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Original Article

Feasibility of producing insulation boards from oil palm fronds and empty Fruit bunches

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Abstract

This research focused on the feasibility of producing insulation boards made from oil palm fronds and empty fruit bunches via the wet forming process. Results confirmed no difference in the visual appearance between both board types. Both displayed low thermal conductivity, offering evidence of being good insulators. Boards made from empty fruit bunch weighed less than boards made from oil palm fronds. Other properties such as fire retardant, water absorption and strength still need to be investigated.

Keywords: thermal conductivity, insulation board, oil palm, frond, empty fruit bunch

1. Introduction

Although the origin of oil palm (*Elaeis guineensis*) was in Africa, suitable plantation areas for this tree are located in the tropical zones. Areas within ±12-15 degrees latitude north or south of the equator provide the environmental conditions suitable for oil palm plantations. Average temperatures of 29-30°C, annual rainfall of 2,000-2,500 millimeters, and a humidity of 80-90% in the tropical zones are the optimal settings for oil palm plants to flourish. Further important requirements for this tree to grow well include six hours of sunlight daily and the exposure to a possible drought should not exceed 60 days. Due to these high demands, only 42 countries provide suitable locations in which to grow this tree.

Thailand has been ranked as one of the biggest producers among countries having plantations of 500,000 hectares. Most of them are cultivated in the southern part of Thailand; notably in provinces such as Krabi, Chumporn, and Surathani. According to the Thai government, it plans to expand the total area designated for oil palm plantation to 1.6 million hectares by the year 2029. This expansion will generate not only valuable food and energy products, but also tremendous amounts of agricultural wastes, such as trunks, fronds, and empty fruit bunches as shown in Table 1. If the plan is implemented, in 20 years Thailand alone will annually generate approximately 9.9 million tons of oil palm frond and 7.9 million tons of empty fruit bunch wastes (calculation based on information from the Ministry of Agricultural and Cooperatives, Thailand; Akesomtramet, 2003). Consequently, the use of these waste materials is already managed in many ways within Thailand. For example, trunks are used instead of wood to make furniture. Shells are produced as activated carbon. Frond and empty fruit bunches are distributed in the fields to maintain good soil moisture levels. Moreover, all materials can be incinerated, thus supplying a direct source of energy. Although these waste materials have been utilized, revenue from the products remains generally low. Therefore, insulation board production is an additional alternative to add value to these materials. Insulation board

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Table 1. Details of expected wastes generated in Thailand from oil palm cultivation in 2005 (Ministry of Agriculture and Cooperatives, Thailand; Akesomtramet, 2003)

Production Rates	Quantity	
Plantation area (2005)	438,900.96	hectares
Oil palm trees (137.5 trees/hectare)	60,348,882	trees
Dried frond (15 fronds/tree/year; approximately 3 kg/frond)	2,715,690	tons
Fresh fruit bunch (17.5625 tons/hectare)	7,708,198	tons
Empty fruit bunch (28 % of a fresh fruit bunch)	2,158,29	tons

production from these materials is feasible for a number of reasons. Cellulose accounts for 47.6% of the oil palm frond (Wanrosli *et al.*, 2007) and for 62.9% of the empty fruit bunch content (Law *et al.*, 2007). Cellulose has a potential to be used in the paper and fiberboard manufacturing. Large amounts of oil palm wastes will be generated in the next 20 years, if the government plans have been implemented. These wastes are biodegradable. Therefore, the objective of this study was to evaluate the potential of producing insulation boards from both oil palm frond and empty fruit bunch. Evaluation mainly included production methods and thermal conductivity measurements.

2. Methods

The production method of insulation boards involved a number of steps. Fronds and empty fruit bunch were dried by sunlight and cut into small pieces (Figure 1). Next, 350 grams of frond chip (dry weight) and 300 grams of empty fruit bunch (dry weight) were soaked in water for 24 hrs before each being cooked at a pressure of 5.20 kg/cm^2 for 16, 19, and 21 minutes. The fibers were grinded by a disk refiner at a disk clearance distance of 0.5, 0.6, and 0.7 mm. The pulps were soaked in an alum solution at a pH of 4.5 for 30 minutes. After 6 grams of wax were added, the pulps were distributed by disintegrator for 8 minutes and were poured into a 35x35 cm square former. Forming occurred when the water passed through the screen and the pulp material remained. The resulting wet boards were exposed to sunlight until fully dry. Density and moisture content were measured after the boards were set aside at room temperature for a week. A 30x 30 cm trimmed sample from each board type was sent to the Thailand Institute of Scientific and Technological Research (TISTR) to measure its thermal conductivity following ASTM C518 at 75°F, an alternative to ASTM C177. Table 2 provides a summary of the aforementioned experimental design.

3. Results and Discussion

3.1 Production process

Thermomechanical pulping was followed with wet forming processes for this experiment, since short cooking time and a high yield production is expected from this type of pulping process. The yield of frond fibers via the thermo-mechanical process ranged from 63 to 68% versus a gain of only 25% from chemical processing in our previous study (Sihabut, 1999; Sihabut and Laemsak, 2008). Furthermore, up to 3 hrs at a temperature of 150°C were required with the caustic pulping process (10% NaOH) in the past study, but only 16-21 minutes at 160°C were necessary in this experiment. The lower yield from chemical processing might be the result of high arabinoxylan and pectic concentrations within fronds, which demand high alkaline consumption (Suzuki *et al.*, 1998). For empty fruit bunches, Ibrahim (2002) demonstrated yields ranging from 40.2 to 44.8%, depending upon

(A) (B)

Figure 1. Raw materials used for cooking process: frond chips (A) and empty fruit bunches (B).

Table 2. Experimental design

Process	Treatment		
1. Cooking	16 minutes	19 minutes	21 minutes
	↓	↓	↓
2. Defibrating	0.5, 0.6, 0.7 mm	0.5, 0.6, 0.7 mm	0.5, 0.6, 0.7 mm
	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓
3. Wet Forming	A B C	D E F	G H I (g/cm^3)
4. Measuring	Density, Moisture Content, Thermal Conductivity		

the type of chemical pulping method applied. However, other researchers have observed yields as high as 76% from the thermomechanical process with NaOH pre-treatment (Akamatsu *et al.*, 1987; Choon and Wan, 1991). Similarly, by shifting to the thermomechanical pulping, we also witnessed both higher yields and lesser time consumptions.

To produce equally-sized products, 350 grams (dry weight) of frond were needed opposed to only 300 grams (dry weight) of empty fruit bunch. This might be due to the higher cellulose content in empty fruit bunches than in oil palm fronds, as evidenced in the work of Wanrosli *et al.* (2007) and Law et al. (2007). With respect to energy demand, the production of empty fruit bunch fiberboards required more energy than frond fiberboards (Table 3). Increased energy consumption resulted from the pulping process, which consumed all the energy used in this production method; while other processes were conducted based on nature and mechanical equipment. In order to fully break down all fiber bundles (without rejects), prepared dry palm fronds (entire frond) were cooked together. In contrast, the empty fruit bunch needed to be divided into two parts (150 grams of dry weight for each part), each part cooked separately. The reason for this difference can be explained by considering the characteristics of the raw materials. Empty fruit bunches are inherently more bulky than oil palm fronds. In this study, when the material was cooked, 20-25% of air volume in the steamer was required. Consequently, smaller amounts of empty fruit bunch were cooked each time. In addition, the

Table 3. Density, moisture content, and thermal conductivity of fiberboard made from oil palm fronds and empty fruit bunches.

Treatment no.	Frond				Empty fruit bunch			
	Consumed Energy (Watt)	Density (g/cm^3)	Moisture Content (%)	Thermal Conductivity $(Btu.in/ft^2.hr)$	Consumed Energy (Watt)	Density (g/cm^3)	Moisture Content (%)	Thermal Conductivity $(Btu.in/ft^2.hr)$
1	75	0.133	6.61±0.74	0.2452	92	0.151	7.82±0.29	0.2556
2	79	0.141	6.72±1.37	0.2552	92	0.155	9.01±0.93	0.2430
3	75	0.132	8.59±0.61	0.2536	92	0.140	8.09±1.41	0.2576
4	93	0.129	8.23±1.61	0.2354	125	0.147	7.43±1.07	0.2466
5	93	0.128	8.64±0.45	0.2484	125	0.141	7.60±1.31	0.2514
6	93	0.136	9.71±1.51	0.2670	125	0.148	8.15±0.33	0.2502
7	103	0.108	8.79±0.34	0.2399	147	0.113	6.83±1.83	0.2288
8	107	0.123	8.01±0.35	0.2419	147	0.136	6.96±0.59	0.2392
9	107	0.135	8.14±1.41	0.2602	147	0.138	7.13±0.37	0.2390

treatment no. 1 - cooking for 16 minutes at 160°C and grinding at the disk distance of 0.50 mm; treatment no. 2 - cooking for 16 minutes at 160°C and grinding at the disk distance of 0.60 mm; treatment no. 3 - cooking for 16 minutes at 160°C and grinding at the disk distance of 0.70 mm; treatment no. 4 - cooking for 19 minutes at 160°C and grinding at the disk distance of 0.50 mm; treatment no. 5 - cooking for 19 minutes at 160°C and grinding at the disk distance of 0.60 mm; treatment no. 6 - cooking for 19 minutes at 160°C and grinding at the disk distance of 0.70 mm; treatment no. 7 - cooking for 21 minutes at 160°C and grinding at the disk distance of 0.50 mm; treatment no. 8- cooking for 21 minutes at 160°C and grinding at the disk distance of 0.60 mm; treatment no. 9 - cooking for 21 minutes at 160°C and grinding at the disk distance of 0.70 mm.

(A)

(B)

Figure 2. Surfaces of insulation boards made from empty fruit bunches (A) and oil palm fronds (B).

composition of fiber bundles in empty fruit bunch is tighter than in fronds, which are mixed between fiber bundles and thin wall parenchymatous tissues. Therefore, empty fruit bunches are more difficult to break down than fronds. To make a mat, a wet forming process (without an adhesive) was chosen. In this process, adhesion among fibers occurs as a result of the surface tension of water pulling the fibers together. This leads to hydrogen bonding to transpire when the water is evaporating from the newly formed mat during the drying process.

3.2 Insulation board appearance, density, and moisture content

The surfaces of both insulation board types were rather rough with a medium brown appearance. Their exteriors could not be visually differentiated (Figure 2). However, when cutting the boards with a jigsaw, frond insulation boards felt easier (physically) to cut than boards made from empty fruit bunch. Better interfiber bonding may be the reason for this. Better bonding depends on the degree of defibration, the area of overlap between the two fibers (Suchland and Woodson, 1986). However, the grounds for this argument should be investigated further in-depth.

The densities of insulation boards made from both materials ranged from 0.108-0.155 g/cm^3 (Table 3). Although the quantity of fronds used to produce an insulator was greater than the amount of empty fruit bunch, insulators made from frond fibers weighed less than those made from empty fruit bunch fibers (Figure 3). This could be due to the fact that empty fruit bunches possessing an abundance of thick sclerenchymatous tissue. The high amount of thick tissue may make refining the empty fruit bunch more difficult than frond; thus resulting in a higher density in empty fruit bunch insulators.

Figure 3 shows that the seventh treatment resulted in the lowest density of both types. From the method used, the cooking duration of the seventh treatment was 21 minutes at a 0.5 millimeter disk clearance distance. This was the most extreme condition that any of the raw materials faced. The result gives evidence to suggest that longer cooking time

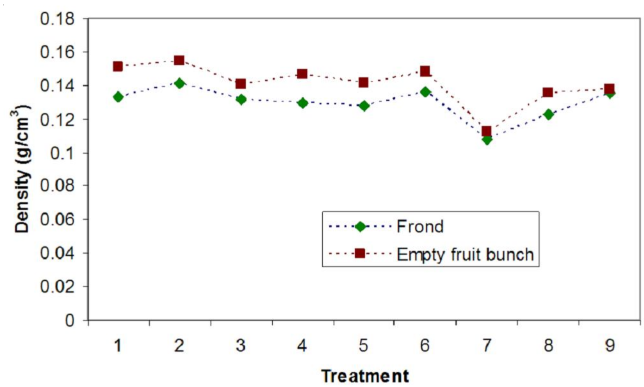

Figure 3. Densities of insulation boards made from oil palm fronds and empty fruit bunches.

results in both softer fiber and cleaner fiber separation. In addition, the disk clearance distance of the defibrator was narrower than in other treatments. The fibers were rigorously squeezed and crushed. This resulted in defibration and swelling of the fibers. When formed, therefore, the mats showed the lowest density due to its featherlike quality. However, cooking with a longer duration also has its disadvantages. Dissolved solids, a result of hemicellulose hydrolysis, are high; thus resulting in high BOD (biological oxygen demand) loading. However, there is opportunity to save energy for treatment costs by promoting renewable energy as an alternative. Another disadvantage of longer cooking is the decreased in fiber yield. Longer cooking results in less fiber production than in shorter cooking due to severe fiber destruction.

Regarding moisture content, the values of frond insulation boards varied from 6.61 to 9.71%, while boards made from empty fruit bunch ranged from 6.83 to 9.01% (Table 3). Moisture affects the insulation board properties by reducing thermal performance, changing material dimensions and composition (Ty *et al.*, 1980), and possibly encouraging fungal growth. Our materials had moisture content values most comparable to the durian peel and coconut coir insulators (6.22-9.47%) observed by Khedari *et al.* (2003, 2004).

These values are approximately half of that of paper and flax insulators (11.53-15.06%) seen in the work of Klamer *et al.* (2004). Our moisture content values may be similar to Khedari's due to wax adding. With Klamer's experiment, there was no usage of wax involved. Additionally, both experiments (Khedari's and our own) were conducted in Bangkok, Thailand (same relative humidity). Although wax helped in resisting water absorption, there was some evidence of fungal growth. This growth was evident even among the inorganic low moisture content materials and cellulose that contained low amounts of boric acid (Ezeonu *et al.*, 1994; Klamer *et al.*, 2004). Therefore, the possibility exists for problems to occur due to molding materials. Adding sufficient amounts of an effective wood preservative to the material, such as boric acid, is recommended.

3.3 Thermal conductivity

The fiberboards made from the two materials proved sufficient to be insulators; for both the thermal conductivity values were low. They ranged from 0.2354-0.2670 and 0.2288-0.2576 Btu.in/ft^2.hr at 75°F (0.034-0.038 and 0.033-0.037 W/m K) for frond and empty fruit bunch boards, respectively (Table 3). When comparing density and thermal conductivity values, the mats made from fronds and empty fruit bunches showed similar patterns (Figures 4 and 5). Obviously, both kinds of mats displayed the relatively low thermal conductivity values from the seventh treatment. As previously mentioned, these mats also had the least density among all treatments. The large number of spaces and voids inside the insulators impeded heat transfer, therefore resulting in considerably lower thermal conductivity.

When compared with the insulation board properties required by USDC NBS (Table 4), the thermal conductivity values of both material types did not exceed the maximum

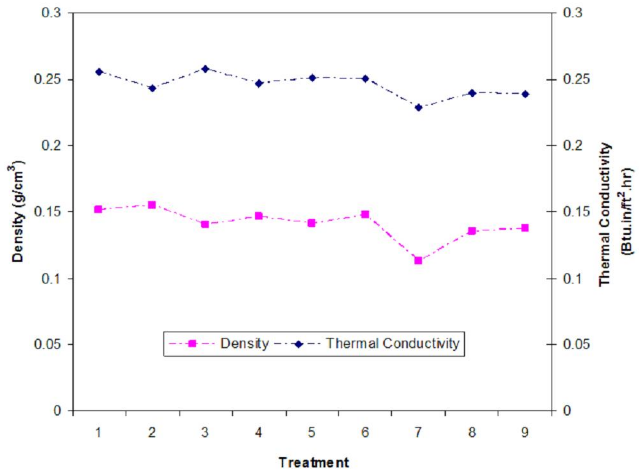

Figure 4. Density and thermal conductivity of insulation boards made from oil palm empty fruit bunches.

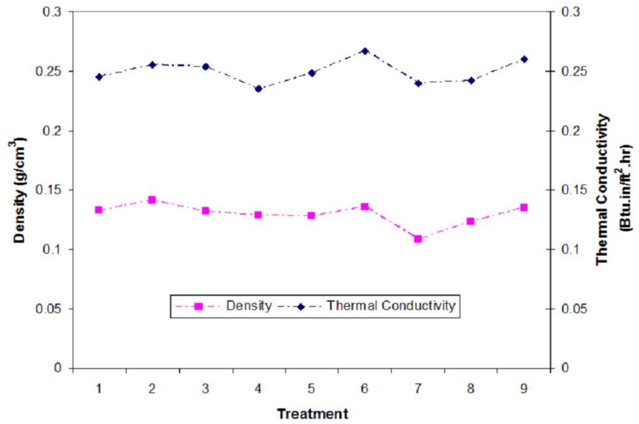

Figure 5. Density and thermal conductivity of insulation boards made from oil palm fronds.

Table 4. Types and classes of insulation boards (U.S. Department of Commerce: National Bureau of Standards, 1973).

Type	Class	Name	Thermal Conductivity avg. max. (Btu.in/ft^2.hr at 75±5 °F)
I		Sound deadening board	0.38
II		Building board	0.38
III		Insulating formboard	0.40
IV		Sheathing	
	1	Regular-density	0.40
	2	Intermediate-density	0.44
	3	Nail-base	0.48
V		Shingle backer	0.40
VI		Roof insulating board	-
VII		Ceiling tiles and panels	0.38
VIII		Insulating roof deck	0.40
IX		Insulating wallboard	0.40

Table 5. Type, density, and thermal conductivity of various materials published elsewhere (Wieland *et al.*, 2000; Kauriinvaha *et al.*, 2001; Khedari *et al.*, 2003 and 2004; Al-Homoud, 2005; Lertsutthiwong *et al.*, 2008)

Form	Raw Material	Density (kg/m^3)	Thermal Conductivity (W/m K)
Mat	Oil Palm Frond	108-141	0.034- 0.038*
	Empty Fruit Bunch	112-155	0.033-0.037*
	Fiberglass	24-112	0.032-0.035
	Expanded polystyrene	16-35	0.037-0.038
	Extruded polystyrene	26-45	0.030-0.032
	Coconut coir and durian peel	288-910	0.074-0.1342
	Durian peel	357-907	0.063-0.185
	Coconut coir	329-664	0.054-0.144
	Flax	5-50	0.038-0.075
	Flax and hemp	39	0.033
	Flax and hemp	19	0.060
	Hemp (green)	5-50	0.044-0.094
	Hemp (retted)	25-100	0.040-0.049
	Corn peel and solid wastes (from tissue paper manufacturing)	726-980	0.140-0.251
Loose-fill blown in or poured in	Vermiculite	64-130	0.063-0.068
	Perlite	32-176	0.04-0.06
	Ground-up waste paper	24-36	0.046-0.054
Blankets: batts or rolls	Fiberglass	12-56	0.033-0.04
	Rock wool	40-200	0.037
	Polyethylene	35-40	0.041
Sprayed-in place	Cellulose	24-36	0.046-0.054

* Our data was converted for thermal conductivity value (from Btu.in/ft^2-hr to W/m-K, respectively)

value. In addition, they exhibit equal (if not better) properties than several other insulation materials (Table 5).

3.4 Other aspects

In this experiment, thermal conductivity of the insulators was the only aspect studied; since the primary function of fibrous insulators entails having low thermal conductivity (Kymäläinen and Sjöberg, 2008). However, other issues need to be further studied. For example, safety can be addressed by using fire retardants that contain higher inorganic salts. Fire safety is a great concern when considering the use of cellulose fiberboards. Retardants rich in inorganic salts ensure more thermal stability. Preservative chemicals can be used in an effort to prevent insect-infested or rotten wood. Also, other important properties of USDC NBS for insulation boards produced by wet process require testing. For example, transverse strength, modulus of rupture and tensile strength require testing by ASTM C209. Water absorption and linear expansion require testing by ASTM D1037. Vapor permeance, racking load, and flame spread index require testing by ASTM E96/E96M, ASTM E72, and ASTM E84, respectively.

4. Conclusion

1. It is possible to produce insulation boards made from oil palm frond and empty fruit bunch, because their thermal conductivities were low and comparable with other commercially available materials. However, other properties require further studies.

2. Although empty fruit bunches are more advantageous than oil palm fronds in terms of accessibility (collected at palm oil factories) and lower quantities of raw material required, it requires more energy to cook the material. Therefore, production costs need to be considered.

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