

## Preliminary Study on Properties of Small Diameter Wild *Acacia mangium* Species as Potential Biomass Energy Sources

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### Abstract

Currently, the primary energy supply in Malaysia is dominant by non-renewable energy sources such oil, natural gas and coal which contributed to the scarcity of these sources and occurrence of global warming. This phenomenon raises the public concerns to diversify the energy sources to sustain energy availability. To address these predicaments, biomass sources is among the prominent alternative energy sources since it is renewable and possesses minimal harms to the environment. Thus, the woody plant with high growth rate and high energy content that can be used to serve as potential biomass energy sources. In this study, small diameter (5-8cm) of wild *Acacia mangium* species have been determined and compared accordingly three (3) different portions (bottom, middle and top) and two (2) different particle sizes (0.5 and 1.5mm). The analysis conducted to determine the properties of raw material of *Acacia mangium* as biomass energy sources were proximate, physical and energy content properties. The result obtained for the energy content analysis of small diameter wild *Acacia mangium* has a mean calorific value range from 16.35 to 18.35MJ/kg between portions and particle sizes. In order to determine the effect of portions and particle sizes on each of the proximate, physical and energy content properties, two-way ANOVA was performed. It shows that both the portions and particle sizes have significant effect on calorific value (energy content) of small diameter wild *Acacia mangium* at 99% of confidence level. In a nutshell, the biomass energy properties of small diameter wild *Acacia mangium* with different portions and particle sizes were being determined.

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### 1. Introduction

Malaysia one of the developing countries in the Southeast Asia is dependent on the energy sources in order to stimulate growth and development in economic. Furthermore, energy sources is not solely contributed to the economic growth for the country, but it also serve as a basic utility of the communities' needs in their daily life as can meet their demand for having a desirable quality life. According to the source from Department of Statistic Malaysia [1], in year 2012, the population of Malaysia has recorded reached 29.46 million with a growth rate of 9.88% as compared with year 2007 with population of 26.81 million. According to the source of National Energy Balance (NEB) [2], it shows that the most of the energy usage goes to transportation sector and followed by the industry sector. From the statistics stated above, it revealed that the growth in population will increase the demand of energy in the nation's daily usage.

Currently, the primary energy supply in Malaysia is dominant by non-renewable energy sources which are oil and natural gas with each contributed 32.1 and 46.0%

respectively [2]. It is estimated that the natural gas reserve is expected to last for around 70 years, while oil is expected to be depleted in 16 years at current rate of usage [3]. In addition, Prime Minister of Malaysia, Najib Razak had declared Malaysia commitment to reduce its carbon dioxide (CO<sub>2</sub>) emission to 40% by the year 2020 compared to 2005 levels subject to assistance from developed countries [4]. Hence, in order to meet this target, the conventional energy sources should be reduced its usage and in the meantime look for alternative energy sources.

Usage of renewable energy sources to meet the increasingly demand for energy is the solution. Hence, Malaysia had been putting effort in venturing more into various forms of renewable energy. Among all the renewable sources, biomass has the highest potential to be utilized as the source of renewable energy [5-8]. It is estimated that biomass electricity could substitute up to 9% of Malaysian electricity and reduce up to 29 Mt of CO<sub>2</sub> annually compared to the current generation mix [9]. Malaysia is one of the countries full with source of renewable energy. In addition, Malaysia is a tropical forest

country with intense sunlight/time and humidity which makes the weather and soil conditions are favourable for various kinds of plantation.

In Malaysia, biomass are generated from different industry, the main contributor goes to oil palm industry which contribute 85.5% of the biomass generation followed by municipal waste with 9.5%, wood industry with 3.7% plus the rice and sugarcane with 0.7 and 0.5% respectively [10]. This statistics revealed that the biomass generation is mainly dependent on the oil palm industry and in order to ensure that each of the various kinds of biomass resources are used in sustainable manner as a contributor in energy supply, the sources of renewable energy should be diversified and it is clearly shows that wood industry holds a huge potential to develop it as the next main contributor of biomass energy resources.

Biomass is not yet competitive compared to fossil fuels as biomass only have one third of energy content of fossil fuels [11]. However, with respect to global issues of sustainable energy and reduction in emission of greenhouse gases, biomass is getting increased attention as a potential for power generation [12]. *Acacia mangium*, the native Australian plantation has been known for its characteristic of high calorific value range between 20.08-20.50MJ/kg and this makes *Acacia mangium* a good fuel [13] and can serve as to provide good quality of charcoal and also suitable for the manufacture of charcoal briquettes and artificial carbon [14]. Hence, this indicates that *Acacia mangium* holds the potential to develop as a biomass energy sources.

In this study, the energy properties of small diameter (5-8cm) wild *Acacia mangium* were determined. Biomass source, particularly *Acacia mangium* in this case is believed to act as alternative source of energy as well as vital role in the welfare of the global environment. There is no net-up build of CO<sub>2</sub> considering the CO<sub>2</sub> released in combustion is compensated for by that absorbed by the growing energy crops [14]. Assuming that the amount of biomass grown is equivalent to that burnt, the sustainability of biomass can be accomplished in terms of diversification of energy sources and global warming mitigation perspective.

## 2. Materials and Methods

### 2.1. Materials

Small diameter of wild *Acacia mangium* species were selected randomly from local residential areas in Jeli, Kelantan, Malaysia. The species samples were collected base on their diameter sizes (5-8 cm) in decay-free and optimum growth condition. The stem was then cut into three (3) different portions (bottom, middle and top) and dividing into two (2) different particle sizes, particularly 0.5 and 1.5 mm.

### 2.2. Methods

The raw material of small diameter wild *Acacia mangium* stem were sampled then followed by cutting the stem into three (3) different portions, particularly bottom, middle and top. To analyse the properties of *Acacia mangium* species, a series process of chipping, crushing, drying and grinding by mean of machinery process were carried out to transform the stems into sawdust form. The screening process was continued on mesh sizes and two (2) different particle sizes will be divided, particularly 0.5 and 1.5 mm. Every two (2) different particle sizes sample from three (3) different portions were then tested to analyse the properties for its raw form.

### 2.3. Proximate Analysis

Proximate analysis was carried out for the purpose to study the thermal properties of *Acacia mangium* particularly based on its moisture content (%), volatile matter (%), ash content (%) and fixed carbon (%). All procedures and analysis were performed according to the British Standard (BS).

#### 2.3.1. Moisture Content

Moisture content for biomass energy sources preferably ranging between 8-12%. The moisture analyser MX-50 machine was used in the identification of moisture content in the samples based on the formula as shown by Equation (1).

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

Where,

$M_g$  = Green weight of wood (g)

$M_0$  = Oven-dry weight of wood (g)

#### 2.3.2. Volatile Matter

Volatile matter of the samples were tested accordingly to BS EN 15148:2009. Specific amount of sawdust samples, which is more than 1g 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 furnace for 7 minutes at a temperature of 900°C. The volatile matter of the sample was generally calculated by Equation (2).

$$\text{Volatile matter (\%)} = \frac{\text{Initial mass (g)} - \text{Mass of residues (g)}}{\text{Initial Mass (g)}} \times 100 \quad (2)$$

#### 2.3.3. Ash Content

Ash content of the samples were tested accordingly to BS EN 14775:2009. The mass of the sample is weighed before the testing of ash content in a small crucible without cap. The selected amount of samples will be burned in furnace for 3 hours under temperature of 815°C. 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 Equation (3).

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

Where,

A = Weight of ash (g)

B = Weight of test sample (moisture free) (g)

Where,

SG = Specific gravity

W<sub>Asample</sub> = Weight of sample

W<sub>AH<sub>2</sub>O</sub> = Weight of water

### 2.3.4. Fixed Carbon

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

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

Where,

MC = Moisture content

VM = Volatile matter

AC = Ash content

### 2.4. Physical Analysis

Physical properties of *Acacia mangium*, particularly bulk density and specific gravity were studied.

#### 2.4.1. Bulk Density

Bulk density is a very important characteristic of substances such as powders, granules and other particles like solid substances. Bulk density is defined as the mass of a bulk material divided by the volume occupied by that material. Bulk density of wood particles was estimated by using beakers and the weights of the samples will be determined by using an analytical balance. Later, the densities of the samples were calculated by using Equation (5).

$$\rho = \frac{m}{v} \tag{5}$$

Where,

ρ = density

m = mass

v = volume

#### 2.4.2. Specific Gravity

Specific gravity of wood can be varied due to several factors, including the geographic location of trees and moisture content, which varies by species, diameter, age and stem position. The electronic MD300s was used to determine the selected sawdust chips and calculated by using Equation (6).

$$\text{SG} = \frac{W_{\text{Asample}}}{W_{\text{AH}_2\text{O}}} \tag{6}$$

### 2.5. Energy Content Analysis

The energy content (calorific value) particularly, is important properties of heating value to be determined. The test procedure was followed BS EN 14918:2009 which is standard test method for 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 into 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

### 3.1. Proximate Properties

The wood sample, *Acacia mangium* with three (3) different portions (bottom, middle and top) and two (2) different particle sizes (0.5 and 1.) were subjected to the proximate properties in order to obtain the information of that particular wood sample such as the moisture content, volatile matter, ash content and fixed carbon. The data obtained for the proximate properties of *Acacia mangium* is expressed in percentage form as shown in Table 1.

#### 3.1.1. Moisture Content

From the Table 1, it shows an increasing trend of moisture content from bottom to top portion. It can be deduce that the higher of bulk density in that particular portion will lead to that portions exhibit lower moisture content. Similar trends of bulk density with change in moisture content also have been reported for other biomass sources such as faba bean [15] and green gram [16].

As for the particle sizes, it shows that the smaller particles, 0.5mm has higher moisture content when compared with the bigger particles, 1.5mm. This can be explained as the small wood particle size well absorbed water than the bigger particle size [17] and hence after subjected to oven dry still contain more amount of water than bigger particle size.

**Table 1:** Mean value for proximate properties of *Acacia mangium*.

Portions	Particle sizes (mm)	Mean value (%)			
		Moisture content	Volatile matter	Ash content	Fixed carbon
Bottom	0.5	9.08	82.45	1.47	7.00
	1.5	5.00	83.94	0.97	10.09
Middle	0.5	9.54	82.40	2.41	5.64
	1.5	8.22	87.02	0.21	4.55
Top	0.5	10.10	80.36	3.00	6.53
	1.5	8.21	84.97	0.23	6.58

### 3.1.2. Volatile Matter

From the Table 1, for the aspects of portions, the volatile matter shows no obvious trend either increasing or decreasing from bottom to top portion. Volatile matter refers to as a composition of a biomass material that is released as volatile gases when it is heated up to 400 to 500°C [18]. In this study, the volatile matter of *Acacia mangium* is range from 80 to 87% which correspond with the statement from [19], as the woody biomass consists of high quantity of volatiles which range between 76 and 86 wt. dry basic. The volatile matter yield of biomass commonly includes light hydrocarbons, CO, CO<sub>2</sub>, H<sub>2</sub>, moisture and tars [20]. As for the particle sizes, the result shows that the bigger particle, 1.5mm has higher volatile matter then the smaller particle, 0.5mm.

### 3.1.3. Ash Content

From the Table 1, it shows that there is no obvious trend for the ash content between bottom, middle and top portions. However, the ash content of all the six (6) wood samples being studied in this study is below 6%. According to standard Austria ÖNORM M7135, that is the value beyond which the ash content of the biomass fuel is considered not adequate [21]. As from the observation from the effect of particle sizes on ash content, it shows that for the smaller particle, 0.5mm has higher ash content when compared with the bigger particle, 1.5mm. In addition, according to Tokan et al. [22], the smaller particle sizes are less coarse, hence, compact easily and this leading to incomplete combustion due to small number of pore spaces.

### 3.1.4. Fixed Carbon

Fixed or non-combined carbon is the fraction remaining after volatile matter is completely released, excluding ash and moisture that burns forming char [23]. From the result obtained in Table 1, it shows that the fixed carbon of *Acacia mangium* is higher in the bottom portion followed by the top and middle portion. In other words, it shows a decreasing trend from the bottom to top portion. As for the aspects of particle sizes, there is no obvious trend can be observed. In addition, a trend of relationship is observed between the volatile matter and fixed carbon. The ratio of volatile matter to fixed carbon indicating the degree of reactivity of the biomass. The higher this factor, the easier the ignition, and hence the lower the residence stage until combustion is completed [24].

## 3.2. Physical Properties

For physical properties, the bulk density and specific gravity of the wood sample *Acacia mangium* with different portions and particle sizes was determined. The mean data obtained for each of the physical analysis of *Acacia mangium* was tabulated in the Table 2.

**Table 2:** Mean for physical properties of *Acacia mangium*.

Portions	Particle sizes (mm)	Mean value	
		Bulk density (kg/m <sup>3</sup> )	Specific gravity
Bottom	0.5	204.33	0.71
	1.5	117.40	0.92
Middle	0.5	202.33	0.89
	1.5	140.43	1.04
Top	0.5	196.00	1.02
	1.5	136.73	1.07

### 3.2.1. Bulk Density

From the Table 2, it shows a decreasing trend for bulk density from bottom to top portion. This evidence proves that the juvenility increase from bottom to top and as juvenility increases, bulk density decreases [25]. Hence, bulk density shows decreasing trend towards top portion as maturity of wood tissues is primarily present in the bottom portion. In addition, the bulk density is higher in the wood particle with particle size 0.5mm when compared with the wood particle with particle size 1.5mm. This finding correspond with the similar relationship between the particle size and bulk densities of other potential biomass energy crop such as wheat straw, barley straw, corn stover and switchgrass [26].

### 3.2.2. Specific Gravity

As observed from the Table 2, it shows that the specific gravity is gradually increase from bottom to top portion and the particle size 1.5mm has higher mean value of specific gravity than particle size of 0.5mm. Changes in specific gravity is directly influence by the variation in fibre cell wall percentage and such variation is dependent mostly on fibre cell wall thickness, lumen diameter and fibre proportions [27-29].

## 3.3. Energy Content Properties

In order to determine the potential biomass energy present in the *Acacia mangium*, the calorific value of the wood particle *Acacia mangium* was being identified by carrying the energy content testing. The result obtained for the calorific value was tabulated in the Table 3.

**Table 3:** Mean for calorific value of *Acacia mangium*.

Portions	Particle sizes (mm)	Calorific value (MJ/Kg)
Bottom	0.5	17.68
	1.5	18.45
Middle	0.5	17.00
	1.5	17.48
Top	0.5	16.35
	1.5	16.87

From the result obtained in Table 3, it indicates that the bottom portion has the higher calorific value when compared with the middle and top portions. As moisture contents can be a contributor affects the potential calorific value; it implies that the higher the moisture content, the lower the calorific value [30]. Also, the bigger the wood particle size, the higher the calorific value it has. The fine

grinding wood particles resulted in loss of some heat and make the sample vulnerable to oxidation as reported by Kumar and Pratt [31].

### 3.4. Analysis of Variances (ANOVA) on Proximate, Physical and Energy Content Properties of *Acacia mangium*

To compare the proximate, physical and energy content properties on three (3) different portions (bottom, middle and top) and two (2) particle sizes (0.5 and 1.5 mm), two-way ANOVA statistical analysis was carried out.

Table 4 displays the results of the proximate, physical and energy content properties obtained by the two-way ANOVA statistical analysis. In this analysis, there are mainly two independent variables which are portions and particle sizes of wood samples. The dependent variables are referred as the proximate properties (moisture content, volatile matter, ash content and fixed carbon), physical properties (bulk density and specific gravity) and energy content properties (calorific value). The p-values act as the indicator of the statistical significant of each of the factors.

**Table 4:** ANOVA on on proximate, physical and energy content properties of *Acacia mangium*.

Source	Dependent variables	Sum of square	Df	Mean square	F-ratio
Portions	MC	15.943	2	7.979	7.682**
	VM	13.505	2	6.752	12.122**
	AC	0.505	2	0.253	1.349 <sup>ns</sup>
	FC	35.693	2	17.847	11.503**
	BD	332.034	2	166.017	18.103**
	SG	0.132	2	0.066	7.216**
	CV	6.387	2	3.193	161.633**
Particle sizes	MC	26.596	1	26.596	25.631**
	VM	57.376	1	57.376	103.000**
	AC	15.069	1	15.069	80.415**
	FC	2.144	1	2.144	1.382 <sup>ns</sup>
	BD	21652.805	1	21652.805	2.361E3**
	SG	0.064	1	0.064	6.954*
	CV	1.562	1	1.562	79.064**

Note: \*\* Significant at  $p \leq 0.01$  AC Ash content  
 \* Significant at  $p \leq 0.05$  FC Fixed carbon  
<sup>ns</sup> Not significant BD Bulk density  
 MC Moisture content SG Specific gravity  
 VM Volatile matter CV Calorific value

#### 3.4.1. Effect of Portions and Particle Sizes on Proximate Properties

From the Table 4, it is clearly shows that both of the value of moisture content and volatile matter shows significant ( $p \leq 0.01$ ) between each portions and particle sizes at 99% of confidence level. In other words, it can be interpreted as both portions and particle sizes have significant interaction effect with the moisture content and volatile matter. For the moisture content, it can be deduce that the lower moisture content in the bottom portions is mainly due to the availability of high amount of mature wood tissues in the bottom portions. In addition, smaller wood particle sizes with larger surface area are tend to be accumulate more moisture than the bigger wood particle sizes. For the volatile matter, it shows both independent variables - portions and particle size have effect on it. The high volatile matter can be represent the ease with which the biomass can be ignited and subsequently gasified or oxidized, depending on how the biomass is to be utilized as an energy source [32].

There is no significant value between the portions to the ash content; it can be interpreted that there is no significant effect of the portions of the tree stem to the ash content in this study. Furthermore, the ash content is

significantly affected by the particles size at 99% of confidence level ( $p \leq 0.01$ ). According to Garcia- Pèrez et al. [33], the smaller the particle sizes have higher surface areas and thus, the higher the deposition of ash which contributing to the heaviest component of biomass. In addition, the larger the particle size, the more loosely the bond with each other and thus allowing adequate flow of oxygen and so combustion was complete and resulting in less ash content [22].

The fixed carbon content value shows no significant value between different particle sizes. It means that the particle size has not effect on the fixed carbon content in this study. However, the factor portions show significant effect at 99% of confidence level on the fixed carbon content. This can be deduced that the fixed carbon content is higher on the bottom portion which mostly consists of maturity tissues.

#### 3.4.2. Effect of Portions and Particle Sizes on Physical Properties

From the Table 4, it shows that, in the aspects of bulk density, there is a statistically significant at 99% confidence level between portions and between particle sizes. It means that both of the portions and particle sizes

have significant effect on the bulk density. This correspond with the statement of Tang et al. [34], it stated that the bulk density is higher in the smaller wood particle as it occupies lesser space with same weight of mass. Therefore, the volume needed to store or transport an equal mass of wood particles will increase as particle size increases [35].

For the specific gravity, it shows that there is a statistically significant at 99% confidence level between portions ( $p \leq 0.01$ ); whereas between particle sizes, there is a statistically significant at 95% confidence level ( $p \leq 0.05$ ). Different in tree height has effect on the specific gravity as it is due to a biomechanical response of the species to the need of providing strength and stiffness to the trunk as the tree develops with diameter increment [36].

### 3.4.3. Effect of Portions and Particle Sizes on Energy Content Properties

From the Table 4, it is clearly shows that there is a statistically significant at 99% confidence level between the calorific value and the portions and also particle sizes. The net calorific value or lower heating value is known as the heat to be removed from the reaction products in order to obtain a final temperature equal to the initial temperature of the reactants; in other words, it is the measure of the amount of heat released by a material during combustion. For the aspects of portion, as the moisture content is lower in the bottom portion due to the high amount of mature woody tissue and hence the calorific value is higher in the bottom portion than the top portion. This finding is found correspond with the statement from Stahl et al. [37] which the disadvantage of biomass fuel is that they often have high moisture content which readily inhibits combustion. Apart from that, the smaller the wood particle size contributing to the higher calorific value as this finding is correspondingly with the same result obtained when selected biomass was investigated in the study of Abdullahi et al. [38].

## 4. Conclusion

In conclusion, the different portions in the proximate, physical and energy content properties had shown an obvious influences on wood raw samples with ash content (proximate properties) as exception, whereas the analysis in the different particle sizes are show a slightly apparent effects towards those properties fixed carbon (proximate properties) as exception. Generally, biomass fuel with lower moisture and ash content, plus higher fixed carbon due to their influences on the calorific values.

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