Drying 2004 – Proceedings of the 14th International Drying Symposium (IDS 2004)
São Paulo, Brazil, 22-25 August 2004, vol. C, pp. 2027-2034

THROUGH DRYING OF OIL PALM EMPTY FRUIT BUNCHES (EFB) FIBER USING SUPERHEATED STEAM

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Keywords: through drying; Empty Fruit Bunches fiber; superheated steam

ABSTRACT

The quality of loose fibers from empty fruit bunches (EFB) of the oil palm that is dried by using hot flue gases in a deisel-fired rotary drum dryer suffers from over-drying, browning and dust explosions. Through drying of loose EFB fibers using superheated steam as the drying medium improves dried fiber quality by avoiding browning and dust explosion due to the absence of air in the drying medium. In this study, the effect of steam temperature and steam velocity on the drying kinetics, drying characteristic and quality of dried EFB were investigated. Steam temperature was set in the range of 122°C to 152°C at one atmsophere pressure whereas steam velocity was varied from 0.6 m/s to 1.2 m/s. The initial moisture content is between 1.8 to 2.3 g moisture per g dry fiber. Quality parameters such as color change and strength properties of EFB fibers were tested using a chromameter and a testometric tensile machine respectively. It was found that moisture removal is faster when the steam temperature is higher and that there is a saturation temperature (142°C) beyond which there is no more increase in the drying rate and no further increase in the slope of the falling rate period. The drying rate curves have two periods: the increasing drying rate period and the falling drying rate period for steam velocity above 1 m/s. The increasing drying rate period is caused by moisture quickly flashing into vapour and being forced out of the fiber by entrainment into the steam and by the rise in moisture vapour pressure within the fiber. The falling rate period is due to internal resistance of the remaining bound moisture within the fiber. Moisture removal was also found to be faster when the steam velocity increases. At lower steam velocity of less than 1 m/s, there is a constant drying rate period at the transition between the increasing and the falling drying rate period which is caused by the lesser ability of the slower steam to entrain more moisture from the fiber. Through steam dried EFB fiber was found to show either no significant color change or a brighter color change in comparison with oven air dried or undried fiber. It was also

found that through steam drying does not significantly change the moduli of elasticity and hence the strength of the EFB fiber.

INTRODUCTION

Malaysia's palm-oil industry currently operates more than 300 palm oil mills that process palm oil from 2.5 million hectares of oil palm estates throughout the country and produce more than a million metric tonne of empty fruit bunches (EFB) as waste material every year (Chua, 1991). In the past, EFB waste was either burnt off or left mulching on the ground neither of which is environmentally and economically viable. The EFB fibers are however found to be strong and stable and could be processed easily into various dimensional grades to suit specific applications in mattress and cushion manufacture, soil stabilization/compaction for erosion control, landscaping and horticulture, ceramic and brick manufacture and flat fiber board manufacture. The first step of producing dry loose EFB fibers using hot flue gases in a conventional deisel-fired rotary drum dryer suffers from over-drying, browning, entangled fiber and dust explosions.

On account of these limititations in the conventional drying of EFB fiber, the objective of this study is to seek an alternative drying medium and drying technique that could improve EFB fiber product quality and dryer safety. Replacing the hot flue gases with steam avoids browning and dust explosions due to the absence of oxygen in the drying medium. Replacing rotary drying with through drying on a belt dryer avoids fiber entanglement as well. Through steam drying with and without impingement jets has been used successfully for the production of sufficiently permeable products such as textile, fibrous mats, porous paper, tissue paper and sugar beet fiber and has the advantages of a shorter drying time and an improved product quality compared to conventional through hot air/flue gas drying (Gummel and Schlunder, 1980, Loo and Mujumdar, 1982, Randall, 1984, Polat et al., 1987, Schwartze et al., 1998, Bernado et al., 1990, Mujumdar and Huang, 1995, Chen and Douglas, 1996, 1998).

In this study, through drying of EFB using superheated steam as the drying medium was investigated for the effect of steam temperature and velocity on drying kinetics, drying characteristics and product quality.

EXPERIMENTAL

Material

The EFB that was obtained from an oil palm mill, was crushed by a crushing machine to obtain the fiber which was cut to a specific size for uniformity. Prior to each experiment, the EFB fiber was wetted in water for 24 hours and drained using a filter. A 20 mm thick fiber "mat" was then placed on a 90 mm diameter aluminium perforated plate and secured by an aluminium net. The plate diameter and the mat thickness were used as the material size. The EFB fiber was then sealed and placed in a cool room for one night to homogenize the moisture content distribution in fiber. The sample was then weighed before drying to obtain the initial mass. The mass of dried sample was determined by drying in a convection oven at 130^{o}C for 24 hours.

Equipment

Figure 1 shows the schematic diagram of the equipment used in this experiment. Superheated steam was produced by a steam generator fitted with a superheater and was supplied directly to the drying chamber via a piping system. The drying chamber is made of steel and is well insulated from the environment. Steam is introduced in the chamber through nozzles at the top of the chamber. A by pass circuit consisting of 142 series type DCX Electric Actuators and a 3-way Ball valve was installed to re-direct the steam flow away during the weighing period of the sample. The weight of the sample plate was measured directly in the chamber by suspending it underneath a digital electronic balance located on top of the chamber with a 0.001 g accuracy (AND GR 200) connected to a computer via an RS-232 connector. The distance between the sample plate and the steam nozzles was 500 mm. The temperature profile in the sample was measured by a K-type thermocouple. The data acquisition software was programmed using LabView™ 6.0 by National Instrument and the analog to digital converter used was the FieldPoint™ manufactured by National Instrument. The product quality was determined by measuring the tensile strengh using the N 350 K model testometric tensile meter and the change of fiber color before and after drying process by using the Minolta Chroma Meter CR-200 (Anon. 2003)**.**

Procedure

The temperature and velocity of the steam in the drying chamber are first set and the system was allowed to reach a steady state. The steam was then bypassed briefly and the fiber sample was quickly suspended to the digital balance in the drying chamber. Moisture loss from the sample during the drying process was measured by the digital balance when the steam was bypassed briefly every one minute. After the end of the drying process, the quality of the dried fiber was measured by using the testometer and the chromameter.

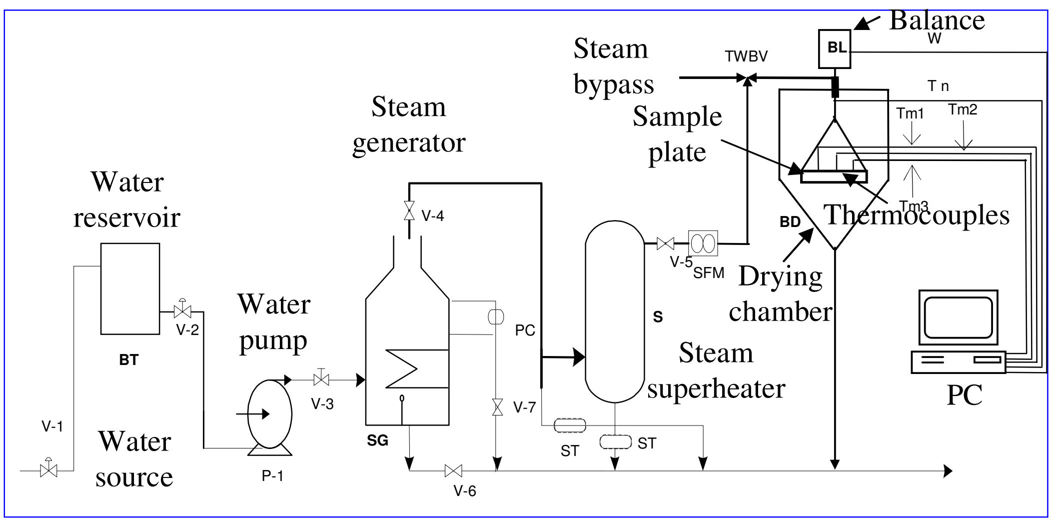


Figure1 The schematic diagram of the through steam drying system test equipment.

RESULT AND DISCUSSION

Effect of Steam Temperature on Drying Kinetic and Drying Characteristic

The effect of temperature for EFB fiber was investigated at 4 different steam temperatures: 122, 132, 142 and 152°C. Figure 2 shows the drying kinetics of through steam drying of EFB fiber having an initial moisture content of between 1.8 to 2.3 g moisture per g dry fiber as a function of temperature and time. Moisture removal is faster when the steam temperature is higher. The drying curves for steam temperatures of 142 and 152 °C are very close together indicating that there is a saturation temperature beyond which there is no more increase in the drying rate. The time required to achieve a moisture content of 0.0275 g moisture per g dry fiber by using steam at an the saturation temperature 142°C and 1.0 m/s was 9 minutes.

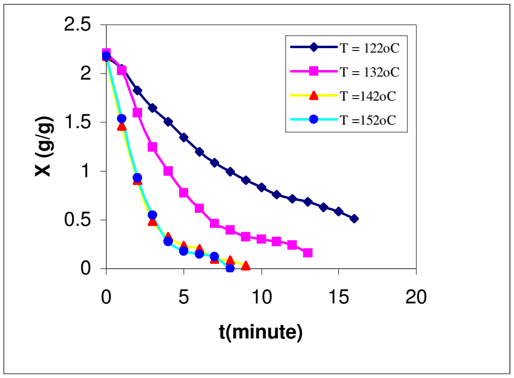


Fig.2 Through steam drying curve of EFB fiber at different temperatures.

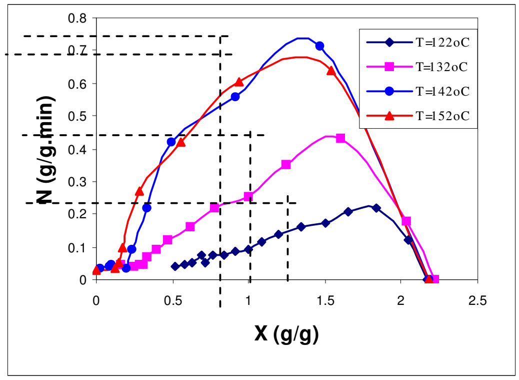


Fig.3 Through steam drying rate curve at different temperatures

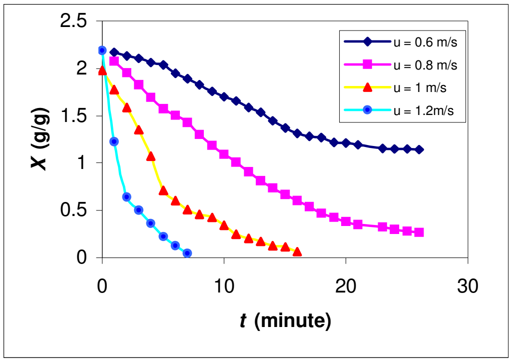
Figure 3 shows that the drying rate curves of through steam drying of EFB fiber have two distinct periods, namely the increasing drying rate period and the falling drying rate period while the constant drying rate period dose not exist. Polat et al., 1987 observed a similar pattern of increasing and falling rate periods in through steam drying but did not discount the existence of a constant drying rate period that would depend on drying conditions. Other workers such as Chen and Douglas, 1996, 1997 did not detect any constant drying rate period at any steam velocity and temperature. The increasing rate period is mainly due to moisture quickly flashing into vapour and being forced out of the fiber by entrainment into the steam and by the accompanying rise in moisture vapour pressure within the fiber. The falling rate period is due to internal resistance of the remaining bound moisture within the fiber.

The present results show that in the increasing drying rate period, the changes in steam temperature yielded similar slopes, but after passing the peak drying rate, the drying process at different steam temperature yielded different slopes in the falling drying rate period. The peak drying rate could be defined as the critical point of transition between the two periods. As the steam temperature increases, the slope of the falling drying rate period becomes larger. Beyond a steam temperature of 142^{o}C, there was no further significant increase in the slope of the falling drying rate period. This indicates that there is a saturation drying temperature beyond which no further increase in the slope of the falling rate period is observed.

Effect of Steam Velocity on Drying Kinetic and Drying Characteristic of EFB fiber

The effect of steam velocity for EFB fiber was investigated for vaious superficial steam velocities ranging from 0.60 to 1.20 m/s at the saturation drying temperature of 142^{o}C. Figure 4 shows the through steam drying kinetics of of EFB fiber at an initial moisture content of between 1.8 to 2.3 g moisture per g dry fiber as a function of steam velocity and time. Moisture removal becomes faster when the steam velocity increases. The time required to achieve a moisture content of 0.0417 g moisture per g dry fiber by using steam at an the saturation temperature 142^{o}C and 1.2 m/s was 7 minutes.

Figure 5 shows that at higher steam velocity (1 m/s and 1.2 m/s) there are only two periods i.e. increasing drying rate period and falling drying rate period, while at lower steam velocity (0.6 m/s and 0.8 m/s) in addition to the increasing and falling rate period, there is also a distinct constant drying rate period at the transition between the increasing and the falling drying rate period. The peak drying rate for the lower steam velocity is a broad plateau. This broad constant drying rate period is due to the weaker ability of the slower steam to entrain more moisture from the fiber.



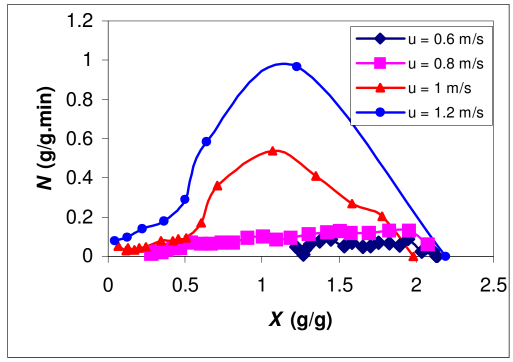


Fig.4 The drying kinetic curve of EFB fiber . at different steam velocity.

Fig.5 The drying characteristic curve at different steam velocity

The Product Quality of EFB fiber in Through Drying

The product quality of dried EFB fiber was determined by the color test and the tensile test after the end of the drying process. In the color test, EFB fiber samples at 25-27^{o}C that was not dried was used as the original samples for comparison.

Table 1 Color measurements of undried, through steam dried and oven air dried EFB fiber.

Sample	Temperature (^{o}C)	L^*	a^*	b^*	Average hue angle $\tan^{-1}(b^*/a^*)$
Undried Fiber	25-27	52.134±1.212	4.168±0.409	13.539±1.107	72.88°
Through steam dried fiber	122	55.293±1.683	2.903±0.276	11.97±1.042	76.36°
	132	55.334±2.060	2.592±0.358	11.108±1.334	76.86°
	142	53.866±2.027	2.744±0.260	10.672±0.682	75.58°
	152	54.548±2.017	2.936±0.140	11.616±0.900	75.81°
Oven air dried fiber	130	50.878±2.09	4.592±0.285	14.086±0.626	71.94°

The color testing method used is CIELAB which is an advanced method for measuring color of objects and is widely used in many fields. In CIELAB notations, the L^* stands for lightness, while a^* and b^* stands for chromacity. The signs of a^* and b^* indicate color direction: $+a^*$ is the direction to red, $-a^*$ is direction to green, $+b^*$ is direction to yellow, and $-b^*$ is direction to blue (Anon., 2003).

There were six samples with ten replications that are averaged and tabulated as shown in Table 1. The values of L* for through steam dried EFB fiber samples are found to be larger than those of the undried EFB fiber sample and the oven air dried EFB fiber samples. This means that through steam drying produces a brighter color than that obtained by oven air drying.

Since the values of a* and b* are found to be positive, the hue angle is therefore in the range between 0 to 90^o, i.e. between red and yellow color. The color of undried fiber samples in this work is found to have an average hue angle of 72.8° which is smaller than the average hue angle of the through steam dried samples of between 75.6° and 76.9°. The higher hue angle is closer to the yellow color direction. This means that through steam drying changes the color of EFB fiber slightly to yellow. On the other hand, average hue angle of oven dried samples (71.9°) is smaller than both that obtained for through steam dried samples and that for undried samples. This means that air drying changes the color of the EFB fiber very slightly to red. Air drying causes slight "browning" indicated by the slightly red color direction whereas through steam drying causes slight "lightening" compared to undried EFB samples.

There is a slight decrease in hue angles with increasing steam temperature for through steam dried samples. This means that the higher steam temperature causes more "browning". There is a slight decrease in hue angle at 122°C and 132°C but a larger increase in hue angles at 142°C and 152°C. Since the hue angles of through steam dried fiber is larger than that by oven air dried or undried fiber, through steam drying produces less "browning" in EFB fiber compared to that produced by oven air drying.

A tensile test machine was used for measuring tensile stress and strain as show in Figure 6.

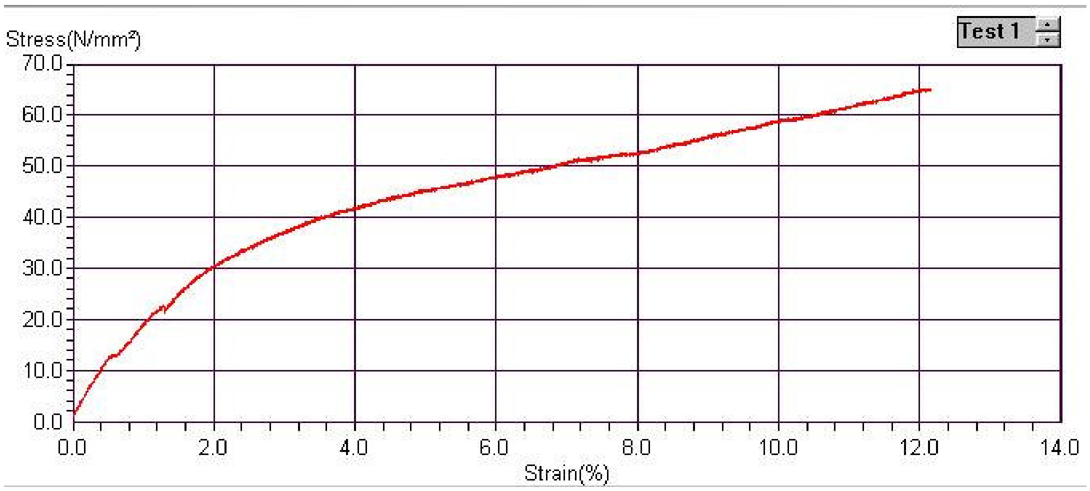


Figure 6. Stress-strain curve of tensile strengh experiment of EFB fiber, at 25 °C, and at a deformation rate 0.01 mm/min

Table 2 The tensile test of EFB fiber

Drying system	Temperature (°C)	Load peak	Strain peak	Strain break	Initial length of EFB fiber, Lo	Cross section area of sample, A	Young modulus elasticity, E
Undried fiber	25	9.44±2.27	12.53±2.73	12.61±2.72	56.23±2.3	0.45±0.05	13.23±2.5
Through steam dried fiber	122	6.57±2.57	11.85±2.97	11.91±2.96	58.88±2.0	0.41±0.15	14.94±2.7
	132	7.71±2.55	9.32±2.17	9.46±2.08	58.12±2.9	0.40±0.08	14.03±2.7
	142	4.91±1.68	5.57±2.15	5.653.160	62.49±2.5	0.38±0.07	13.93±2.1
	152	3.68±1.47	4.94±2.52	5.47±2.34	53.41±0.8	0.38±0.04	17.43±2.5
Oven air dried fiber	130	4.12±1.89	5.59±2.19	5.63±2.19	68.79±2.6	0.37±0.08	18.01±2.1

Figure 6 shows one of the stress-strain curves of an EFB fiber sample that was tested on a tensile machine. Each sampling has 6 replications. The overall measurements for each sampling are averaged and tabulated as shown in Table 2. The load peak, strain peak and strain break decrease as the steam temperature is increased. At higher steam temperature, the lower moisture content of the fiber gives rise to brittleness in the fiber.

The moduli of elasticity of through steam dried fiber at various steam temperatures of 122, 132, and 142^{o}C do not significantly differ from the modulus of elasticity of undried EFB fiber except at 152^{o}C where the modulus of elasticity is significantly larger. This means that through steam drying does not change significantly the sterngth of EFB fiber. On the other hand, oven air dried fiber at 130^{o}C exhibits a larger modulus of elasticity than that exhibited by through steam dried fiber at all temperatures. According to Cui et al., 1986 steam drying of higher yield pulp paper improved the paper's physical strength, while steam drying of lower yield pulp paper produces no discernible negative effect on the paper's physical strength.

CONCLUSIONS

It can be concluded that in through steam drying of EFB fiber, moisture removal is faster when the steam temperature is higher. There is also a saturation temperature (142^{o}C) beyond which there is no more increase in the drying rate and no further increase in the slope of the falling rate period. The drying rate curves of through steam drying of EFB fiber have two distinct periods, namely the increasing drying rate period and the falling drying rate period while the constant drying rate period does not exist for a steam velocity above 1 m/s. The increasing rate period is mainly due to moisture quickly flashing into vapour and being forced out of the fiber by entrainment into the steam and by the accompanying rise in moisture vapour pressure within the fiber. The falling rate period is due to internal resistance of the remaining bound moisture within the fiber. Moisture removal becomes faster when the steam velocity increases. At lower steam velocity of less than 1 m/s, there is also a distinct constant drying rate period at the transition between the increasing and the falling drying rate period. The peak drying rate for the lower steam velocity is a broad plateau which is caused by the lesser ability of the slower steam to entrain more moisture from the fiber. Through steam dried EFB fiber was found to show either no significant color change or a brighter color change in comparison with oven air dried or undried fiber. It was also found that through steam drying does not significantly change the moduli of elasticity and therefore the strength of EFB fiber.

ACKNOWLEDGEMENTS

The authors would like to thank the Malaysian Ministry of Science, Technology & Environment for sponsoring this work under project IRPA 03-02-02-0028

NOTATION

N	drying rate (g/g.min)
T	temperature (^{o}C)
t	time (minute)
u	velocity (m/s)
X	moisture content (g/g or kg/kg, dry basis)

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