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THERMAL INSULATION MATERIAL MADE FROM OIL PALM EMPTY FRUIT BUNCH FIBRES

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ABSTRACT

The objectives of this study were to characterize cut oil palm empty fruit bunch (EFB) fibres and to focus on the manufacturing of environmentally friendly thermal insulation material from these fibres for building purposes. Originally, the EFB fibres were heterogeneous, and rolled up in compacted wads in a disorderly fashion, with fibre lengths of approximately 50 mm to more than 200 mm. The moisture content and density of these fibres were approximately 12.7% and 18.1 kg/m^3, respectively. For the production of thermal insulation material (patent DE 43 16901 A1 with some modifications) the EFB fibres were cut and needles, dust and dirt were removed to improve the homogeneity of the raw material. Potassium water glass and water were used as a binding agent and as a solvent, respectively. Carbon dioxide gas and hot air (60°C) were blown through the fibres in a fumigation room to cure the water glass and produce a hardened fibre sheet. The results of this study were gathered from the information on the characteristics of the cut EFB fibres as a raw material (incl. fibre length distribution, density, moisture and oil content), physical properties (incl. moisture content, density and thermal conductivity) and the technical aspects of insulation material production. According to the results obtained, moisture content and density of the cut EFB fibres were approximately 11.36% and 40.5 kg/m^3, respectively. Density of the insulation material was approximately 116.4 kg/m^3 with thermal conductivity between 0.049 and 0.054 W/mK. Using cut EFB fibres as raw material for the insulation material production technique appear to be technically acceptable based on this investigation and the above mentioned patent. EFB fibre insulation material is also acceptable as an environmentally-friendly insulation material for building purposes according to the insulation for buildings requirement DIN 4102-1 (1981).

Keywords: oil palm, empty fruit-bunch, fibre, insulation material, potassium-water glass.

INTRODUCTION

The primary purpose of thermal insulation is to control heat transfer through the exterior construction of a house. To guarantee the comfort of the occupants and the energy efficiency and durability of the home, the thermal barrier, or insulation, and the air barrier should form a continuous envelope around the house.

World demand for insulation materials is projected to increase approximately three percent per annum through 2006. Unit price increases will help to boost the value

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of demand to US$18 billion over the forecast period (Freedonia 2002). The fastest growth in demand is expected in the Asia/Pacific region, where building construction activity and increasing industrialisation will generate opportunities for insulation (Freedonia 2002). Furthermore, the increasing environmental pressures that have recently arisen in many European countries have led to an important change in the field of insulation, particularly with regard to the emissions of volatile organic compounds, which has lead to the development of new environmentally-friendly insulation production. Currently, insulation material is produced from mineral wool, fibreglass, perlite, vermiculite, corkboard, powdered gypsum, and wood fibre (Bynum 2001). Meanwhile, alternative production of insulation material made from renewable materials such as wheat straw, miscanthus fibre, maize straw, sunflower pith, hemp fibre and spruce fibre has been greatly advanced by Richter (1993).

Successful work from Richter & Bücking (1993) led to a patent for producing insulation materials on the basis of hot waste vapour containing carbon dioxide for the hardening process of water glass as a binding agent. This binding agent is a colourless, transparent, glass like substance and available commercially as a viscous solution in water. Water glass or soluble glass has adhesive properties and is also fire resistant (Scheiding 2001). The technological process of insulation production based on patent DE 43 16901 A1 is very simple and it is particularly suitable for application in Indonesia as a developing country as it has various renewable resources and low-production costs.

This study focused on the manufacturing of insulation board from the empty fruit bunch fibres (EFB fibre) of oil palm. This material is one of the solid waste products from palm oil mills and is available in large quantities throughout the year. EFB fibre was being used as a raw material for fibre based products, such as oil palm seedling pots or pulp and paper. There were more than 6 million tones of EFB by the end of 2002 and so far, this material has not been fully utilized (Erwinsyah 2004). The characteristics of cut EFB fibres including fibre length distribution, density, moisture and oil content of the fibres; the optimization process; and production of insulation material were investigated.

MATERIALS AND METHODS

Oil palm empty fruit bunches were taken from Aek Pancur Palm Oil Mill, Sumatra, Indonesia and the production of EFB fibres was carried out at the Agricultural Engineering Laboratory of the Indonesian Oil Palm Research Institute, Medan, Indonesia. Potassium water glass was provided by Bielac Lagerdienstleitungs GmbH & Co. KG. The manufacture of the insulation material was carried out at the Institute of Forest Utilization and Forest Technology, Tharandt, Germany.

EFB fibre production

Extraction of the EFB fibres was carried out using an EFB Fiberizer Machine at the Indonesian Oil Palm Research Institute, Medan, Indonesia (Figure 1). This machine consists of several sets of knives in a rotary drum, which loosens the EFB fibres from the bunch. The extracted fibres were directly loaded to a washing pond to eliminate the starch content, dust and waste. The EFB fibres were then dried in the sun for 2 to 3 days until the moisture content of the fibres was between 10 and 12% (Malaysian Standard 1408 1997). The dried EFB fibres were then packed into bales (25 kg/bale) using a packaging hydraulic pressure machine and the bales were wrapped and sewn in gunny-sacks. The EFB fibres were then shipped to Germany.

Raw material preparation

The dried EFB fibres imported from Indonesia were heterogeneous, and rolled up in compacted wads in a disorderly fashion, with very long fibres (50mm to more than 200mm). To improve the homogeneity of the raw material, the fibres were loosened and needles were removed. The EFB fibres were then cut into lengths of approximately 20mm to 50mm using a conventional manual cardboard and veneer cutter to achieve the material requirements for insulation materials as stated by Richter & Bücking (1993) in their patent.

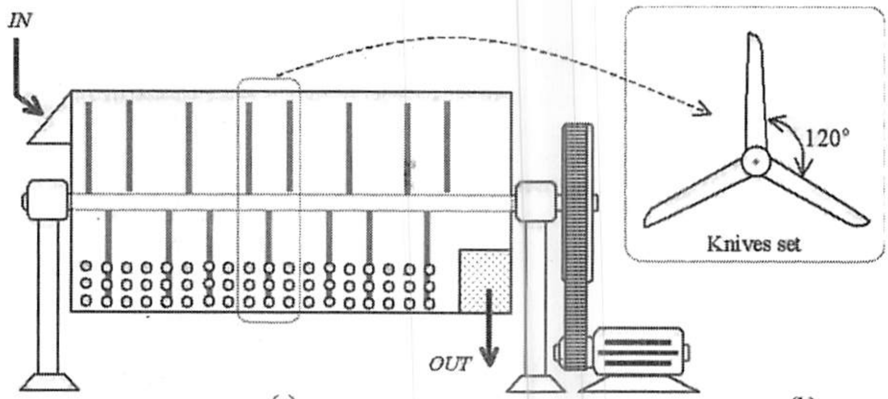

Figure 1. EFB Fiberizer Machine (a). The EFB Fiberizer machine and (b). The knives set of the machine

Defining EFB fibre distribution

The length (mm) of the cut EFB fibres was measured manually using a ruler and calliper. The distribution of EFB fibres was then analysed and classified based on the obtained fibre length data and visual investigation.

Determination of EFB fibre density

The determination of the EFB fibre density was adopted from textile fibre density determination using the cylinder-volume method. The fibre density (*w/v*) was measured on the basis of weight and volume of the fibre. This method was carried out using a fibreglass cylinder (diameter 18.9cm and height 40.0 cm) and a Sartorius balance. The density of the EFB fibre was defined by calculating the ratio value between fibre weight and volume of fibres using the following equation:

$$\sigma = \frac{w_f}{0.25\pi h D^2}$$

where, π is density of cut EFB fibre (kg/m^3); w_f is weight of fibre (kg); *h* is height of fibre in cylinder (m) and *D* is diameter of cylinder (m). Number of replication for this experiment was 10.

Moisture and oil content

With reference to patent DE 43 16901 A1, the range of moisture content of the raw material for producing insulation material is between 12% and 20% (Richter & Bücking, 1993). According to the ASTM standard D 2016-74, the moisture content in this study was analysed based on dry weight basis. To define the moisture content, the fibre was dried in a drying oven at (103$\pm$2°C) until a constant value of the sample weight was attained. PORIM Test Method for palm and palm oil products (PORIM p5.3, 1995) was used to determine the oil content of EFB fibre using hexane to leach and release oil from the fibres.

Water glass preparation

Potassium water glass (34/36 Bé.) was used as a binding agent. A water glass solution was prepared by adding 10% *aqua destilata* to potassium water glass to increase the viscosity of the solution and also to improve the spreading process efficiency.

Production of the insulation material

Production of the insulation material made from cut EFB fibres was carried out with reference to patent DE 43 16901 A1 (Richter & Bücking 1993), but with some modifications. The target density of the insulation material was about 100 kg/m^3. The experiment was divided into two stages, *i.e.* optimization at laboratory scale and production of the insulation material at pilot scale.

The optimization was carried out according to previous research conducted by Scheiding (2001). Various ratios of material and binding agent (MB ratio) were investigated to achieve the best conditions for the production of the insulation material. The MB ratio 1:1; 1:1.2; and 1:1.6 were applied during the optimization process. The insulation sheet dimension (length x width x thickness) was 30cm x 30cm x 5cm with 2 to 3 replications for each condition. The dimension of the insulation sheet for the main experiment was 50cm x 50cm x 5cm. The obtained insulation boards were evaluated further based on quality control indicators, such as target density, presence of carbonation spots (Figure 5) and performance of the insulation material. The target density was about 100 kg/m^3 based on the requirement for building insulation (DIN 4102-1 1981).

The presence of carbonation spots was investigated with the naked eye to identify the presence of residual water glass in the form of solid material spots on the surface of the insulation board. Performance of the insulation material was evaluated based on visual and qualitative examination. The sample was signed or marked as 'good' and 'compact'.

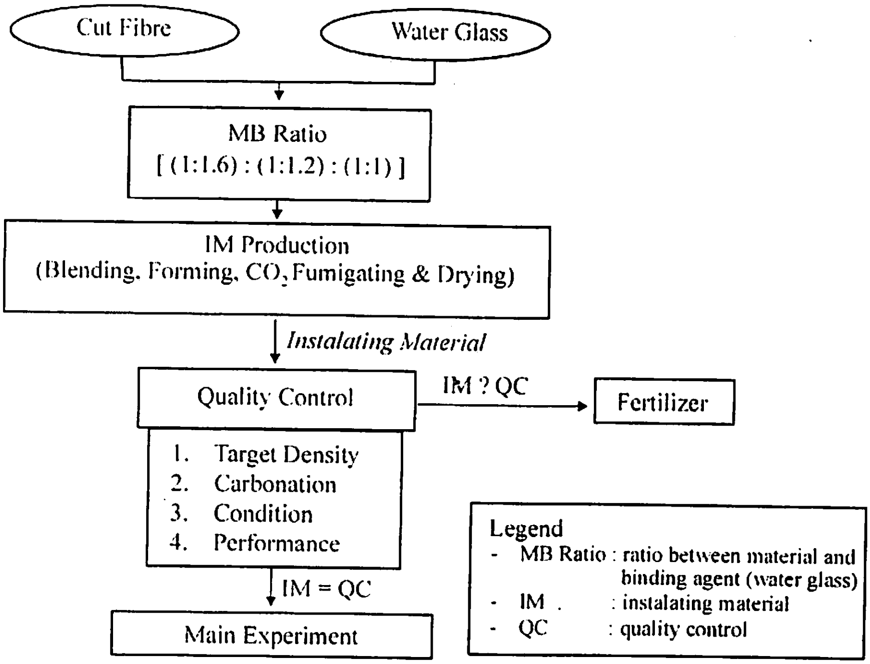

Figure 2. Optimization process of insulation material production

Figure 3a provides an overview of the production process of EFB fibre insulation boards at pilot scale. During production, there are three important processes taking place, *i.e.* carbon dioxide (CO_2) fumigation, hardening and drying. Firstly, potassium water glass was sprayed onto the loose fibres using a separate gun sprayer at the rotary blender. The mixture was then formed into fibre sheets and placed in the carbon dioxide fumigation room. After placing the fibre sheets in the fumigation room, the CO_2 gas from the reactor was pumped into the room for about one minute to start the chemical reaction between carbon dioxide and water glass. Flow direction of the processes was in two directions, *i.e.* up-down flow and down-up flow in order to reach the full cross section of the insulation board (Figure 3b). Hot air (60°C) was also pumped continuously into the fumigation room for about four minutes during each flow direction in order for hardening of the insulation sheet to take place. Fumigation with CO_2 and the hardening process were thus carried out simultaneously in the fumigation room.

The resulting insulation board was then dried in the drying oven at (103±2°C) until a constant weight was attained. It was then stored in a conditioning room for a week at 22°C and 65% relative humidity for further investigation such as thermal conductivity, physical properties and board performances.

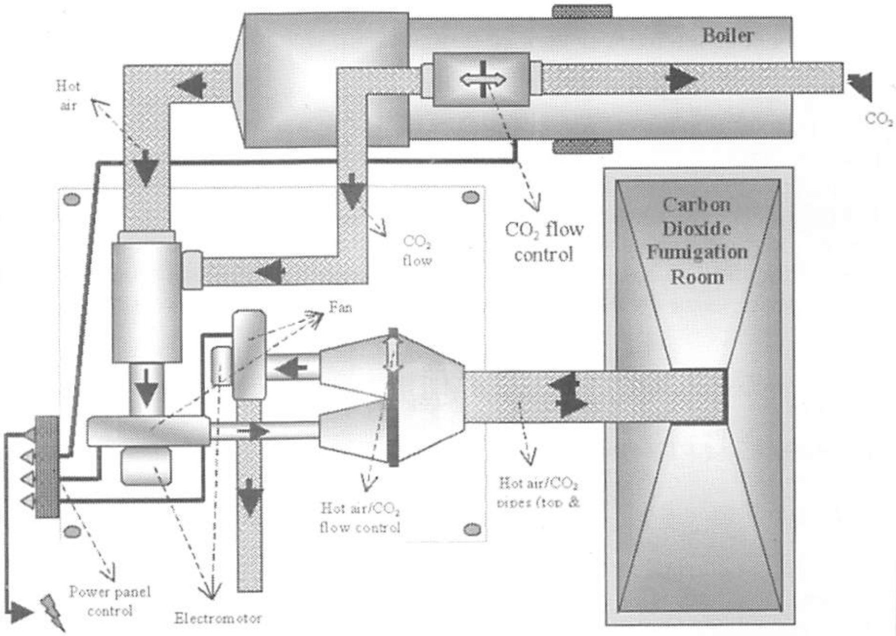

Figure 3a. Insulation material production at pilot scale (view from above)

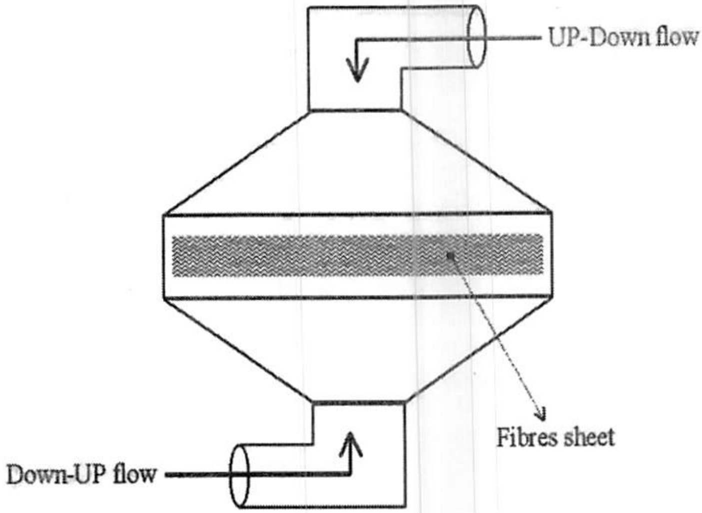

Figure 3b. Fumigation room and hot air flow

The insulation material made from cut EFB fibre was tested based on the ASTM standard for physical properties, such as density (ASTM D2395-93 1989) and moisture content (ASTM D2016-74 1983). Thermal conductivity was tested with reference to DIN 4108 (1995). A visual examination was also carried out to investigate the performance of the insulation material, such as homogeneity of the fibre distribution, compaction of the insulation, binding agent distribution, presence of carbonization spots and other performances which would influence the quality of the final product.

RESULTS AND DISCUSSION

Characteristics of EFB fibres

Fibre length distribution

The experimental results indicate that the cut EFB fibre material contained pure cut fibres, calyx and other components such as cut thorns, dust or fine particles and parenchyma cells. Although the cutter was installed to produce cut fibres of 20 mm, they still contained fibres longer than 20 mm. This was due to the fact that the fibres were rolled up in wads in a disorderly fashion. The length of the cut fibres varied from a few millimetres to more than 50 mm. The highest portion of the cut fibres was between more than 10 mm and 20 mm in length, whilst the lowest portion was between more than 40 mm and 50 mm. More than 70% of the fibres showed a length less than 50 mm (Figure 4). The proportion of calyx was relatively high (6.3%) as well as other components (12.9% thorn, dust and parenchyma cells). All these percentages were based on a dry weight basis.

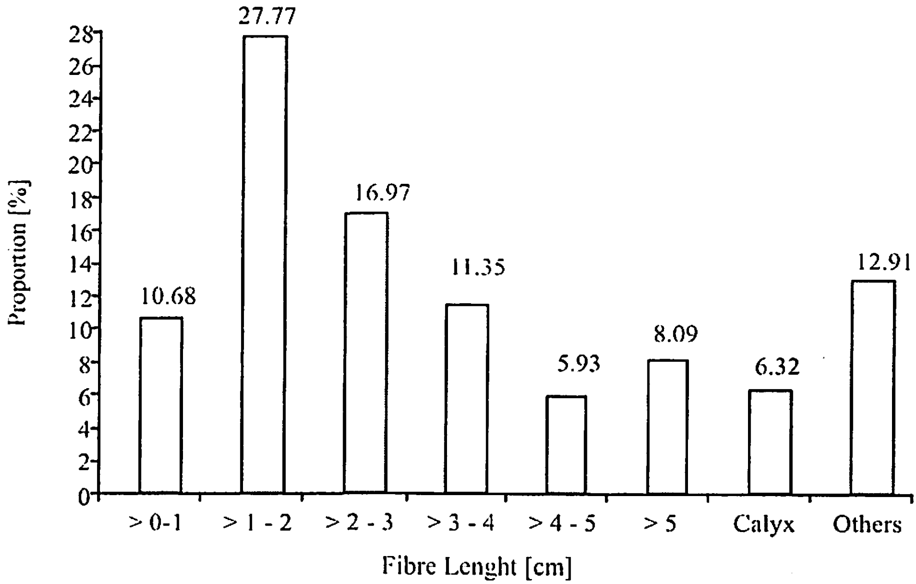

Figure 4. Length distribution of cut EFB fibres

Based on visual examination, the size of calyxes was less than 2 cm and most of the other components were contaminating cut thorns (>75%) with lengths of about 2 cm. Therefore, both of them were also suitable for use as raw materials. According to the material requirement established in patent DE 43 16901 A1, the cut EFB fibres obtained were of good quality and potentially suitable as a raw material for manufacturing insulation material.

Moisture content of the EFB fibre and the cut EFB fibre

Moisture content of the cut EFB fibres was determined to investigate the condition of the raw material before processing the insulation material. The presence of water in the fibres influences the curing process of water glass and the hardening process of insulation material. The experimental results showed that the moisture content of the original EFB fibres imported from Indonesia was about 12.7% (Table 1) and freshly cut fibres about 11.36% (Table 2).

Table 1. The moisture content of EFB fibres

Sample Code	Weight [g]	Weight (open dry) [g]	Moisture Content [%]
MC 01	4.3770	3.8834	12.7105
MC-02	4.3910	3.9177	12.0811
MC-03	4.1683	3.6954	12.7970
MC-04	5.0356	4.4609	12.8831
MC-05	4.2547	3.7837	12.5274
MC 06	4.1216	3.6517	12.8680
MC-07	4.0502	3.5802	12.1278
MC-08	4.6412	4.0999	12.2028
MC-09	4.1826	3.7224	12.3630
MC-10	4.1762	3.7088	12.6025
		Average	12.7163

Note:

MC-i : Sample code for moisture content of EFB fibres; where i is replication The EFB fibres were taken and picked randomly from the bales.

Therefore, both the original and the cut EFB fibres were acceptable in terms of the moisture requirement for insulation materials stated in patent DE 43 16901 A1, which recommends that the moisture content of material should be lower than 20% and in some cases lower than 12% (Richter & Bücking 1993). The Malaysian Standard for oil palm fibre specification for producing fibre based products states a maximum moisture content of about 15% (Malaysian Standard MS 1408 1997).

Table 2. The moisture content of cut EFB fibres

Sample Code	W0 [g]	W1 [g]	MC [%]
MCF1	5.0005	4.5500	9.9011
MCF2	5.0010	4.5050	11.00999
MCF3	5.0100	4.5100	11.08647
MCF4	5.0001	4.5303	10.37017
MCF5	5.0002	4.5302	10.37482
MCF6	5.0010	4.5201	10.63915
MCF7	5.0004	4.4006	13.62996
MCF8	5.0003	4.4005	13.63027
MCF9	5.0007	4.4010	13.62645
MCF10	5.0002	4.5346	10.26772
MCF11	5.0001	4.5296	10.38723
		Average	11.356666

Note:

MCFi : Sample code for moisture content of cut EFB fibre; where, i is replication

MC : Moisture Content (%)

W0 : Weight of cut EFB fibre before drying (g)

W1 : Weight of cut EFB fibre after drying (g).

In order to produce fibre-based products, especially using water-based adhesive such as water glass, the presence of a significant percentage of residual oil poses a major problem particularly during the curing process of water glass. On the other hand, it will react with the moisture content, giving rise to rancidity and ultimately fungal growth. Therefore, the oil content must be defined as a critical factor in the production of insulation material using water glass as a binding agent. The analysis of the cut EFB fibre showed that the oil content value was about 2.08% (Table 3). The value obtained achieved the required oil content limit with reference to MS 1408 (1997), which recommends that the control limit for oil content should not exceed 3%.

Density of cut EFB fibre

The results showed that the density of the cut EFB fibres determined by the cylinder-volume method was between 38.19 and 42.80 kg/m^3 with an average value of 40.5 kg/m^3 (Table 5). This was higher than the density of the originally imported EFB fibres which had an average value of 18.1 kg/m^3. (Table 4) This was technically acceptable because the cut EFB fibres were shorter in length from a few millimetres to more than 50mm. The condition of the fibres was more homogeneous and significantly different compared to the original fibres. They were no longer rolled up in wads because the cutting process not only reduced the fibre length in order to make it homogeneous in size, but also eliminated the EFB fibre from needles, dust and dirt. This could also be attributed to the fact that the cutting process had a positive effect on increasing the homogeneity of the material. Therefore, the density value of the cut fibres was acceptable as a raw material for manufacturing insulation material (DE 43 16901 A1).

Table 3. The oil content of cut EFB fibres

Sample Code	W0 [g]	Oil [g]	OC [%]
OCF1	5.0006	0.086	1.71979
OCF2	5.0005	0.0867	1.73383
OCF3	5.0007	0.0869	1.73776
OCF4	5.0006	0.0849	1.6978
OCF5	5.0005	0.085	1.69983
OCF6	5.0004	0.0853	1.70586
OCF7	5.0005	0.1233	2.46575
OCF8	5.0008	0.1236	2.4716
OCF9	5.0006	0.1231	2.4617
OCF10	5.0007	0.1302	2.60364
OCF11	5.0005	0.1304	2.60774
		Average	2.0823

Note:
OCFi : Sample code for oil content of cut EFB fibre; where i is replication
OC : Oil Content (%)
W0 : Weight of sample (g)
W1 : Weight of oil after leaching (g).

Table 4. The density of EFB fibres

Sample Code	Weight [kg]	Height [m]	Volume [m^3]	Density [kg.m^{-3}]
DF-01	0.053	0.100	0.0028040	18.902
DF-02	0.054	0.106	0.0029722	18.168
DF-03	0.051	0.125	0.0035050	14.551
DF-04	0.053	0.096	0.0026918	19.689
DF-05	0.054	0.106	0.0029442	18.168
DF-06	0.053	0.105	0.0029442	18.001
DF-07	0.055	0.105	0.0029442	18.681
DF-08	0.049	0.095	0.0026638	18.395
DF-09	0.050	0.094	0.0026358	18.970
DF-10	0.058	0.119	0.0033368	17.382
			Average	18.091

Note:
DF-i : Sample code for density of EFB fibre; where i is replication.
Diameter of cylinder was 0.189 m and area of cylinder was 0.02804 m^2

Table 5. The density of cut fibres

Sample Code	Weight [kg]	Height [m]	Volume [m^3]	Density [kg/m^3]
DCF1	0.085	0.0775	0.0021731	39.11
DCF2	0.089	0.0800	0.0022432	39.68
DCF3	0.082	0.0750	0.0021030	38.99
DCF4	0.084	0.0700	0.0019628	42.80
DCF5	0.090	0.0800	0.0022432	40.12
DCF6	0.083	0.0775	0.0021731	38.19
DCF7	0.089	0.0750	0.0021030	42.32
DCF8	0.086	0.0750	0.0021030	40.89
DCF9	0.088	0.0750	0.0021030	41.84
DCF10	0.081	0.0700	0.0019628	41.27
			Average	40.52

Note:
DCFi : Sample code for density of cut EFB fibre; where i is replication.

Insulation material from cut EFB fibre

Optimization process

In early research of insulation material production from soft wood fibres, Scheiding (2001) stated that the maximum carbon dioxide reaction with water glass during the fumigation process is reached in the first minute of the fumigation process.

Therefore, the carbon dioxide fumigation process in this study was also carried out for one minute for both up-down and down-up hot air flows.

According to the results obtained during the optimization process (Table 6), the optimum process was achieved at an MB ratio of 1:1, whilst the insulation with MB ratios of 1:1.2 and 1.6 were not effective, even though the products were compact. However, many carbonation spots on the surface of the products were observed (Figure 5). This was attributed to the fact that there was too much water glass producing a lot of carbonation spots.

Table 6. The condition and performance of EFB fibre insulation during the optimization process

IM Code	MB Ratio	Density [kg/m^3]	IM Condition and Performance
IM 1.6 (1)	1 : 1.6	100.15	relatively good. compact. carbonation spots
IM-1.6 (2)	1 : 1.6	154.27	atively good. compact. carbonation spots
IM-1.2 (1)	1 : 1.2	103.23	good, compact, and carbonation spot
IM-1.2 (2)	1 : 1.2	152.52	good, compact, and carbonation spot
IM-1.1 (1)	1 : 1	98.12	very good. compact. no carbonation spot
IM-1.1 (2)	1 : 1	106.72	very good. compact. no carbonation spot
IM-1.1 (3)	1 : 1	96.46	very good, compact, no carbonation spot

Note:
IM : Insulating Material
MB Ratio : ratio between material and binding agent, in this case cut EFB fibre and water glass.

The carbonation spots were from the remaining water glass in the form of white spots of solid material, which could be seen on the surface of fibre sheet directly with the naked eye. The average densities of insulation material at MB ratio of 1:1; 1:1.2 and 1:1.6 are about 100.4, 127.9 and 127.2 kg/m^3, respectively.

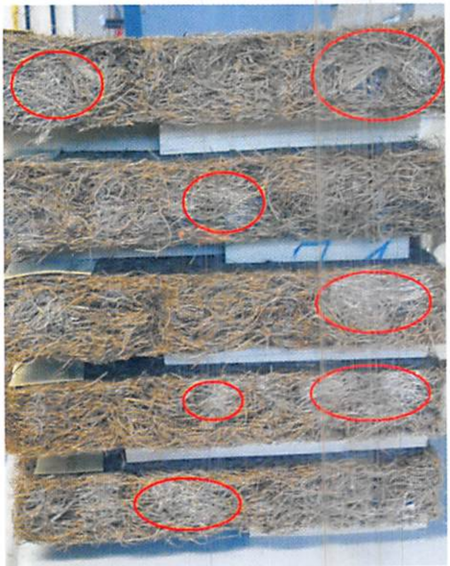

Figure 5. Presence of carbonation spots (red circles) on insulation material made from EFB fibres

Based on the obtained results, the condition and performance of the board were influenced by the presence of the carbonation spots on the surface of the board caused by an incorrect ratio of fibre and water glass with an excessive amount of binding agent being present. The presence of carbonation spots also indicated that the water glass was not spread homogeneously and it was not distributed properly at each connection point of the fibre mass. According to the experimental results, the optimum conditions for manufacturing insulation material made from cut EFB Fibre is presented in Table 7.

Table 7. The optimum condition for insulating material production

Parameter	Unit
MB Ratio	1 : 1
Water content	10% of fibre weight
Carbon dioxide fumigation	1 minute for each flow (Up
Hardening*	4 minutes for each flow (Up
Target density	100 kg/m
Thickness	50 mm

* Hardening time depends on several parameters: Board thickness, board density, initial board moisture content, target moisture content of the board, velocity of gas passage, gas temperature, resistance against the gas passage through the calibration sieve, tightness of production compartment (Scheiding 2001).

Production of EFB fibre insulation boards

The experimental data during the production of insulation material made from cut EFB fibre at pilot scale is presented in Table 8.

Table 8. Condition during insulating material production at pilot scale

Parameter		Insulating Material Made from EFB Fibre*							
		IM1		IM2		IM3		IM4	
MB Ratio		1:1		1:1		1:1		1:1	
t-SI	T	2	19.5	1	21.5	1	17.0	2	17.5
t-F Up	T	1	24.0	1	24.0	1	24.0	1	24.0
t-F Down	T	1	32.0	1	33.0	1	35.5	1	36.0
t-CH Up	T	4	32.0-34.5	4	33.0-34.5	4	35.5-33.0	4	36.0-33.5
t-CH Down	T	4	34.5-55.5	4	34.5-55.5	4	33.0-53.0	4	33.5-54.0
EP	T	2	53.0	2	53.0	2	46.0	2	50.0
W0		1580.48		1607.00		1564.68		1615.95	
W1		1416.12		1415.44		1367.68		1359.90	
σ0		118.22		122.41		121.45		123.98	
σ1		108.04		109.88		105.89		108.04	
MC0		11.61		13.53		14.40		18.83	
MC1		< 10		< 10		< 10		< 10	

Note:

Imi : insulating material made from EFB fibre, where i is number sample board (i=1,2,3,4)
t-SI : time for starting instrument in pilot scale
t-F Up : time for CO_2 fumigation process at Up-Down flow
t-F Down : time for CO_2 fumigation process at Down-Up flow
t-CH Up : time for curing and hardening processes at Up-Down flow
t-CH Down : time for curing and hardening processes at Down-Up flow
T : temperature (°C)
EP : Ending process
W0 : weight of insulation before drying process (g)
W1 : weight of insulation after drying process (g)
ó0 : density of insulation before drying process (kg/m^3)
ó1 : density of insulation after drying process(kg/m^3)
MC0 : moisture content of insulation before drying process (%)
M1 : moisture content of insulation after conditioning (%)
*) Dimension of insulating material: 50cm X 50cm X 50cm with target density 100 kg/m^3.

Table 8 shows that the time required for producing the insulation material from preparing the fibre sheet to unloading the insulation board from the fumigation room was about 13.5 minutes. Under optimum conditions the temperature recorded during production increased from 17°C to 55.5°C (Table 8 and Figure 6). The fluctuations in temperature during production were gradual increasing and it has similar trends for all samples.

In a major industrial plant with optimized production parameters, drying time can be reduced drastically in comparison to the drying times mentioned above.

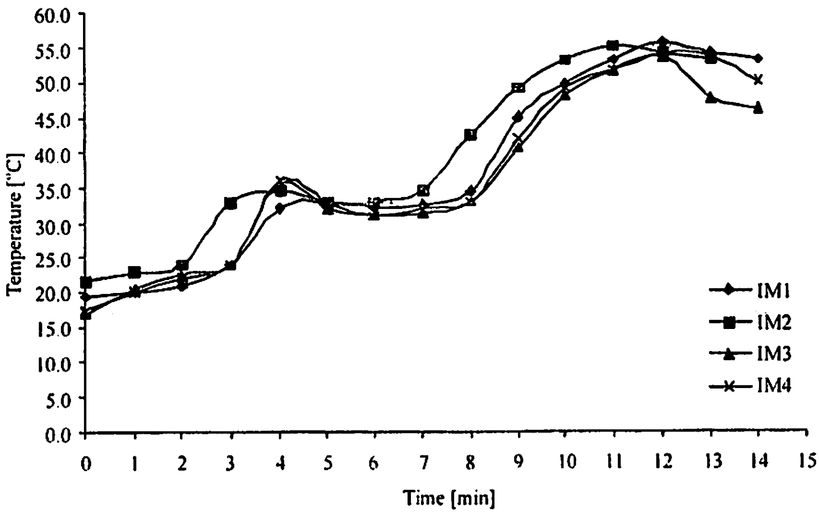

Figure 6. Temperature during insulation material production under optimum conditions for insulation material (IM) 1 to 4

With reference to Figure 6, after opening the fumigation valve the chemical reaction was initiated immediately and the temperature slightly increased during the CO_2 fumigation in both directions (up and down). After closing the fumigation valve (2 minutes), the temperature reached the first peak and then the hardening and drying process (4 minutes for each direction) started. During this period, the temperature slightly decreased relatively constantly until the hot air flow (60°C) changed. The temperature then immediately increased very rapidly and reached its maximum (55°C) at the end of the drying process. Lastly, the temperature decreased until the end of the processes, since the hot air flow stopped.

The curing and hardening processes were very important during the board production, where the fibres and the water glass were bonded and hardened by fumigation with carbon dioxide and hot air through the fibres. The fumigation reaction reached its maximum within the first minute and almost all the carbon dioxide gas was fixed in the water glass at that moment. The chemical reaction between potassium water glass and carbon dioxide gas can be described in the equation:

$$(K_2O \bullet \%\ nSiO_2 \bullet \%\ mH_2O) + CO_2 \rightarrow K_2CO_3 + nSiO_2 + x\ H_2O)$$

Carbon dioxide gas reached the spots of the particle mixture and the potassium water glass reacted with the carbon dioxide gas. The connection points between fibres were then bonded and the water glass was carbonized. During the drying process to harden the sheets using hot air flow, silicone dioxides were precipitated and subsequently moisture was released and evaporated off (Scheiding 2001).

Physical properties of EFB fibre insulation boards

Moisture content of the EFB fibre insulation boards were investigated based on ASTM D2016-74 (1983). The results showed that the moisture content of the insulation material directly after the production process was between 11.6% and 18.8% with average moisture of approximately 14.6% (Table 8). The increase in moisture content is a result of the chemical reaction process (Table 9). To achieve the required final moisture content (patent DE 43 16901 A1, Richter & Bücking, 1993) the insulation boards were dried in the drying oven (80°C) for 24 hours and stored in the conditioning room for a week (temperature 22°C and RH 65%).

Density of the insulation material was one of the important parameters for evaluation of its physical and mechanical properties. This value was calculated based on dry weight basis with a sample size of 10cm x 10cm x 5cm (ASTM D2395-93, 1989). All samples were conditioned in the conditioning room at 22°C and relative humidity 65%. The results showed that the density of the EFB fibre insulation material varied between 99kg/m^3 and 129.1kg/m^3 with an average value of approximately 116.4kg/m^3 (Table 9), whilst the density of the fibre raw material was about 40.5kg/m^3. This was acceptable according to the insulation material for building purpose requirement (DIN 4102-1 1981).

Table 9. The density of insulating materials made from the oil palm EFB fibres

Sample	Density [kg/m^3]	Sample	Density [kg/m^3]
DIM-01	98.98	DIM-09	128.86
DIM-02	115.24	DIM-10	115.96
DIM-03	124.86	DIM-11	118.05
DIM-04	108.07	DIM-12	119.12
DIM-05	102.15	DIM-13	121.31
DIM-06	100.93	DIM-14	119.79
DIM-07	129.06	DIM-15	120.57
DIM-08	123.18	DIM-16	114.90
		Average	116.35

Note:
DIM-i : Density of insulating material [kg/m^3] ; i = replication 1....16

Heat or thermal energy flows continuously through materials and space taking the path of least resistance and flowing from the warmer object to the cooler object. Insulation material attempts to keep thermal heat where it is required (Bynum 2001). Richter & Sterzik (2000) stated that the thermal conductivity of insulation material made from oil palm empty fruit bunch fibre, with reference to DIN 4108 (1995), was between 0.049 and 0.054 W/mK. Therefore, the average thermal conductivity of the obtained product is concurrent with the thermal conductivity groups of WLG 050 and WLG 055 (DIN 4108), respectively.

Figure 7. Water glass bonded insulation board made from oil palm empty fruit bunch fibres

CONCLUSION

The manufacture of insulation material from oil palm empty fruit bunch fibre appears to be technically acceptable based on the patent DE 43 16901 A1 (Richter & Bücking, 1993). The utilization of this fibre could be a new solution for producing environmentally-friendly insulation materials and an alternative to substitute wood fibre, cellulose, cotton and non-renewable raw materials, such as polystyrene, vermiculite, perlite, fibreglass, mineral wool, *etc.*

The original EFB fibres were rolled up in compacted wads in a disorderly fashion with fibre lengths from approximately 50mm to more than 200mm. The moisture content and density of this fibre was about 12.7% and 18.1 kg/m³ respectively.

The EFB fibres were cut using a conventional manual cardboard and veneer cutter with a knife distance of 20mm. The cut EFB fibre material contained fibres, calyx and other components, which included cut thorns, dust or fine particles and parenchyma cells. The fibre length varied from a few millimetres to more than 50mm with about 70% of the fibre with lengths less than 50mm. The average moisture content and density of the cut EFB fibres were about 11.36% and 40.5 kg/m³ respectively. As expected, the cut EFB fibres were more homogeneous compared to the original EFB fibres and these fibres (cut and original EFB fibres) were potentially acceptable as a raw material for manufacturing insulation material with reference to patent DE 43 16901 A1.

The density of the insulation material made from the EFB fibres was about 116.4 kg/m³. The thermal conductivity of this product was between 0.049 and 0.054 W/mK. EFB fibre insulation is acceptable as an environmentally-friendly insulation material for building purposes with reference to the insulation for building purpose requirement DIN 4102-1 (1981).

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