ENHANCING THE ENERGY PROPERTIES OF FUEL PELLETS FROM OIL PALM FRONDS OF AGRICULTURAL RESIDUES BY MIXING WITH GLYCERIN

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ABSTRACT

Nowadays, the main largest energy resource is coal followed by oil and natural gas. This phenomenon raises the public concerns to diversify the energy sources to sustain energy availability. To address these predicaments, biomass from agricultural residue is an important source for renewable energy. Oil palm frond is one of the abundant agricultural residues available from the oil palm plantation area in Malaysia. Processing the oil palm fronds into fuel pellets are seen as an attractive option, which is expected to reduce the amount of agricultural residue in the plantation area. In this study, 3 portions of oil palm fronds which are bottom, middle and top have been divided and 2 different particle sizes which are 0.5 and 1.5 mm were used combination with glycerin, a by-product from biodiesel production to determine their influences on the energy properties of fuel pellets. The glycerin was combined with oil palm fronds as a biomass binder to enhance the energy properties with the optimum ratio of ingredients (ratio of raw material and glycerin) for producing fuel pellets. Proximate properties (moisture content, volatile matter, ash content and fixed carbon) and energy content (calorific value) were conducted as the parameters to determine the energy properties of the fuel pellets. The glycerin content ranging from 15 to 45% (by weight), enhanced the calorific value of the oil palm fronds' fuel pellets from 16.73 to 22.72 MJ/kg. The results from the proximate and energy content analyses met the fuel pellet standard requirement according to the Pellet Fuel Institute (PFI). The highest of 22.72 MJ/kg heating value of fuel pellet were achieved from the middle portion of 1.5 mm particle size with the mixture ratio was 55:45; oil palm frond and glycerin respectively. In the result, the combination of oil palm fronds and glycerin can be used as an alternative material for biomass energy sources.

Keywords: oil palm fronds, glycerin, fuel pellets, proximate properties, energy content.

1. INTRODUCTION

Energy consumption has steadily increased over the last century as world population and industrialized developing country grown since 1900. Fossil fuel is now currently predominant energy source in the world. However, this fossil fuel will be depleted in the future. In addition, the burning of fossil fuels may cause environmental concern such as greenhouse gases (GHG) emission which known to be a major reason for global warming and climate change [7]. Nowadays, people are trying to find alternative energy for coal, oil and natural gas. One of the promising renewable energy nowadays is biomass.

Lignocellulosic biomass residues play a major role in the production of sustainable energy, because it is abundant, relatively cheap and often locally available [16, 19]. One of the examples is oil palm fronds. In recent years, growing attention worldwide has focused on the use of lignocellulosic biomass residues as a feedstock to produce biofuel pellet, as an alternative to fossil fuel [17]. The main advantages with pelleted biofuels in comparison to unprocessed biofuels are the higher energy density, which means lower transport and storage costs and even better quality. The pellets also have constant moisture content. The higher mass fluidity which means that automatic feeding equipment can be used even in small-scale boilers and the smaller fuel particles, which means more even boiler feeding lead to lower emissions and better possibilities to fire at lower loads in which resulting in longer boiler utilization times [22].

In a country that has a significant amount of agricultural activities such as Malaysia; biomass can be used as an alternative source of renewable energy. The rapid expansion of oil palm cultivation has raised concerns about the sustainability and environmental impact of oil palm plantations, in particular with regard to biodiversity, destruction of old growth rainforest and air pollution [20].

The biomass materials have low bulk density and high moisture content. These undesirable properties cause several major hindrances for biomass collection, transportation and storage. One of the solutions is to pelletize the bulky biomass materials. Pellets are often favored for fuel applications because of their enhanced physical properties as well as being easy to utilize and store. A number of researchers reported that sawdust [2], peanut hull [8], grasses [15], cotton waste [10], palm kernel cake, palm fiber and empty fruit bunch have been pelletized to be utilized a good fuel and examined for energy properties [21]. Several of study to improve the pelletized energy properties had been done. This includes many factors such as moisture content, particle size, type of binders and pelletizing processes which include pelletizing pressure, temperature and pretreatment of raw material [6].

There are few researches that combined the waste glycerol from biodiesel process with biomass to produce fuel pellet. The energy content of fuel containing glycerol in biomass such as paper, sawdust and agricultural waste is in the range 16.9-17.1 MJ/kg [3]. In the production of biodiesel, a large quantity of crude glycerol are produced which known as biodiesel by-product through the transesterification reaction method [18]. In [11] report that 10% by weight of crude glycerol are produced during biodiesel production. By 2020, it has been estimated up to 40,000 tons per year of crude glycerol will be produce from biodiesel synthesis [1]. Calorific value of crude glycerin has a great potential to be used as an energy source with 25 MJ/kg compared with 41 MJ/kg of fuel oil, while oil palm fronds have a calorific value of 17 MJ/kg [6].

2. MATERIALS AND METHODS

Materials

Oil palm fronds with no defect and decay-free were selected from oil palm plantation located in Kelantan, Malaysia. The fronds divided into 3 portions which were bottom, middle and top portion before their skins were peeled off. Next, each portion compressed using a roller type equipped with a servomotor having power supply with a capacity of 750 W to increase their density before undergoing sun-drying process till the moisture content reaches about 8 to 12%. Then, each portion of the oil palm fronds was milled and separate into 2 particle sizes which were 0.5 and 1.5 mm selected through sieve.

Glycerin is a by-product of biodiesel production process and used in this study as an additive in purpose to enhance the energy content (calorific value) of oil palm fronds' fuel pellets as a ratio range from 15-45% (by weight).

Methods

Pelletized of oil palm fronds and glycerin were varied ratio of mixture (percent by weight) for each portion and particle size. Percent of oil palm fronds varied from 55% to 100% while glycerol varies from 0% to 45% by weight to analyze the effect of the ratio between oil palm fronds with glycerin fuel pellets characteristics on energy properties with different portion and particle size as shown in Table-1. All of the ratio were mixed through a mixer and pelletized by pellet machine. Glycerin was heated to 75-80 ºC before mixed for better mixing. Finally, pellets were dried in the sunlight after pelletizing.

Table-1. Ratios of oil palm fronds and glycerin for pelletized fuel.

Mixture Ratio (wt.)%	Oil Palm Fronds	Glycerin
100:0	100	0
85:15	85	15
70:30	70	30
55:45	55	45

Assessment of Proximate properties and energy content of Oil Palm Fronds' Fuel Pellets

Each type of pellet mixture was analyzed their proximate properties to find the optimum ratio of the mixture. The moisture content was analyzed based on ASTM D3173 standard. The samples were dried in oven at 105 ºC for 1 hour. Volatile matter was analyzed based on ASTM D3175 standard, with the sample were burned in a furnace at 950 ºC for 9 minutes. Ash content was obtained using ASTM D3174 standard by burned the sample in a furnace at 750 ºC for 1 hour. While, fixed carbon content were gained following the ASTM D3172 standard, where 100% minus moisture content, volatile matter and ash content. Energy content (calorific value) of the fuel pellets was tested based on ASTM D1989 standard, employing bomb calorimeter.

Proximate analysis

The proximate analysis was carried out for the purpose to study the thermal properties of the oil palm fronds' fuel pellets particularly based on its moisture content (%), volatile matter (%), ash content (%) and fixed carbon (%). All procedures and analysis were performed according to the American Society of Testing and Materials (ASTM).

Moisture content

One of the major factors in the biomass energy content is moisture content, which is preferably ranging between 8-12 %. According to [5], the mold formation and degradation may occur. Lower moisture content is usually preferable since more heat per unit mass can be produced. The test procedures of moisture content were carried out according to the guidelines of ASTM D3173. The moisture analyzer MX-50 machine was used in the identification of moisture content in the samples based on the formula as shown by Eqn. (1).

$$\text{Moisture Content (\%)} = \frac{M_g - M_0}{M_0} \times 100\% \tag{1}$$

where M_g = green weight of wood (g) and M_0 = oven-dry weight of wood (g).

Volatile matter

To test the volatile matter of the samples, the test procedures ASTM D3175 were followed. Specific amount of sawdust samples, which is more than 1 g be placed inside a small crucible enclosed with cap. The weight of samples was then measured by analytical balance. The samples were then burned in a furnace for 7 minutes at a temperature of 900 ºC. The volatile matter of the sample was generally calculated by Equation (2).

$$\frac{\text{Initial mass(g)} - \text{Mass of residues (g)}}{\text{Initial Mass (g)}} \times 100 \tag{2}$$

Ash content

The test procedures ASTM D3174 were followed to test the ash content of samples. The mass of the sample is weighed before the testing of ash content in a small crucible without a cap. The selected amount of samples will be burned in a furnace for 3 hours under temperature of 815 ºC. Generally, high ash content is less preferable since the formation of ash layer will lead to incomplete combustion. The ash content of the sample was generally calculated by Eqn. (3).

$$\text{Ash}\ (\%) = \frac{\text{A x 100}}{\text{B}} \tag{3}$$

where A = weight of ash (g) and B = weight of test sample (moisture free) (g).

Fixed carbon

The fixed carbon value was calculated through the obtained results of moisture content, ash content and volatile matter. It was obtained through the summation of percentage in all 3 different values of moisture content, ash content and volatile matter subtracted from 100%. The fixed carbon of the sample was generally calculated by Eqn. (4).

$$\text{Fixed Carbon}(\%)=100(\%)-\text{MC}(\%)+\text{VM}(\%)+\text{AC}(\%) \tag{4}$$

where MC = moisture content, VM = volatile matter and AC = ash content.

Energy content

The energy content (calorific value) particularly is important properties of heating value to be determined. The test procedure was followed ASTM D1989 which is a standard test method for the gross calorific value of the sample through Adiabatic Bomb Calorimeter. The automatic Calorimeter 500 that has been used for this testing need to be connected with computer software for one hour initially before testing. The combustion chamber was determined to be in dry condition and the oxygen gas valve was opened. The sample was weighed and then put into the holder crucible. The ignition wire was then coiled in U-shaped and tied to the both end connectors above the crucible. The oxygen gas was then supplied in the container after the cap vessel was tightened. The calorific value of the sample was then obtained after 3-7 minutes of equilibrating and analyzing.

3. RESULTS AND DISCUSSION

Proximate properties

Proximate properties for the oil palm fronds' fuel pellet for each portion, size and ratio shown in Table-2. Through the same particle size and ratio of the mixture, the value indicated that top portion possessed the highest value for moisture content, ash content and fixed carbon. Meanwhile, volatile matter was high in the bottom portion.

Only 2 sizes were analyzed in this study, which are 0.5 and 1.5 mm. Based on Table-2, moisture content and ash content were higher in smaller particle size (0.5 mm) whereas volatile matter, fixed carbon content high value on large particle size (1.5 mm). According to previous studies by [15], small particle sizes tend to have a high surface area compared to large particle size. The high value of parameter on small particle size is due to the small particle size tend to have high ability to absorb water, tend to have concentrated inorganic matter and low pore space between particle size.

The ratio also affects the pellet properties. The increased amount of glycerin on ratio gave the high moisture content and volatile matter. In contrast, it gave the lower ash content and fixed carbon on pellet which is better to improve fuel pellet quality. This result is same with the study by [21].

Table-2. Proximate properties of oil palm fronds' fuel pellets.

Portion	Size (mm)	Ratio (OPF: Glycerin)	Proximate Properties (%)			
			MC	VM	AC	FC
Bottom	0.5	100:0	4.82	81.18	2.20	11.80
		85:15	5.02	81.58	2.19	11.21
		70:30	5.16	81.89	2.16	10.78
		55:45	5.58	82.27	1.88	10.27
	1.5	100:0	4.39	82.63	2.04	10.94
		85:15	4.68	83.10	1.07	11.15
		70:30	4.97	83.14	1.03	10.86
		55:45	5.30	83.38	1.03	10.29
Middle	0.5	100:0	5.17	80.89	2.49	11.46
		85:15	5.42	81.04	2.25	11.29
		70:30	5.75	81.52	1.57	11.15
		55:45	5.67	82.16	1.53	10.36
	1.5	100:0	4.71	82.17	2.18	10.94
		85:15	4.91	82.77	1.14	11.19
		70:30	5.38	82.55	1.37	10.69
		55:45	5.32	82.89	1.06	10.73
Top	0.5	100:0	5.24	80.81	3.51	10.43
		85:15	5.50	80.95	2.42	11.13
		70:30	5.95	81.35	2.01	10.69
		55:45	6.22	81.66	1.56	10.56
	1.5	100:0	4.86	81.94	2.33	10.92
		85:15	5.05	81.84	1.23	11.88
		70:30	5.71	82.19	1.29	10.81
		55:45	5.96	82.64	1.15	10.25
PFI standard			< 10	-	< 1.0	-

To compare the proximate properties on 3 different portions, 2 particle sizes and 4 ratio, two-way analysis of variances (ANOVA) statistical analysis was carried out. Table-3 displays the results of the proximate properties obtained by the two-way ANOVA statistical analysis. In this analysis, there are mainly 3 independent variables which are portions, particle sizes and ratio of oil palm fronds and glycerin. The dependent variables referred to proximate properties which are moisture content, volatile matter, ash content and fixed carbon.

From the statistical data, portion, particles size and ratio gave the significant different ($p \leq 0.01$) with the proximate properties except for fixed carbon content, which only significant with ratio. This result indicates that, different portion, particle size and ratio affected the moisture content, volatile matter and ash content value. Meanwhile, fixed carbon only influence on different ratio but not to portion and particle size. This result was same as reported by [9].

Table-3. ANOVA on proximate properties of oil palm fronds' fuel pellet.

Source	Dependent Variables	Sum of Squares	Df	Mean Square	F-Ratio
Portions	MC	3.914	2	1.957	100.751**
	VM	6.330	2	3.165	36.922**
	AC	0.863	2	0.432	63.315**
	FC	0.247	2	0.124	1.459ns
Particle sizes	MC	2.254	1	2.254	116.067**
	VM	24.290	1	24.290	283.390**
	AC	9.968	1	9.968	1.462E3**
	FC	0.030	1	0.030	0.0359ns
Ratio	MC	7.290	3	2.430	125.123**
	VM	7.747	3	2.582	30.129**
	AC	11.962	3	3.98	584.842**
	FC	7.966	3	2.655	31.325**

Note: nsnot significant value, **significant value P ≤ 0.01, MC = moisture content, VM = volatile matter, AC = ash content, FC = fixed carbon content.

Table-4. Tukey's post hoc test on proximate properties for portion and ratio.

Source		MC	VM	AC	FC
Portions	F- Ratio	118.76**	36.92**	63.31**	0.84ns
	Bottom	4.99a	82.40a	1.70a	10.91a
	Middle	5.29b	82.00b	1.70a	10.97a
	Top	5.56c	81.67c	1.93b	10.83a
Ratio	F-Ratio	172.44**	30.13**	412.26**	35.14**
	100:0	4.87a	81.60a	2.45a	11.08a
	85:15	5.10b	81.88b	1.72b	11.31a
	70:30	5.49c	82.11b	1.57c	10.83b
	55:45	5.68d	82.50c	1.37d	10.41c

Note: nsnot significant value, **significant value P ≤ 0.01, MC = moisture content, VM = volatile matter, AC = ash content, FC = fixed carbon content.

Statistical analysis of Turkey's post hoc test is shown in Table-4. The analysis was conducted to determine which group of portion and ratio differ with each other. Based on Table-4, Turkey's post hoc test concluded that all portion gave significantly different for moisture content and volatile matter. Ash content only differs bottom and top, besides middle and top portion. Meanwhile, there are no significant for fixed carbon as shown in Table-4. In the ratio, there are significant of all ratios for moisture content and ash content.

Energy content

The result obtained for the energy content (calorific value) was tabulated in Table-5. The trend showed that portion, particle sizes and ratio of the sample have an effect to the calorific value. The value of oil palm fronds' fuel pellets were increased from 16.73-17.93 MJ/kg of pure oil palm fronds' fuel pellets (OPF: Glycerin; 100:0) to 17.02-22.72 MJ/kg after mixing with glycerin at 15, 30 and 45% by weight.

Furthermore, the calorific value was decreased from bottom to top portion. These results were similar with [23]. The difference of calorific value in each portion is due to the influenced on its major biochemical components, including cellulose, hemi-cellulose, lignin, extractives and other ash forming minerals [12].

Calorific value also high for large particle size (1.5 mm) compares to small particle size (0.5 mm). This resulted is supported by [13] statement, where fine grinding particles resulted in loss of some heat and make the sample vulnerable to oxidation.

The increasing amount of glycerin in a mixture of oil palm fronds' fuel pellet resulting enhanced its calorific value of them. The glycerin itself has a greater calorific value, thus the use of glycerin in a mixture enhances the calorific value [6].

Table-5. Energy content (calorific value) of oil palm fronds' fuel pellets.

Portion	Particle Size (mm)	Ratio (OPF: Glycerin) MJ/kg 100:0	85:15	70:30	55:45
Bottom	0.5	17.53	17.96	18.73	19.11
	1.5	17.93	19.06	20.02	21.76
Middle	0.5	17.28	17.35	18.17	18.86
	1.5	17.88	19.02	21.16	22.72
Top	0.5	16.73	17.02	17.12	17.21
	1.5	17.87	18.63	19.95	19.72
PFI standard (MJ/kg)		19.08			

Note: OPF = oil palm fronds.

Two-way ANOVA statistical analysis on energy content (calorific value) was carried out to compare it on 3 different portions, 2 particle sizes and 4 ratios as shown in Table-6. From the statistical data, there were significant differences between portions, particle sizes and ratio of the calorific value with P-value ≤ 0.01. These mean that portion, particle size and ratio were influencing the calorific value. This result also resembles as reported by [14], with the preliminary study of selected wood species shows that the energy content tends to decrease with the height of trees decrease from bottom to top portion. Besides, in part of particle size, a study by [4] showed that larger particle size has a higher calorific value compared to small particle size. For the ratio, in [21] stated that the increasing amount of glycerin in oil palm fronds with ratio 20-50% increase the calorific from 17.25 MJ/kg to 20.51 MJ/kg.

Table-6. ANOVA on energy content of oil palm fronds' fuel pellet.

Source	Dependent Variables	Sum of Square	Df	Mean Square	F-Ratio
Portions	CV	16.144	2	8.072	37.635**
Particle sizes		63.939	1	63.939	298.117**
Ratio		59.765	3	19.922	92.886**

Note: **significant value P ≤ 0.01, CV = calorific value.

Table-7. Tukey's post hoc test on energy content for portion and ratio.

Source		Calorific Value
Portion	F- Ratio	37.64**
	Bottom	18.03[a]
	Middle	19.01[b]
	Top	19.06[b]
Ratio	F-Ratio	92.89**
	100:0	17.53[a]
	85:15	18.17[b]
	70:30	19.19[c]
	55:45	19.90[d]

Note: **significant value $P \leq 0.01$.

Statistical data for Turkey's post hoc test on energy content for portion and ratio shown in Table-7. It was found significant differences existed among all of the portion and ratio except for the portion between middle and top portion.

Optimum ratio of mixture

To evaluate the optimum ratio of mixture, several aspects should be considered such as ash content should be low to increase combustibility and calorific value must be high enough to support the need of customer and industry sector. According to Table-2 and 5, the optimum ratio of oil palm fronds was 55:45 (oil palm fronds: glycerin) in the middle portion with 1.5 mm particle size respectively. This due to almost all of the parameters according to PFI fuel standard except for ash content which exceed the standard requirement.

CONCLUSION

This study examined the properties of fuel pellets from oil palm fronds which differ in portion and particle size through an addition of glycerin in the mixture of the pellets. The findings indicated this 3 factor; portion, particle size and ratio of glycerin affect the fuel pellet's energy properties and suitable for combustion as an alternative biomass energy source. The calorific value was increasing from top to bottom portion, small to large particle size and the increase amount of glycerin in fuel pellets. All parameters of each factor met the standard except for ash content.

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