time (kg)
X	Moisture content (kg water/kg dry solid)
ΔE^*	Color difference

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