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Production of Oil Palm Frond Fiberboard and its Sound Absorption Characteristics

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ABSTRACT

This study investigated the sound absorption capacity of fiberboards produced from oil palm fronds treated by nine different combinations of cooking and refining processes. The percentage fiber yield, consumed energy and wastewater characteristics were also compared. The results showed that all acoustic boards had high sound absorption capacity at high frequencies. Although boards produced from fronds cooked for 21 min at 162 ± 2 ºC and crushed by a disk refiner with clearance distance of the disk set at 0.5 mm showed the best sound absorption capacity, the fiber yield gained from this condition was the lowest and the consumed energy and biological oxygen demand were the highest.
Keywords: fiberboard, oil palm**,** acoustic material, sound absorption, natural fibers

INTRODUCTION

Due to a growing number of noise problems, sound absorbers are increasingly used in buildings to facilitate human comfort and while both inorganic and organic materials have been commonly used as raw materials, the popularity of inorganic materials has been questioned due to the health and environment concerns that have gradually arisen (Newhouse and Thomson, 1965; Saracci *et al.*, 1984; Ribak *et al.*, 1988; Roller *et al.*, 1996; Miller *et al.*, 1999; Drent *et al.*, 2000). Therefore, much research has focused on natural fibers such as bamboo, rice straw, coconut coir and tea leaf, among others, which have proven to have good sound absorption capacity (Koizumi *et al.*, 2002; Yang *et al.*, 2003; Nor *et al.*, 2004; Sihabut and Laemsak, 2008; Ersoy and Küçük, 2009; Oldham *et al.*, 2011). Still, a few questions regarding fire retardant properties and sufficient amounts of these raw materials for manufacturing remain. To enhance their fire retardant properties, inorganic salts have been accepted for use in the process (Goldstein, 1973). To address supply issues, oil palm frond is an interesting material; in addition to the huge amount which will be produced, estimated to be 9.9 million t in 2013 in Thailand alone, their high sound absorption capacity has been confirmed (Sihabut, 1999). Nevertheless, previous experiments clearly identified a flaw in the production process in that only 25% fiber yield was obtained and a huge amount of time was consumed by the chemical pulping method as explained elsewhere (Sihabut, 1999; Sihabut and Laemsak, 2010). Therefore, forming fiberboard by a thermo-mechanical method was substituted and the sound absorption capacity was re-investigated in the current study.

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In addition, other information such as the energy consumed and the percentage of fiber yield was recorded.

MATERIALS AND METHODS

Oil palm (*Elaeis guineensis*) fronds were cut into small pieces by a chipper and then exposed to sunlight until dry. To produce fiberboard, 350 g (dry weight) of raw materials were soaked in water for 24 hr and then cooked at 162 ± 2 ºC for different durations (16, 19 and 21 min). At this stage, the percentage of fiber yield, biochemical oxygen demand over five days (BOD_5), suspended solids (SS) and total dissolved solids (TDS) of the released wastewater were measured. The fibers were refined by a disk refiner with three different disk clearance settings (0.5, 0.6 and 0.7 mm), with each sample being soaked in an aluminum sulfate ($Al_2(SO_4)_3$) solution for 30 min after refining. Then, fiber bundles were separated by a disintegrator for 8 min. During this process, 6 g of wax were added. Finally, a wet board produced by a 35 × 35 cm former was left to be exposed to sunlight until dry (Figure 1A). All fiberboard samples were left inside a laboratory room for 2 w to allow the moisture content to reach a state of equilibrium before they were tested for their physical characteristics and sound absorption.

To check for the quality of the production process, three fiberboard samples produced from each production condition were tested for density and thickness. To test for the sound absorption coefficients of fiberboard under each condition, three sets of round-shaped specimens (one set composed of two specimens with diameters of 99 and 29 mm, respectively, as shown in Figure 1B) were randomly selected from a pile of cut samples and sent to the acoustics laboratory at the National Institute of Metrology (Thailand). Two out of three sets of specimens were randomly picked by a laboratory analyst to measure their coefficients using a Brüel & Kjaer Standing Wave Apparatus type 4002 (Nærum, Denmark). The bigger specimens were used to measure their coefficients at a frequency of 250, 500 and 1000 Hz while the remainder were used to measure their coefficients at a frequency of 2000 Hz. At each frequency, three repeated sound absorption measurements of a specimen were conducted. Two commercialized fiberboards imported to Thailand were selected to compare the sound absorption efficiency. The temperature, pressure and relative humidity in the laboratory test room was 23 ± 3 ºC, 1,013.25 ± 15 hPa and 50 ± 15% , respectively. The experimental design is summarized in Figure 2.

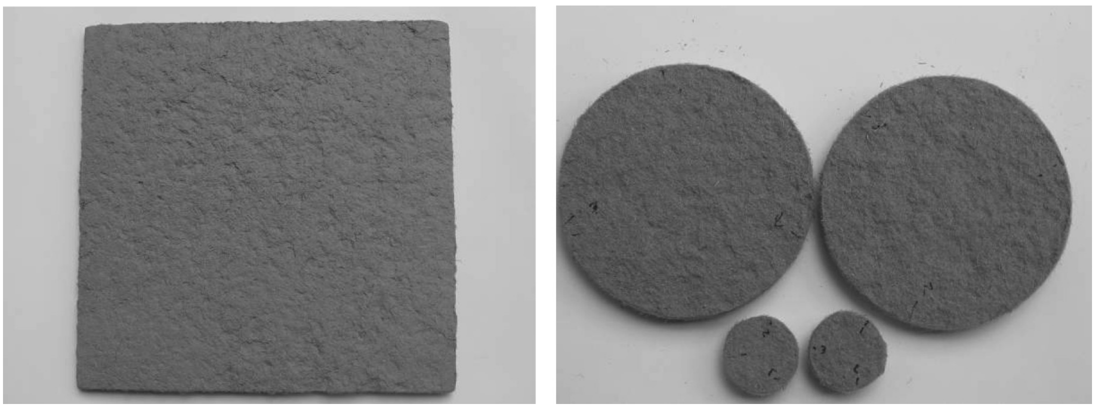

Figure 1 Fiberboard sample (35 × 35 cm) (A); and a set of samples prepared for testing their sound absorption coefficients (B).

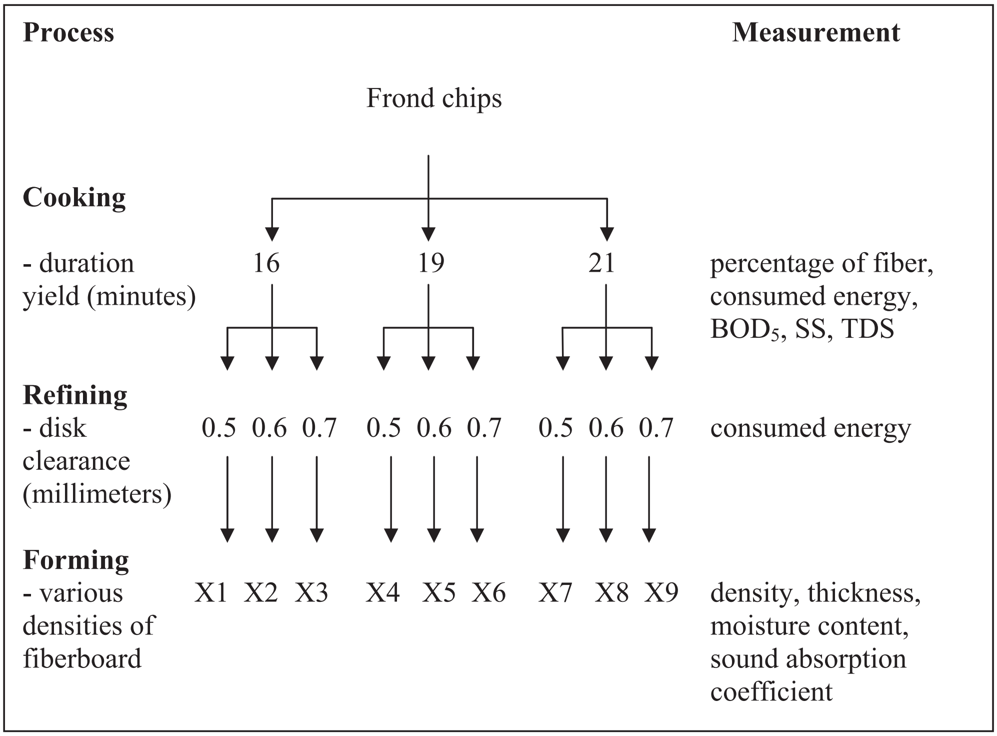

Figure 2 Experimental design. (BOD_5 = Biochemical oxygen demand over 5 days; SS = Suspended solids; TDS = Total dissolved solids.)

RESULTS AND DISCUSSION

As shown in Table 1, the density and thickness of oil palm frond fiberboard samples produced by this method ranged from approximately 0.12 to 0.15 g.cm^{-3} and 12 to 13 mm, respectively. Boards produced using 21 min cooking time and 0.5 mm disk clearance were the thickest, while their density was the lowest. This resulted from the combinations of the most severe treatments. For this sample (condition number VII in Table 1), the longer cooking duration made the fibers softer and grinding by a refiner with the disks closer together made the fibers fluffier, thus forming the thickest and lowest density boards. Once dried, the color of the fiberboards was medium brown with a somewhat rough surface as shown in Figure 1.

As shown in Table 2, the amounts of oil palm frond fiber yield cooked at 162 ± 2° C for 16, 19 and 21 min reduced from approximately 68 to 63% with increasing cooking time. The wastewater characteristics as determined by the SS values were significantly higher than the average SS value of manufactured insulation board of 1,600 mg.L^{-1} (Environmental Protection Agency, 1978). This substantial difference might be caused by artifacts such as dust being mixed in with the frond chips and a portion of the fibers might have passed through the screen while washing. Therefore, cleaning the raw material and choosing a finer screen are recommended for future experiments. For BOD_5, some reported values were close to the average for manufacturing (3,600 mg.L^{-1}), depending on the treatment conditions (Environmental Protection Agency, 1978). It should be noted that the longer

Table 1 Physical characteristics of fiberboard samples and consumed energy in the production process. Data are presented as mean (standard deviation).

Condition No.	Condition		Consumed energy (watt)	Thickness (mm)	Density (g.cm^{-3})	Moisture content (%)
	Cooking (min)	Disk clearance (mm)				
I	16	0.5	114.17(17.29)	12.68(0.62)	0.15(0.01)	6.93(0.71)
II	16	0.6	112.50 (1.67)	12.05(0.30)	0.15(0.01)	7.51(0.07)
III	16	0.7	123.33(15.87)	12.39(0.93)	0.14(0.01)	8.23(0.39)
IV	19	0.5	133.26 (6.05)	11.78(0.38)	0.15(0.01)	9.08(0.89)
V	19	0.6	139.53(23.61)	12.04(0.52)	0.14(0.02)	8.41(0.30)
VI	19	0.7	132.60 (3.96)	11.32(0.46)	0.15(0.01)	8.84(0.02)
VII	21	0.5	146.56(11.01)	13.28(0.38)	0.12(0.00)	8.67(0.38)
VIII	21	0.6	147.66 (8.28)	11.26(0.54)	0.14(0.01)	7.82(0.08)
IX	21	0.7	154.22(37.19)	11.24(0.49)	0.15(0.01)	8.88(0.85)

Table 2 Fiber yield and wastewater characteristics from different cooking processes. Data are presented as mean (standard deviation).

Cooking duration (min)	Fiber yield (%)	Wastewater Characteristics		
		BOD_5 (mg.L^{-1})	TDS (mg.L^{-1})	SS (mg.L^{-1})
16	68.37(0.60)	3,640(780)	799 (39)	5,594 (631)
19	66.59(1.19)	4,195(916)	806 (68)	5,144 (904)
21	63.00(1.18)	5,150 (87)	782(105)	6,042(1,420)

BOD_5 = Biochemical oxygen demand over 5 days; TDS = Total dissolved solids; SS = Suspended solids.

the cooking duration, the lower the fiber yield and the higher the amounts of BOD_5 and consumed energy (Figure 3). These results were caused by the extended exposure of the frond chips to a harsh temperature causing more fiber destruction and releasing more hemicelluloses into the water, thus resulting in a comparatively lower percentage of fiber yield and higher amounts of BOD_5 (Suchland and Woodson, 1986).

Table 3 shows the sound absorption coefficients and Figure 4 shows the absorption characteristics at frequencies of 250, 500, 1,000 and 2,000 Hz. Like other porous materials (Koizumi *et al.*, 2002; Yang *et al.*, 2003; Nor *et al.*, 2004; Ersoy and KÜÇÜk, 2009; Oldham *et al.*, 2011), the higher the sound frequency, the better the sound absorption coefficients. However, the sound absorption capacity of most oil palm frond fiberboard samples clearly differed at 2,000 Hz. The group of fiberboard sample produced from fibers cooked for 21 min presented the highest values for the average sound absorption capacity. Among these, fiberboard sample under condition number 7 produced the best sound absorption capacity. This may have been due to the fiber characteristics of this sample as a result of being subjected to the most severe treatment as mentioned above, so that the softness and numerous fibrillated fibers formed an optimum porosity board which was not too tight or loose. Once the sound energy hit these sample boards, friction, air viscosity and vibration due to sound movement inside the tortuous parts of these materials were greater than for the other board samples. Therefore, the energy that was converted to other types of energy, such as heat, was relatively greater, resulting in the greatest sound

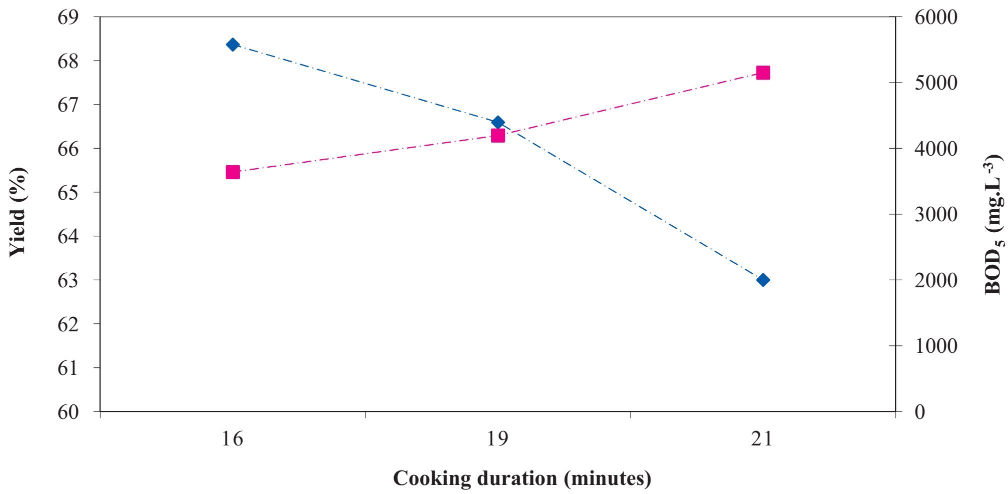

Figure 3 Fiber yield and released biochemical oxygen demand over five days (BOD_5) from various cooking durations (- · -♦- · - = Yield; - · -■- · - = BOD_5).

Table 3 Sound absorption coefficients of oil palm frond fiberboards produced under various conditions. Data are presented as mean (standard deviation).

Condition No.	Sound Frequency (Hz) 250	500	1,000	2,000	Mean*
I	0.1200(0.0071)	0.2825(0.01106)	0.5925(0.0035)	0.5825(0.0177)	0.3944
II	0.1350(0.0071)	0.3125(0.0247)	0.5650(0.0636)	0.5350(0.0636)	0.3869
III	0.1300(0.0000)	0.2675(0.0247)	0.5375(0.0318)	0.7150(0.0424)	0.4125
IV	0.1300(0.0071)	0.2725(0.0247)	0.5825(0.0350)	0.6725(0.0106)	0.4144
V	0.1200(0.0000)	0.2050(0.0212)	0.4175(0.0350)	0.7500(0.0000)	0.3731
VI	0.1200(0.0000)	0.2775(0.0247)	0.5600(0.0424)	0.6350(0.0495)	0.3981
VII	0.1400(0.0071)	0.2825(0.0035)	0.4500(0.0495)	0.8475(0.0035)	0.4300
VIII	0.1275(0.0106)	0.2850(0.0141)	0.4200(0.0070)	0.8300(0.0424)	0.4156
IX	0.1250(0.0000)	0.2625(0.0460)	0.5675(0.0247)	0.7475(0.0601)	0.4256
CP1	0.1050(0.0071)	0.3200(0.0283)	0.4175(0.0389)	0.4850(0.0636)	0.3319
CP2	0.1050(0.0071)	0.2425(0.0035)	0.4775(0.0106)	0.6500(0.0424)	0.3688

* = Mean value is the average of the sound absorption coefficients at the frequencies of 250, 500, 1,000 and 2,000 Hz
CP1 = Comparable values for commercial samples of fiberboard with a density of 0.39 $g.cm^{-3}$. CP2 = Comparable values for commercial samples of fiberboard with a density of 0.32 $g.cm^{-3}$.

absorption. When this material was compared to commercialized rock wool fiberboard samples with densities of 0.39 $g.cm^{-3}$ and 0.32 $g.cm^{-3}$ with the same thickness and intended uses, the oil palm fiberboard sample had sound absorption qualities that were generally superior at several frequencies (Figure 4). However, other properties, such as strength, still need to be investigated.

CONCLUSION

Oil palm frond fiberboard samples were

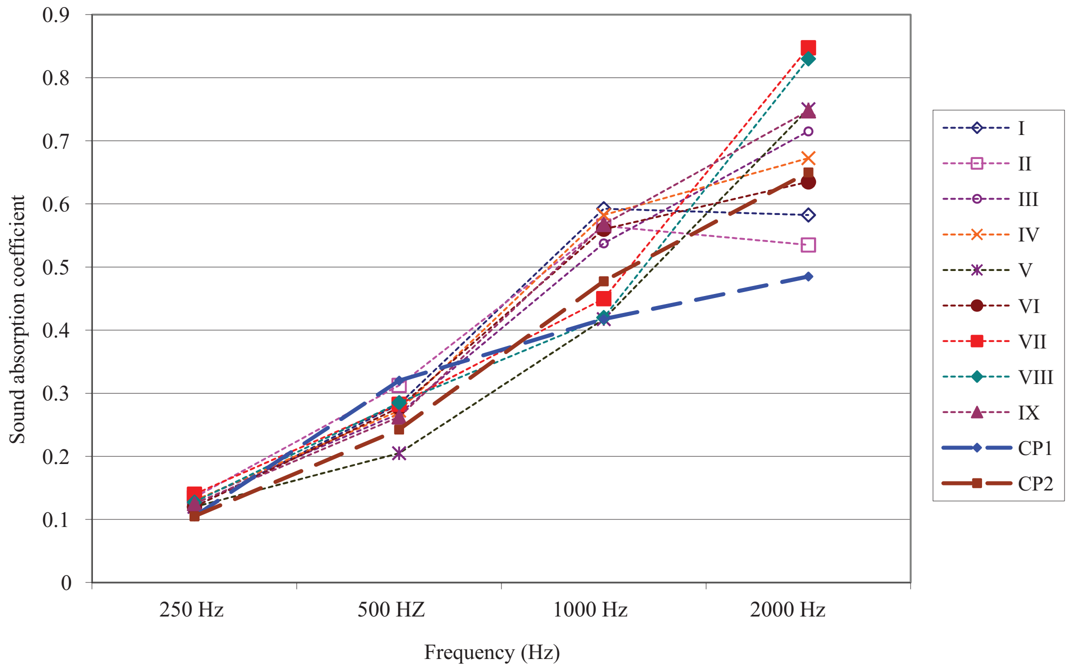

Figure 4 Sound absorption characteristics of oil palm fiberboard samples (I to IX) produced under various conditions and of compared materials (CP1 = Commercial samples of fiberboard with a density of 0.39 g.cm^{-3}; CP2 = Commercial samples of fiberboard with a density of 0.32 g. cm^{-3}.)

produced under nine different conditions and their sound absorption capacity were determined. Although oil palm fiberboard samples produced using the longest cooking duration generally showed the best sound absorption capacity, interestingly, those produced under other conditions could also be considered because the amounts of fiber yield were higher, environmental effects (consumed energy and BOD_5 in wastewater) were relatively lower and their sound absorption capacities were still competitive with commercialized products.

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