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Briquetting of Empty Fruit Bunch Fibre and Palm Shell as a Renewable Energy Fuel

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Abstract: Malaysian palm oil industry produces vast amount of biomass, mainly from the palm oil milling sector. Converting oil palm biomass into a uniform solid fuel through briquetting process appears to be potentially an attractive solution in upgrading its properties and to add value as renewable energy fuels. In this study, raw materials including Empty Fruit Bunch (EFB), in fibrous form and palm shell were mixed in certain ratios and densified into briquettes at high pressure using piston press technology in a palm oil mill. The blending ratios of shell to EFB (w/w%) for the production trials were fixed at 20, 30, 40 and 60%. The raw materials and briquettes produced were analysed to determine their physical and chemical properties. From the analysis, it was found that the average calorific values and specific densities for the blending ratios of 20-60% ranged from 17995-18322 kJ kg^{-1} and from 1179-1225 kg m^{-3}, respectively. All these figures were higher than the calorific value and specific density of palm biomass briquettes produced from 100% EFB fibre. The properties of palm biomass briquettes obtained from the study were compared with those of the commercial sawdust briquettes and selected parameters of German standard DIN 51731 on calorific value, density and moisture content. The details of the study were highlighted in this study. Some of economic advantages in setting up the briquetting plant in a palm oil mill was also discussed. Overall, the presence of high shell in palm biomass briquettes increased the calorific value, specific density and quality of the briquette as well. Palm biomass briquettes can become an important renewable energy fuel source in the future for the global market, especially for the development of the second generation biofuel via thermochemical conversion.

Key words: Empty fruit bunch, palm shell, biomass pre-treatment, piston press technology, renewable energy

INTRODUCTION

Malaysian oil palm industry continues to expand and diversify its uses and products to fulfill the demand of rapid market growth. Besides producing crude palm oil and palm kernel oil for edible and non-edible applications, the industry also produces the high volume of biomass waste, particularly from the palm oil milling activity. According to Basri, 90% of palms are non-oil biomass while the remaining 10% comprises of oil component. In general for 1 ton of fresh fruit bunch processed, the following residues are generated at the mill; 0.23 ton of Empty Fruit Bunch (EFB), 0.13 ton of mesocarp fibre, 0.06 ton of palm shell and 0.65 ton of Palm Oil Mill Effluent (POME). All these resources have long been identified and utilized as sustainable Renewable Energy (RE) fuels in the country. With enormous interests on the sustainability development of the industry, environmental concerns, the utilization of could be expended and efficiently used as feedstock for value added products and resources of renewable energy. Table 1 shows the biomass generated from the Malaysian palm oil mills in 2010.

Table 1: Palm biomass generated in year, 2010

Biomass	Quantity (million ton)	Moisture content (%)*	Calorific value (kJ kg^{-1})*	Main uses
Fibre	10.8	37.00	19068	Fuel
Shell	4.80	12.00	20108	Fuel
Empty fruit bunches	19.11	67.00	18838	Mulch/Fuel
POME (biogas)	54.00 (1512 million m^3)	-	20000 kJ m^{-3}	Mulch/Fuel

*(Vijaya *et al*., 2004)

Oil palm biomass is known as a RE resource that available through out the year in abundance, easily collected and grossly underutilized. Mesocarp fibre and shell are the main fuels used for cogeneration plant in the palm oil mills. These two fuels supply more than sufficient

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energy to meet the energy demand of a palm oil mill (Ma, 2002). In 2010, based on 85.09 million ton of Fresh Fruit Bunch (FFB) processed at 20 kW h ton^{-1} FFB (Mahlia *et al*., 2001), the off-grid electricity generated from 418 mills nationwide was about 1702 GW h. At average monthly processing hours of 400 h $month^{-1}$, this amounted to 356 MW of total off grid generating capacity. Besides mesocarp fibre and shell, EFB is another biomass that can be readily used as fuel. However due to its poor physical characteristics and sufficient energy supplied from fibre and shell, the use of EFB as fuel is limited. In the recent years, EFB is mechanically treated and converted to EFB fibre as boiler fuel, especially for the mills that require more energy for processing purposes, however its quality is yet to be improved. In order to enhance fuel quality and to facilitate handling and transportation of the fuel, EFB and palm shell can be mixed and further treated to become a uniform and more dense solid fuel via the briquetting process. This approach could expand the use and marketability of palm biomass fuel either for domestic or export market.

Briquetting or densification is the mechanical process of compacting the biomass residue into a uniform solid fuel called briquettes. It has higher density and energy content as well as less moisture compared to its raw materials. These processes are among ways to improve the behavior of fuel because it increases the homogenity and facilitate the logistic and storage of the fuel. Briquetting of biomass can be done using various techniques either with or without binder addition. There are two commercial technologies namely screw extrusion and piston press technologies. Due to technology and economic factors, piston press technology is used for the production trial of palm based biomass briquettes. Generally in a piston press, palm biomass is pressed in a die by reciprocating ram at a very high pressure (Grover and Mishra, 1996).

Biomass briquettes have wide applications as fuel either for household usage or for larger industrial applications in producing heat and electricity generation. Global interests on renewable energy has put biomass briquette as among potential replacement as fuel for fossil fuel fired cogeneration plant in particularly coal. The Malaysian briquette industry was started with wood wastes, mainly in the form of sawdust (Hoi, 1995). Most of the local sawdust briquettes or charcoal briquettes are exported for oversea markets (Hoi, 1995).

Due to superior quality of biomass briquettes compared to its raw material, briquettes are also identified as a feedstock for the development of the second generation biofuel, especially for thermochemical based energy conversion such as pyrolysis, gasification and Biomass to Liquid (BTL). Utilization of palm briquette as fuel offers numerous advantages such as better fuel characteristics and consistent burning quality compared to its raw material, reduction of Greenhouse Gases (GHG), contains a very low sulfur and ease of transportation and logistics as well.

Briquetting of palm biomass is relatively new commercial initiative for the palm oil industry. Due to the low supply of sawdust, oil palm biomass can be an alternative raw material either to be used 100% or can be blended with other biomass for the production of briquettes in the country.

Briquetting is also one of the potential downstream activities that could be integrated with existing palm oil mill to make the business more attractive and feasible to millers. Through this approach, it offers as an option for the industry to dispose of the palm biomass in a profitable and sustainable manners. Therefore, this is a business opportunity for the oil palm industry to make use of all these wastes as value added products. Therefore, the objectives of the research were to get an overview about the properties of the oil palm biomass briquettes as commercial RE fuels and to study the effect of blending ratio of palm shell with EFB fibre to the properties of palm biomass briquettes. Some of economic advantages of integration of the briquette plant with palm oil mill are also discussed in this study.

MATERIALS AND METHODS

EFB fibre and palm shell were used as feedstocks for the production of palm based biomass briquettes using a unit of 1 ton h^{-1} piston press technology. The production of palm biomass briquettes involves two main processes, namely pretreatment of EFB and the briquetting. The pretreatment and briquetting plants of EFB and shell were set up and integrated in a palm oil mill. Raw EFB was mechanically pretreated and dried using a series of machineries to reduce the size and moisture content. The temperature of rotary dryer was at 180-200°C. Treated EFB with fibre length and moisture content <5 cm and 20%, respectively was evenly mixed with palm shell prior to briquetting process. Shell was used as received without any pre-treatment.

The blending ratios of shell to EFB (w/w%) for the production trials were fixed at 20, 30, 40 and 60%. The process flow of the production trial of palm based briquettes are shown in Fig. 1. The briquettes produced then were analyzed to determine their physical and chemical properties using standard methods as shown in Table 2. The results were compared to the commercial sawdust briquettes and to selected parameters of DIN

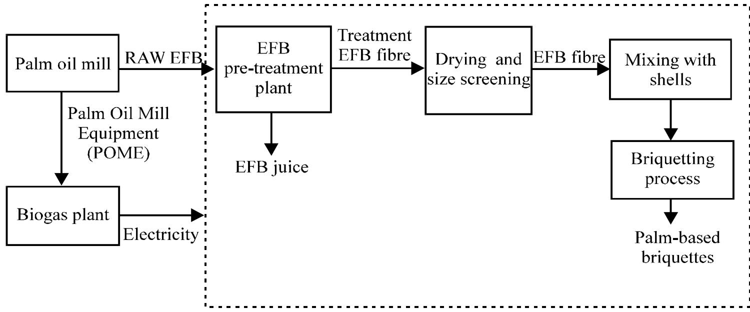

Fig. 1: Process flow diagram for the production of palm biomass briquettes in palm oil mill

Table 2: Methodology and standard for properties study of raw materials and products

Experimental	Standard method/Methodology
Moisturecontent	BS 4289 part 3: 1978/MPOB test method
Calorific value	ASTM 2015 (bomb calorimeter)
Ash content	ISO 1171-97
Fixed carbon	MPOB test method
Volatile matter	ISO 562-98
Specific density	ASTM D792-08/Water displacement/by calculation*
Ultimate analysis	Elemental analyzer

*(Brown, 1997; Obernberger and Thek, 2004)

51731: Testing on solid fuels; compresses untreated wood-requirements and testing (Deutsches Institut fur Normung e.V, 1996).

RESULTS AND DISCUSSION

Production trials: The aim of the production trials was to produce binderless palm biomass briquettes from EFB fibre and palm shell without affecting the overall quality of the product and production process. From the production trial conducted using piston press technology, it was found that binder free palm biomass briquettes can be produced from the mixture of EFB fibre and palm shell. About 10-20% of lignin is available in EFB fibre (Astimar *et al.*, 2002; Rahman *et al.*, 2007) which indirectly used as a natural binder (Grover and Mishra, 1996). The high pressure applied during the compaction process fluidized the lignin and assisted in binding (Sharif *et al.*, 2008).

Presence of shell increased the feedstock density and smooth flow ability of biomass to ease the briquetting process. However, the increment of the palm shell >60% (w/w) of the weight basis resulted in low physical strength and surface properties of briquettes. Hence, the low quality briquettes were produced and easily broken into pieces during briquetting. This was due to less amount of EFB fibre in briquettes that helps in the binding process of palm briquette. The study shows that in order to have good physical appearance, strength and density, the maximum blending ratio of palm shell must be at 60% of total weight.

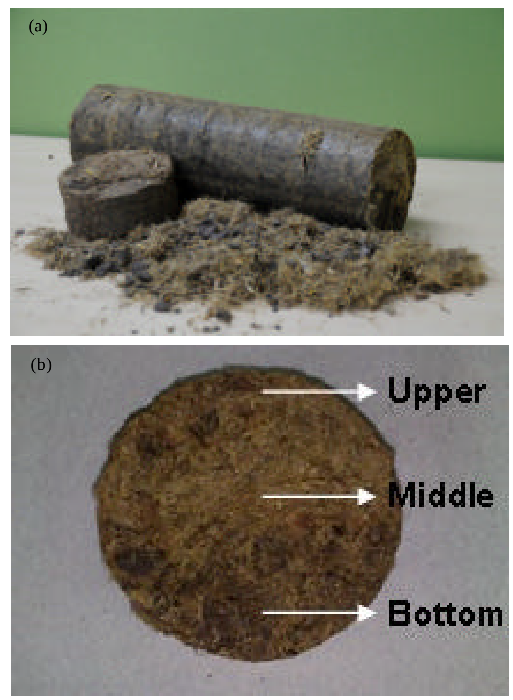

Fig. 2: Quality of; a) palm briquettes and b) sampling parts of briquettes for CV analysis

Products properties: The quality of produced palm briquettes is shown in Fig. 2a. Basically, the briquette is in cylindrical logs, 1 foot or 30 cm in length, 9 cm in diameter and weighing 2.2 kg each. Table 3 shows the general specification of the raw materials and the briquettes in terms of its ash content, moisture content, fixed carbon and volatile matters. There was no significant difference on the properties of the briquettes and the feedstock except for the moisture content. High pressure and temperature applied during the briquetting process have significantly reduced the moisture content of palm briquette. Low moisture content contributes the maximum energy of the biomass as the amount of water in biomass will affect the recoverable heat (Demirbas, 2001). According to Reddy (1994) in a study on Indian firewood,

Table 3: General specification of the raw materials and results of the analyses of palm biomass briquettes

Biomass briquettes	Ash content (%)	Moisture content (%)	Volatile matter (%)	Fixed carbon (%)
EFB fibre (Feedstock) and 100% EFB fibre briquette	6.43	15.80	80.21	13.05
Shell (Feedstock)	4.36	9.25	77.36	18.21
Palm briquette-shell ratio, 20 %	6.35	6.76	79.65	13.30
Palm briquette-shell ratio, 30%	6.12	6.55	79.53	13.80
Palm briquette-shell ratio, 40%	5.99	6.13	78.55	14.22
Palm briquette-shell ratio, 60 %	5.50	5.52	78.08	14.93
Sawdust briquette (control)*	<4.00	<7.00	-	-
DIN 51731	<0.70	<10.00	-	-

*(Nasrin *et al*., 2008)

the variations of energy indicated that with increasing moisture content, the energy content decreases linearly. Therefore, the moisture content has an influence on the net calorific value, the combustion efficiency and the temperature of combustion (Obernberger and Thek, 2004). Moisture content may also affect the strength and durability of briquette (Husain *et al*., 2001).

Besides that there were some improvements in terms of volatile matter and fixed carbon of the products. These two parameters contributed to good combustion property. In term of ash content, the high ash content of briquettes produced from EFB fibre and shell in a range between 5.50 and 6.35% was due to high ash content of the raw materials (Obernberger and Thek, 2004). These figures were also higher than an acceptable limit of DIN 51731 which was developed for briquettes made from wood waste only and not for briquettes made from agriculture waste such as oil palm biomass.

Calorific Value (CV): Figure 2b represents sampling parts of briquette for CV analysis. The upper part contains more EFB fibre while most of the shells were found at the bottom part of briquettes. These patterns were due to the difference of density of EFB and palm shells. The CV of briquette made from 100% EFB fibre was 17660 kJ kg^{-1} and with addition of shell, average CV for the blending ratios of 20-60% ranged from 17995.3-18322.7 kJ kg^{-1}. Presence of palm shell which has a higher CV compared to EFB fibre has contributed to the increment of CV for blended EFB fibre-shell briquettes.

CV is an important commercial factor in determining the trading price of palm briquettes and to be utilized in coal fired power plant. Table 4 and Fig. 3 shows the CV of palm biomass briquettes at different parts and ratio of shell. The higher CV of palm biquettes is also contributed by low moisture content and high carbon content compared its raw materials (Reddy, 1994; Demirbas, 2001).

Specific density: Specific density is another important commercial parameter for briquettes which influences the strength and durability of biomass briquette

Table 4: Calorific value of biomass briquettes at different parts and ratio

	Sampling part			
Briquette/parameter	Upper	Middle	Bottom	Average CV (kJ kg^{-1})
100% EFB briquette (control)	-	-	-	17660.0
Shell ratio, 20%	17921.0	17926.5	18138.0	17995.3
Shell ratio, 30%	17895.0	18019.0	18235.0	18049.7
Shell ratio, 40%	17872.5	18135.5	18312.5	18106.8
Shell ratio, 60%	18121.0	18254.0	18586.0	18322.7
Palm shell (control)	-	-	-	18590.0
Sawdust (control) *				18936.0
DIN 51731	-	-	-	>17500.0

*(Nasrin *et al*., 2008)

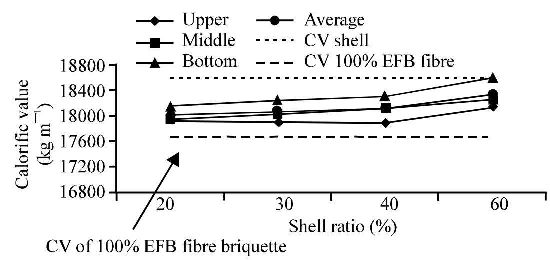

Fig. 3: Calorific value (kJ kg^{-1}) of palm briquettes at different parts and shell ratio (%)

briquettes with addition of shell was 1204 kg m^{-3} which was higher compared to 100-200 kg m^{-3} of loose palm biomass.

The specific density of briquette produced from 100% EFB fibre was 1108 kg m^{-3} and the addition of palm shell with 20-60% (w/w%) increased the specific density of briquettes in a range between 1179-1225 kg m^{-3}. These density values met the requirement of 1000-1400 kg m^{-3} according to the German standard DIN 51731 (Koutny *et al*., 2007).

The high density would give an advantage for palm briquette in terms of transportation and storage requirements (Deutsches Institut fur Normung e.V, 1996; Koutny *et al*., 2007). Specific density also influences the bulk density and the combustion behavior of the biomass fuel as dense particles or show a longer burnout time (Obernberger and Thek, 2004). Specific density of palm briquettes is shown in Fig. 4.

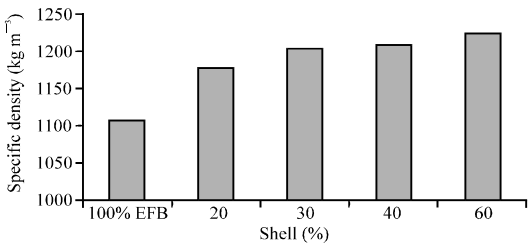

Fig. 4: Specific density (kg m^{-3}) of palm briquettes at different shell ratio (%)

Table 5: Ultimate analysis for palm biomass briquettes

Biomass briquettes	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen
	(%)				
100% EFB fibre	54.10	5.85	0.58	0.09	36.50
Palm shell	58.20	5.45	0.40	0.05	32.10
Briquette 30% shell	55.70	5.78	0.46	0.04	34.86
Briquette 40% shell	56.05	5.78	0.44	0.04	34.51

Ultimate analysis: The ultimate analysis gives the composition of the biomass in wt.% of carbon, hydrogen and oxygen as well as sulfur and nitrogen. Results for ultimate analysis for the raw materials and palm based briquette are shown in Table 5. In this study, only palm briquettes with 30-40% of shell were analyzed for their chemical content using standard method ASTM D5373-08. From the results, there was no significant increment on the chemical elements of the products compared to its raw material as the process is more on the mechanical treatment for physical improvement of palm biomass (Nasrin *et al*., 2007). Addition of palm shell in EFB briquettes improves the chemical elements of the products, especially in carbon content. The CV of biomass depends on the percentage of carbon and hydrogen which are the main contributors to the heat energy value of biomass material (Demirbas, 2001). Therefore, energy content or CV of the briquette may also be determined by these element compositions using the equation developed by DuLong and other researchers as well (Mahlia *et al*., 2001).

Further studies will be conducted to compare the calorific value of the palm briquettes obtained from the experimental method and by calculation.

Integrated of briquette plant in a plam oil mill; commercial benefits: Oil palm biomass briquettes can be used as coal and as a petroleum oil substitute for combined heat and power plants. With the increasing global interest for renewable energy fuels and the decreasing sawdust supply in the country, EFB fibre and palm shells are potential raw materials for the production of palm biomass briquettes. To make the production more economically viable and sustainable, EFB pretreatment and briquette plants can be integrated into existing palm oil mills. This approach would significantly reduce the production cost of commercial palm biomass briquettes, mainly on the raw material and utility costs. Biogas from the palm oil mill effluent can be tapped for electricity generation and hot fluegases from the palm oil mill boiler can be used for palm biomass drying. It was estimated that the specific energy requirement to produce 1 ton of palm briquette was about 200 kW h (Table 6). Based on the 60 ton h^{-1} mill capacity, the potential capacity of biogas plant and briquetting plant which can integrated with the mill is 1.85 MW and 6 ton h^{-1}, respectively. The potential estimated annual production of palm briquettes from a 60 ton h^{-1} mill is summarized in Table 7. The trading price of briquettes is determined by their energy content and the market price of commercial coal. At a CV of 18,000 kJ kg^{-1} or 4,300 kcal kg^{-1} EFB shell briquettes can be sold at USD 100 ton^{-1}. Based on 25% thermal efficiency, 1 ton of palm briquettes can generate about 1.25 MW h. Utilization of palm biomass briquettes as fuel for power generation may be entitled for additional profits via RE incentives or tax exemptions in many countries and also to carbon credits under the Clean Development Mechanism (CDM). The investment cost for a 1 ton h^{-1} briquetting machine is estimated at RM 5,00,000 (USD 1,66,667) excluding the pre-treament plant for EFB. Six machines are required to be installed in a 60 ton h^{-1} mill for a production volume of 38,448 ton $year^{-1}$ or 3,204 ton $month^{-1}$ from EFB fibre and shells. The total investment and payback period for the technology to be installed in a 60 ton h^{-1} mill are estimated at <RM 7 million (USD 2.33 miilion) and 2 years, respectively.

Table 6: Estimated electrical requirement for the production of 1 ton briquettes (kW h ton^{-1})

Operation unit	kW h ton^{-1}
Pretreatment plant (pressing, hammer mill (grinding), drying and conveyor)	~150
Briquetting	50
Total	200

Table 7: Estimated annual production of blended EFB shell briquettes from a 60 ton h^{-1} mill and electrical requirement

Raw materials	Quantity (ton $year^{-1}$)
Fresh Fruit Bunches (FFB) processed annually	288,000
Raw EFB produced (at 23% of FFB) annually	66,240
Treated EFB (at 10% moisture content)	29,808
Shells produced (at 6% of FFB) annually	17,280
At 50% of shell usage for briquettes	8,640
Potential annual production of blended EFB shell briquettes	EFB: 29,808
Shells	8,640
Total	38,448
Proposed plant capacity (ton h^{-1})	6
Electrical requirement for the proposed plant (at 200 kW h ton^{-1})	1.2 MW
Potential biogas from 60 ton h^{-1} mill*	1.85 MW

*(Tong, 2011)

CONCLUSION

Palm based biomass briquettes could be commercially produced using piston press technology. Properties of palm biomass briquettes were comparable to commercial briquettes and meet the selected parameters requirements of DIN 51731 on moisture content, density and calorific value. Oil palm biomass has good potential to be used as an alternative fuel for heat and power applications. Presence of shell in certain ratios enhanced the properties of palm briquette as well as the commercial value of the product. From the results, it shows that briquetting can serve as pretreatment process to prepare good quality of palm biomass as feedstocks, especially for a direct burning and thermochemical conversion of biomass for energy.

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