INFLUENCE OF GLYCERIN ON ENERGY PROPERTIES O FUEL PELLETS FROM OIL PALM FRONDS OF AGRICULTURAL RESIDUES

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ABSTRACT

Biomass from agricultural residue is an important source for renewable energy. Oil palm frond is one of the abundantly agricultural waste available from oil palm plantation area in Malaysia. Processing the oil palm fronds into fuel pellets are seen as attractive option, which is expected to reduce the amount of agricultural waste in plantation area. The present study investigate the influence of oil palm fronds on pelletizing and combination with glycerin, a by-product from biodiesel production on energy production. The glycerin was combined with oil palm fronds as a biomass binder to enhance the properties with optimum ratio of ingredients (ratio of raw material and glycerin) for producing fuel pellets. The glycerin content ranging from 15 to 45% (by weight), enhanced the calorific value of the oil palm fronds from 16.25 MJ/kg to 17.02 – 22.72 MJ/kg. The results from the proximate and energy content analyses met pellet fuel standard requirement according to Pellet Fuel Institute (PFI). The highest of 22.72 MJ/kg heating value of fuel pellet were achieved from middle portion of 1.5 mm particle size with the mixture ratio was 55:45; oil palm frond and glycerin respectively. From 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, Energy properties.

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INTRODUCTION

With the target to turn the nation into a developed country by 2020, Malaysia has face a rapid economy changes in the urban and rural areas. Indirectly, the demand of petroleum as the main source of electricity and transportation fuel rise dramatically. About 3% of the electricity supply and demand were increased annually (Chong and Lam, 2013). It is rather surprising that even in a country like Malaysia where biomass can easily obtained, the utilize of renewable energy are still low compare to the usage of non-renewable source to generate energy. If this reliance continued, Malaysia would sufferer a lack of energy security since Malaysia fossil fuel reserves is predicted to be use only for another 30–40 years as non-renewable energy are depleting by the year (Hassan *et al*., 2005).

They are currently many sources of renewable energy such as solar, wind, tidal, geothermal and biomass. However, in a country that has significant amount of agricultural activities such as Malaysia, biomass can be a very promising alternative source of renewable energy. As the second largest producer and exporter of palm oil since 2006, Malaysia's palm oil industry have leaves behind an enormous amount of biomass from plantation and milling activity, with a high amount of agricultural residues compared to other types of biomass (Shuit *et al*., 2009).

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 (Bergstrom *et al*., 2008), peanut hull (Fasina, 2007), grasses (Mani *et al*., 2006), cotton waste (Holt *et al*., 2006), palm kernel cake, palm fiber and empty fruit bunch have been pelletized to be utilized a good fuel and examined for energy properties (Trangkaprasith and Chavalparit, 2011). Various 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 (Chavalparit *et al.*,2013).

There is a few research that combined the waste glycerol from biodiesel process with biomass to produced fuel pellet. The energy content of fuel containing glycerol in biomass such as paper, sawdust and agricultural waste is in range 16.9-17.1 MJ/kg (Brandy *et al*., 2009). In the production of biodiesel, a large quantity of crude glycerol are produces which known as biodiesel by-product through transesterification reaction method (Raghatreutai *et al*., 2010). Johnson and Taconi (2007) report that 10% by weight of crude glycerol are produce 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 (Bauer and Hulteberg, 2013). Calorific value of crude glycerin has a great potential to be use 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 (Chavalparit *et al.*,2013).

Therefore, this study aimed to investigate the influence of oil palm fronds through pelletizing with the combination of glycerin to their calorific value. The effect of portion, particle size of oil palm fronds were investigated for each of ratio of mixture in fuel pellet and they were compared to pellet standard requirement.

MATERIALS AND METHODS

Materials

The oil palm fronds with no defect and decay-free were selected from oil palm plantation located in Kelantan, Malaysia. The fronds divided into three portion 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 reach about 8 to 12%. Then, each portion of the fronds were mill and separate into two particle size which is 0.5 mm 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 calorific value of oil palm fronds fuel pellets as ratio 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 frond varied from 55 to 100% while glycerol are varied from 0 to 45% by weight to analyze

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the effect of ratio between oil palm frond with glycerin fuel pellets characteristics on energy with differ portion and particle size as shown in Table 1. All of the ratio were mixed through 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: Ratio's of oil palm fronds and glycerin for pelletized fuel

Mixture ratio (wt.)%	Frond	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 pellets mixture were analyzed their proximate properties to find the optimum ratio of the mixture. Moisture content based on ASTM D3173 standard. The sample were dried in oven at 105 ºC for 1 hour. Volatile matter were analyze based on ATM D3175 standard, with the sample were burned in furnace at 950 ºC for 9 minutes. Ash content were obtained using ASTM D3174 standard by burned the sample in 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 of the pellet were tested based on ASTM D1989 standard, employing bomb calorimeter.

RESULTS AND DISCUSSIONS

This study aimed to identify the effect of pelletizing on oil palm fronds and combination with glycerin through certain portions, particle sizes and ratio of the mixture on the properties of oil palm frond fuel pellets. To defined this aim, several parameter which includes proximate properties (moisture content, ash content, volatile matter and fixed carbon content) and energy content (calorific value) on pellet were consider.

Energy Properties of Raw Oil Palm Frond

The measurement of oil palm frond characteristic is important to predict the appropriate of the sample as a fuel and compare the characteristic between oil palm frond raw and oil palm frond pellet. This analyses include proximate properties refers to the moisture content, volatile matter, ash content and fixed carbon content along with energy content (calorific value). Table 2 show the mean value of proximate properties and energy content of raw oil palm frond characteristic.

Table 2: Proximate properties and energy content of raw oil palm frond

Portion	Particle Size (mm)	Proximate Properties (%)				Energy Content (MJ/kg)
		MC	VM	AC	FC	CV
Bottom	0.5	11.91	81.02	2.48	4.59	17.12
	1.5	10.67	82.48	2.18	4.67	17.77
Middle	0.5	12.20	80.68	2.60	4.52	16.88
	1.5	11.43	81.92	2.26	4.39	17.54
Top	0.5	12.49	79.93	3.60	3.98	16.25
	1.5	11.63	80.66	2.31	5.40	17.25

Note: MC = Moisture content, VM = Volatile matter, AC = Ash content, FC = Fixed carbon content, CV = Calorific value

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The result of oil palm frond raw material showed volatile matter has a high value with mostly exceed 80% which is close up to those found in previous study as reported by Trangkaprasith and Chavalparit (2011) with 72.53%. ash content of oil palm frond is considerably low with not exceed 4% as compared to other oil palm wastes such as oil palm shell with 6.7% and empty fruit bunches with 5.43% (Abdul Rahman *et al*., 2014). Besides, energy content of oil palm frond was in between 16.25-17.77 MJ/kg which is showed that it had a higher calorific value compare to other residual part of an oil palm tree.

Energy Properties of Oil Palm Fond Fuel Pellet

Energy properties of this study include two part which are proximate properties and energy content.

Proximate Properties

Proximate properties for the pelletized fronds for each portion, size and ratio shown in Table 3. 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 were high in bottom portion.

Only two size were analyzed in this study which are 0.5 mm and 1.5 mm. Based on Table 3, moisture content and ash content was 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 study by Sonthi and Nitipong (2013), small particle size tend to have high surface area compare 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 results is same with the study by Trangkaprasith and Chavalparit (2011).

Table 3: Proximate properties of oil palm fronds fuel pellets

Portion	Particle 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

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55:45	5.96	82.64	1.15	10.25
PFI standard	<10	-	<1.0	-

To compare the proximate properties on three different portions, two particle sizes and four ratio, two-way ANOVA statistical analysis was carried out. Table 4 displays the results of the proximate properties obtained by the two way ANOVA statistical analysis. In this analysis, there are mainly three independent variables which are portions, particle sizes and ratio of wood samples. The dependent variables referred to proximate properties of 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 results indicate 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 Hew (2015).

Table 4: Analysis of variances (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	1.459^{ns}
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	0.0359^{ns}
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: ^{ns} not significant value, **significant value $P \leq 0.01$, MC = Moisture content, VM = Volatile matter, AC = Ash content, FC = Fixed carbon content

Table 5: Tukey's post hoc test for proximate properties for portion and ratio

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

Statistical analysis of Tukey's post hoc test is shown in Table 5. The analysis was conducted to determine which group differ with each other. Based on Table 5, Tukey's post hoc test concluded that all portion gave significant different for moisture content and volatile matter. Ash content only differ bottom and top and middle and top portion. Meanwhile, there are no significant for fixed carbon as shown in Table 4. For the ratio, there are significant of all ratio for moisture content and ash content.

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Energy content

The result obtained for the calorific value was tabulated in the Table 6 and illustrated in the bar graph in the Figure 1. The trend showed, portion, particle sizes and ratio of the sample have an effect to the calorific value. The value of fronds were increased from 16.25 MJ/kg of raw fronds to 17.02-22.72 MJ/kg after pelletizing and mixed with glycerin. Furthermore, the calorific value were decreased from bottom to top portion. These result were similar with Zheng *et al*. (2014). The different of calorific value in each potion is due to the influenced on its major biochemical components, including cellulose, hemi-cellulose, lignin, extractives and other ash forming minerals (Kataki and Konwrer, 2001).

Calorific value also high in large particle size (1.5 mm) compare to small particle size (0.5 mm). This resulted is supported Kumar and Pratt, (1996) statement, where fine grinding particles resulted in loss of some heat and make the sample vulnerable to oxidation.

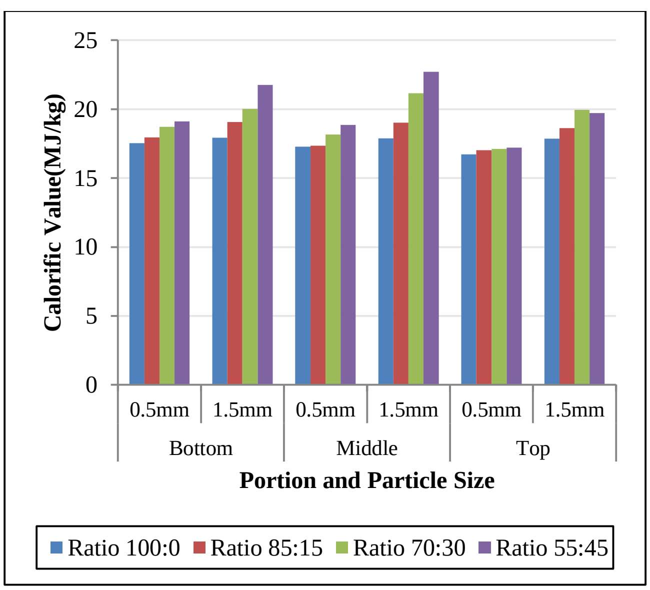
The increasing amount of glycerin in a mixture of pellet resulted the increase of calorific value on the pellet. The glycerin itself has a greater calorific value, thus the use of glycerin in a mixture enhance the calorific value (Chavalparit *et al*., 2013)

Table 6: Energy content (calorific value) of oil palm frond 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 stamdard (MJ/kg)		19.08			

Note: OPF = Oil palm frond

Figure 1: Trend of energy content (calorific value) on portions, particles sizes and ratio of oil palm fronds fuel pellets



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The two-way ANOVA statistical analysis on energy content were carried out to compare the energy content on three different portions, two particle sizes and four ratio as shown in Table 7. From the statistical data, there were significant differences between potions, particle sizes and ratio to calorific value with P-value ≤0.01. These means, portion, particle size and ratio influence the calorific value. This result also resemble as reported by Kumar *et al.* (2010), with the preliminary study of selected wood species shows that 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 Bridgeman *et al*. (2007) showed that larger particle size have the higher calorific value compared to small particle size. For the ratio, Trangkaprasith and Chavalparit (2011) stated that, the increasing amount of glycerin in oil palm frond with ratio 20-50% increase the calorific from 17.25 MJ/kg to 20.51 MJ/kg.

Table 7: Analysis of variances (ANOVA) on energy content of oil palm fronds fuel pellet

Source	Dependent Variables	Sum of Squares	*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 8: Tukey's post hoc test of 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]

Statistical data for Tukey's post hoc test of energy content between portion and ratio shown in Table 8. It was found significant different existed among all of the portion and ratio except between middle and top portion.

Correlation coefficient between proximate properties and energy content of oil palm fronds fuel pellets

The correlation among proximate and energy content of oil palm fronds fuel pellets is presented in Table 9. There was a correlation between proximate and energy content of oil palm fronds fuel pellets with portions, particle size and ratio except between portion with ash content and fixed carbon and also between moisture content and volatile matter, ash content and calorific value.

Among proximate value and energy content, significant different exist between all of them with significant level P ≤0.01 except for fixed carbon content significant level P ≤0.05 and moisture content with no significant (P >0.05). A positive correlation exist for volatile matter and a negative correlation exist between ash content and fixed carbon content.

The correlation result for volatile matter and ash content resembled with previous study done by Chavalparit e*t al.* (2013) and Trangkaprasith and Chavalparit (2011). They found that, the increase of glycerin enhance the calorific value with have the high amount of volatile matter, decrease the ash content and low the fixed carbon content value.

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Table 9: Correlation coefficient between proximate properties and energy content of oil palm fronds fuel pellets

	Por	Size	Ratio	MC	VM	AC	FC	CV
Por	1	.000	.000	.507**	-.377**	.154^{ns}	-.065^{ns}	-.255*
Size		1	.000	-.385**	.741**	-.604**	-.041^{ns}	.600**
Ratio			1	.686**	.415**	-.614**	-.561**	.578**
MC				1	-.239*	-.120^{ns}	-.411**	.027^{ns}
VM					1	-.755**	-.430**	.728**
AC						1	.073^{ns}	-.715**
FC							1	-.289*
CV								1

Note: * significant value, P ≤0.05, ** significant value, P ≤0.01, ^{ns} not significant, Por = Portion, MC = Moisture content, VM = Volatile matter, AC = Ash content, FC = Fixed carbon content, CV = Calorific value

Optimum ratio of mixture

To evaluate the optimum ratio of mixture, several aspect should be consider such as ash content should be low to increase combustibility and calorific value must be high enough to support the need of customer and industrial sector. According to Table 3 and 6, the optimum ratio of oil palm fronds was 55:45 (oil palm frond: 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.

CONCLUSIONS

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 pellet. The findings indicated this three factor; portion, particle size and glycerin affect the fuel pellet energy properties and suitable for combustion as an alternative biomass energy source and promote reduce the agricultural waste in plantation area. The calorific value of oil palm frond pellet were increasing from top to bottom portion, small to large particle size and the increase amount of glycerin in fuel pellets. All parameter of each factor met the standard except for ash content.

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