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CALORIFIC VALUE ANALYSIS OF AZADIRACHTA EXCELSA AND ENDOSPERMUM MALACCENSE AS POTENTIAL SOLID FUELS FEEDSTOCK

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ABSTRACT

Thermal conversion of woody biomass to fuel has been intensified in recent decades due to the depletion of fossil fuels, greenhouse effect and high energy demand worldwide. Screening the potential feedstock is being considered as one of the alternatives to identifying the most suitable biomass resources prior to being converted into renewable energy in the form of solid fuels, such as charcoal and briquettes. Generally, high calorific value (CV) indicates high potential of feedstock for briquettes, torrefied wood and coal generation. In this study, CV was characterized using a bomb calorimeter that was based on 3 different ranges of moisture content (MC) that are > 25%, 20%–25% and < 20% for two tropical tree species, namely Azadirachta excelsa (Sentang) and Endospermum malaccense (Sesenduk), respectively. This standard method for the characterization process was considered to determine the CV. Average CV for both samples ranged between 16–17 MJ/kg. The highest CV was 17.3490 MJ/kg and 17.1273 MJ/kg for Sesenduk and Sentang, respectively and calorific values were obtained at MC less than 20%. The experimental study demonstrated that the decreasing value of MC has increased the CV because of the high value of oxygen-to-carbon (O/C) ratio in the wood; additionally, the energy density of the wood sample was also improved when CV increased. Both of these species were proved to contain the potential of being feedstock as wood fuel resources, since they carry standard CVs, obtain fast growth with suitable conditions in Malaysia and are grown at very low cost of production for plantations, fertilizer, pesticides, labor, transportation and handling.

Keywords: *Azadirachta excelsa*; Bioenergy conversion; Calorific value; *Endospermum malaccense*; Energy density; Moisture content

1. INTRODUCTION

High demand of renewable energy sources expanded significantly to lessen global warming impact in the recent era (Hossain et al., 2017). Biomass turned out to one of the most attractive forms of renewable energy sources, especially in Asia and Africa because of suitable soil properties and climate conditions. A number of researches are currently being conducted

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successfully to identify suitable biomass candidates that are capable of generating high energy yield. This yield is to compete with conventional fossil fuel energy so that the world can stop mono-dependence on fossil fuels for energy production. Like other countries in Asia, nowadays in Malaysia, research is being focused on the suitability of energy producing local wood species that can contribute to fulfilling the energy demand of this country. Recently *Azadirachta excelsa* (*Sentang*) and *Endospermum malaccense* (*Sesenduk*) wood species are being researched in Malaysia to be among the potential feedstocks for bio-energy production. Usually both of these species are native to Brunei, Malaysia, Indonesia, Thailand and Singapore (McKendry, 2002; Hossain & Jalil, 2015). Figure 1 shows the distribution map of these wood species available in South and Southeast Asia.

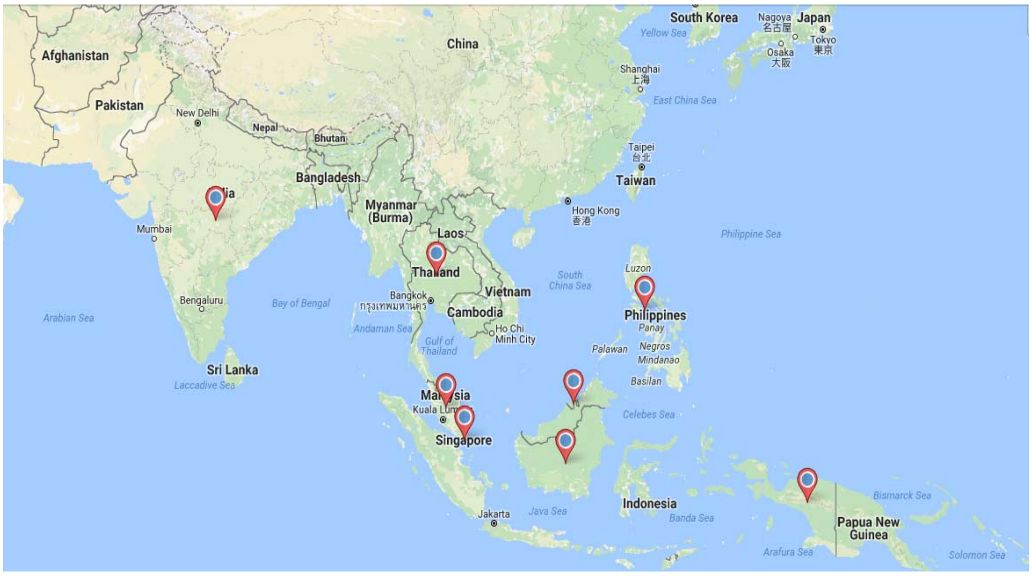

Figure1 Distribution map of *Sesenduk* and *Sentang* plantations around South and Southeast Asia

For the last decade, biomass has been projected worldwide as an energy source because of certain significant factors. The main factor is lower cost with higher conversion efficiency and this low cost heat generation is playing a key role in producing electricity without fossil fuel usage that is counted as a well-advanced option for electricity production. According to the renewable intensive global energy scenario discussed at the United Nations Conference on the Environment and Development (UNCED, 1992 also known as the Rio di Janeiro Earth Summit), by 2050 half of the world's primary energy consumption of 400 EJ/yr could be fulfilled by biomass and 60% of the world's electricity market would be dominated by biomass resources (McKendry, 2002). Meanwhile, the UK government targeted generating 10% of the national electricity demand of 60 GW/yr from biomass production. Like the UK and other developed countries, Malaysia targeted producing heat energy as well as obtaining wood timber from local species in various locations, such as in Lentang, Bukit Tinggi, Kemasul, Ulu Sedili, Batu Arang, Sungai Buloh, Kepong, Setul, Gunung, Bongsu, Bukit Perak, etc. for meeting the high demands for wood and electricity production (McKendry, 2002; Hashim et al., 2015). *Sesenduk* and *Sentang* are among the top 15 fastest growing and high yielding wood species, which grow quickly in idle or barren lands in Malaysia (Poopathy, 2002). A crucial factor to improve afforestation in barren lands is in the village area where barren lands are usually left empty, since non-food based trees are not prevalent. In this case, while wood species would have a market value for heat generation, village people would be encouraged to cultivate more plantations, what are very good for both the environment and the economy (Poopathy, 2002; Hashim et al., 2015). One the most significant factors of heat generation from these wood species is to challenge the potential threat posed by climate change due to greenhouse gas emissions from fossil fuels, such as coal and natural gas, and oil (Poopathy, 2002). Usually fossil fuels take millions of years for the conversion of biomass to fuel, so fossil fuels utilize old biomass and produce new CO_2, which contribute to the greenhouse effect with non-renewable characteristics (McKendry, 2002). But burning new biomass, such as *Sesenduk* and *Sentang* trees will in theory add 'zero' CO_2 emissions to the environment. This is because the amount of CO_2 emissions from new bio-fuel will be absorbed by replanting the biomass and returning CO_2 emissions in the new forest within a natural cycle, known as photosynthesis. Without these factors, there are some other stimuli related to heat generation from these wood species, such as a novel source of secured energy, a new window for employment, diversity of fuel supply in different situations, restoration of degraded lands, reduction in fertilizer and pesticide usages and instant fuel availability everywhere (McKendry, 2002; Hossain & Jalil, 2015).

Calorific Value (CV) of a wood sample defines the form of energy content or heating value produced by its combustion, which is simply measured by the energy content per unit mass for a solid, hence MJ/kg (Oduor & Githiomi, 2013). However, the moisture content level indicates the measurement of the water amount (H_2O) impregnated in the wood sample. Usually wood sustains an affinity for moisture and living wood holds relatively high moisture content inside, due to soil moisture, fresh air, humidity and climatic changes, such as rain (Hossain & Jalil, 2015). According to the Van Krevelen diagram, moisture content is directly correlated with calorific value of biomass. Moisture or water in a wood sample consists of hydrogen (H) and oxygen (O). The higher content of oxygen in the sample determines a low energy content. Thus, the higher O/C ratio in both wood samples showed the lower energy content (Ahmad & Subawi, 2013). The Van Krevelen diagram also illustrated that when the material dehydrated or reduced in moisture, calorific value (CV) started to increase linearly. Similarly, at the stage of negligible moisture for coal, the heating or calorific value is much higher than woody biomass (Chaula et al., 2014).

2. MATERIALS AND METHOD

2.1. Materials

Endospermum malaccense is under the Euphorbiaceae family classification known as '*Sesenduk'*, locally called *kayu labuh* or *garung* in Malaysia as well as in other Southeast Asian countries. This hardwood tree is a fast growing species, which is grown in rainforests in Malaysia. It grows very well almost everywhere (Figure 2). *Sesenduk* wood is very light, coarse and floatable, soaks up less humidity, produces low ash and is easily burnable. For these characteristics, *E. malaccense* has been chosen as a wood energy production candidate (Uyup et al., 2012).

On the other hand, *Azadirachta* ***excelsa*** under the *Meliaceae* (mahagony) family classification is commonly, known as *'Sentang'* internationally and as *'Kayu Bawang'* or *'Ranggu'* locally in Malaysia (Figure 3). This species is randomly grown in Malaysia yielding $12m^3$/ha. Besides the potential for veneers, *Sentang* wood is traditionally used for wood fuel in village areas or for barbecue purposes. The tree is fast growing and grows up to 50 meters (160 feet) tall, dries very fast and is highly burnable. From these characterizations, this tree is considered as a potential candidate for bio-energy production (Poopathy, 2002).

Sentang (*A. excelsa)* and *Sesenduk (E. malaccense)* wood chip samples used throughout this study were obtained from *Sentang*) Bioenergy Laboratory of the Forest Research Institute Malaysia (FRIM). Collected samples were taken from three different parts of the tree, at the bottom, middle and upper levels. Samples were cut into 2 to 3 cm square pieces; air dried and kept in zip-lock plastic bags before use.

Figure 2 *Endosperum malaccense* (*Sesenduk*) tree

Figure 3 *Azadirachta excelsa* (*Sentang)* tree

2.2. Methods

Three sets of wood chips with 3 replicates of each part were experimented with for each tree species. Experimental procedures in this research including Moisture Content analysis and Calorific Value determination, both of which were chosen from British Standards BS: 3631 of 1973 (Milne et al., 1990). Graphical experimental procedures are shown in Figure 4.

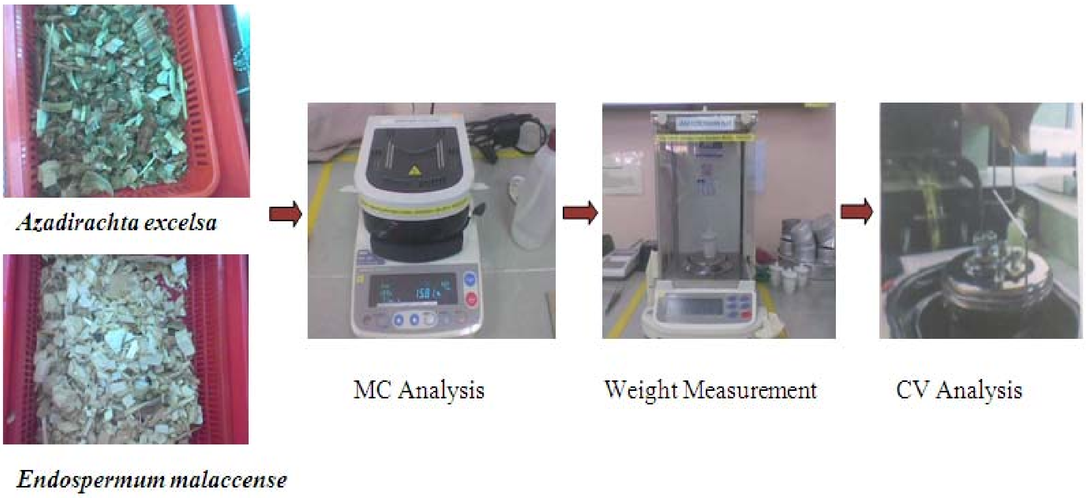

Figure 4 Experimental procedures from raw material to calorific value analysis

2.2.1. Moisture Content (MC) analysis

Wood samples collected were chipped, grinded and sieved, washed with water to remove dust and unwanted impurities. Then, the wood chips were soaked in water for 2 hours and the water was filtered. Afterwards, the wet samples were preceded by moisture content analysis using the MX50 Moisture Analyzer. Then, the wet wood chips samples were oven dried for 24 hours. The MC % was measured again with using the same procedure until the MC was less than 20%. Equations 1 and 2 were used for determining the MC of the samples (Norhisham et al., 2015).

$$MC\ (\%) = \frac{Weight\ of\ water}{Weight\ of\ wood\ sample} \times 100 \qquad (1)$$

$$MC\ (\%) = \frac{Initial\ sample\ weight - Oven_{dry}\ sample\ weight\ @\ 214°F}{Oven_{dry}\ sample\ weight\ @\ 214°F} \times 100 \qquad (2)$$

2.2.2. Determination of Calorific Value (CV)

Calorific Value was determined by a Bomb Calorimeter AC500 with the standard test method of calorific value of derived fuel by the bomb calorimeter ASTM E711-87 (Davis, 2007). After weighing about 0.5g of test samples in triplicate, the samples were placed into a crucible and were placed inside the vessel and tied with ignition wires. Both ends of the wires were connected with bomb calorimeter electrodes and the bomb was firmly closed, the bomb was placed into a bucket filled with 2 Liters of water inside the chamber and the bomb was connected with an oxygen source. After placing the samples, the top cover of the chamber was closed and the CV of the samples was analyzed by computer within 7 minutes. The chamber was left open 30 minutes to cool down after analyzing every sample. Set up of the bomb calorimeter for analysis of CV are shown as detailed in Figure 5. Equation 3 was used for determining the CV of the samples:

$$CV = \frac{waterequivalent + [water\ quantity\ of\ bucket \times rise\ in\ temperature] - correction\ value}{quantity\ of\ wood\ sample} \quad (3)$$

where, CV is the Calorific Value; correction value is the sum of the calorific values of the ignition wires.

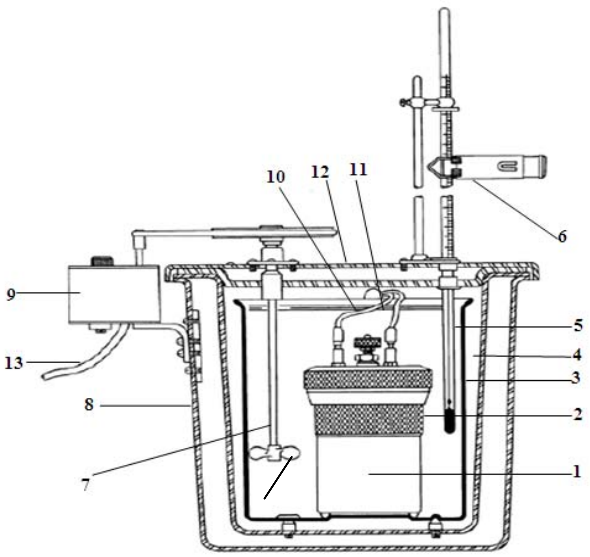

Figure 5 The set of a Bomb Calorimeter assisted calorific value analysis
(1) Sample inserting position; (2) Bomb or Vessel; (3) Bucket filled with 2L water; (4) Insulating Jacket; (5) Thermometer or Temperature sensor; (6) Temperature sensor holder; (7) Water stirrer; (8) Combustion Chamber; (9) PID temperature feedback controller; (10) Wires; (11) Oxygen gas valve; (12) Top Cover; (13) Water Exit

3. RESULTS AND DISCUSSION

There were three ranges of moisture content experiments conducted in this research for both species with moisture content more than 25%, moisture content more than 20%, but less than 25% and moisture content less than 20%. MC less than 20% is usually desired for higher heating values, according to the Van Krevelen diagram (Ahmad & Subawi, 2013). Leaving the wood chips in open air or in dry store for few weeks are the conventional processes to acquire expected MC reduction which is less than 20%. The factors behind the experiment with MC between 20–25% are either climatic impact, such as rain, fog, high humidity in the air, etc. or damp from the storeroom floor. MC more than 25% is usually noted for newly deforested batch of trees or water impregnated wood due to weather issues, such as rain. Experiments were conducted on these samples for utilization purposes of wood supply for heat production in an emergency situation, especially while in the process of looking for well-dried and well-seasoned woods (Ahmad & Subawi, 2013; Chaula et al., 2014).

According to Odoh et al., (2015), the moisture content range is one of the influencing factors for calorific value. Calorific value or heating value of wood samples varies with the change in the percentage of moisture content (% MC). For instance, at 58% ≤ MC, it was extremely hard to burn soft wood chips for combustion, while at 20% ≥ MC, those wood chips provided a very effective combustion result. *Alstonia boonei* wood samples showed that their CV increased to 0.2 MJ/kg and 0.27 MJ/kg, when MC was improved from 20% to 15% and from 10% to 7.5%, respectively (Odoh et al., 2015). Bagasse biomass showed that while MC decreased from 32% to 7%, CV increased from 5.57 MJ/kg to 14 MJ/kg (Omoniyi & Olorunnisola, 2014). Thus, it was shown to be significant to study CV in terms of MC range for the experimental wood samples.

Figure 6 indicates that the CV for *E. malaccense*, (*Sesenduk*) wood was 16.7103 MJ/kg when MC was more than 25% and then when MC started to decrease, CV gradually improved with de-moisturizing and peaked at 17.3490 MJ/kg, while MC was less than 20%. Similar with *Sesenduk* wood, *A. excelsa* (*Sentang*) wood experiments proved that the more MC reduced, the more CV increased. With MC higher than 25%, CV was at a minimum amount 16.3824 MJ/kg and CV was at a maximum of 17.1273 MJ/kg when MC was less than 20%. The CV curve was plotted based on different MC ranges. Both of these indicated that CV was 16-18MJ/kg at various MC ranges where pine wood species produced 15.10 MJ/kg at 16% MC and bagasse biomass produced 14 MJ/kg at 7% MC (Chaula et al., 2014; Omoniyi & Olorunnisola, 2014).

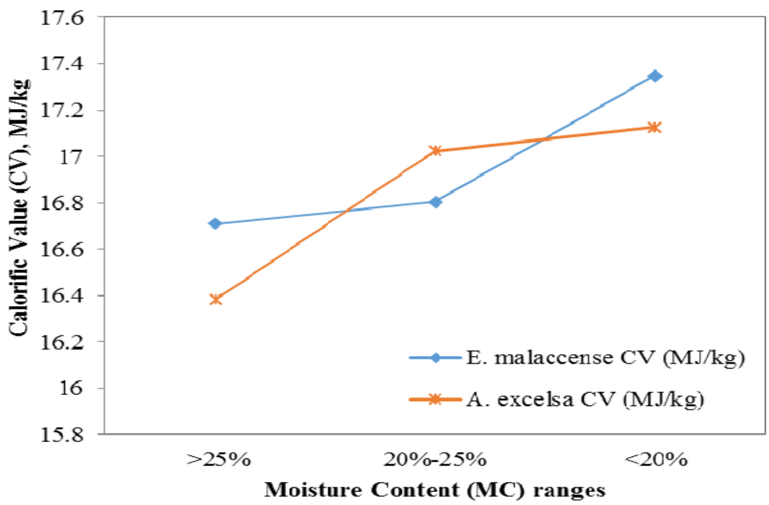

Figure 6 Calorific Value of *E. malaccense* (*Sesenduk)* wood and *A. excelsa* (*Sentang)* wood with different Moisture Content

The factors that influenced the calorific value of solid fuels were the oxygen-to-carbon (O/C) ratio and hydrogen-to-carbon (H/C) ratio as shown in the Van Krevelen diagram (Ahmad & Subawi, 2013). Due to the presence of water molecules, the elemental composition of wood samples with inherent moisture content provided the atomic ratio of O/C which was different than fossil fuels with zero or negligible moisture content. For instance, coal is one of the popular solid fossil fuels that has a heating or calorific value of 30 MJ/kg (Chaula et al., 2014), while *Sesenduk* and *Sentang* wood samples had a calorific value of 17.3490 MJ/kg and 17.1273 MJ/kg, respectively at MC < 20%. So, this comparison cleared up the fact that the calorific value of wood samples was lower because of the O/C ratio as well as high moisture content. Thus when MC increased, CV started to decrease.

Another significant factor was the energy density of wood samples where calorific value was related to wood density (Nunesa et al., 2014). According to (Omoniyi & Olorunnisola, 2014), bagasse biomass energy density rose from 1782.4 MJ/m^3 to 3920 MJ/m^3 while MC rose from 32% to 7%. Usually the density of wood determines the fraction of wood mass and wood volume on average. The basic density of *E. malaccense* (*Sesenduk)* and *A. excelsa* (*Sentang)* wood samples were 143.92 kg/m^3 and 152.5 kg/m^3, respectively (Hossain & Jalil, 2015). The energy density was calculated based on the basic density for both species using Equations 4 and 5 (Nunesa et al., 2014).

$$Density = \frac{Mass}{Volume} \tag{4}$$

$$Energy\ Density = Calorific\ Value \times Basic\ Density \tag{5}$$

Table 1 Energy Density of *E.malaccense* and *A.excelsa* with different Moisture Content

Moisture Content (%)	Energy Density (MJ/m^3) of *Sesenduk (E. malaccense)*	Energy Density (MJ/m^3) of *Sentang (A. excelsa)*
MC > 25%	2404.94	2498.31
20% < MC < 25%	2418.44	2596.06
MC < 20%	2496.86	2611.91

Table 1 indicates that the higher the MC, the lower the energy density and that the energy density improved when calorific value improved. For both species, the energy density was very high and maximum values were 2496.86 MJ/m^3 and 2611.91 MJ/m^3; however, the MC was less than 20% for *Sesenduk* and *Sentang* wood samples, respectively. Both species showed very high energy density and *Sentang* was higher than *Sesenduk* energy density, comparatively. *Sentang* energy density was 93.37 MJ/m^3, 177.62 MJ/m^3 and 115.05 MJ/m^3 at MC > 25%, 20% < MC < 25% and MC < 20%, respectively which was higher than *Sesenduk* energy density. It proved the highest energy density differs at 20% < MC < 25%.

Usually energy density was measured due to transportation and storage advantages. As the experiments in this research indicated, wood samples with very high energy density levels, can be transported by truck, train or ship and at the same time, less storage space will be required for storage and seasoning, which directly leads to cost savings. Moreover, improvement of functionality and reduction of the energy usage of conveyors and mills at a power plant will add extra advantages for both wood species (Onuegbu et al., 2012; Nunesa et al., 2014).

A good point about this experiment was that even with a high degree of moisture content, both species produced a higher amount of energy than some other energy crops, such as pine wood samples with 15.10 MJ/kg and wheat straw bagasse with 12.3 MJ/kg heating values ranging from 6%–8% MC (Chaula et al., 2014). If in such cases, emergency heat production is needed when seasoned raw material is lacking, then these wood species undoubtedly can be utilized for heat production even with more than 25% MC. Another advantage in utilizing these kinds of wood chips for heat production is that they can be easily used in their original form as they do not require transformation into briquette or pellet formations. By improving energy density, these kinds of transformations usually add extra energy consumption and cost (Onuegbu et al., 2012; Chaula et al., 2014).

Recently, research is ongoing to improve high heating value properties by transforming raw wood to torrefied wood and charcoal formations (Jalil et al., 2015a; Jalil et al., 2015b). For torrefaction, the moisture content inside the wood should be reduced to a range from 0-1% and then the heating value would be improved closer to CV 30 MJ/kg (Nunesa et al., 2014).

Apparently, these formations can be attractive, but they require high thermal conversion with temperatures ranging from 200°−300°C under atmospheric pressure with an absence of oxygen that includes excess thermal energy and added cost (Bagramov, 2010; Jalil et al., 2015b).

In addition, from the early 1990's onwards, afforestion of *E. malaccense* and *A. excelsa* wood species for wood production occurred in rural areas of Johor, Kedah, Negeri Sembilan, Selangor in Malaysia. Those kinds of trees are easily grown in idle or barren lands and both species are hydrophobic, which results an exclusion of water molecules in tropical conditions. Malaysia remains sunny and hot throughout the year, thus facilitating sun drying and wood seasoning without investing excess costs for thermal energy (Poopathy, 2002; Hashim et al., 2015).

However, both *Sentang* and *Sesenduk* wood samples contain very high amounts of volatile matter (VM) with ratings of 88.55% for *Sentang* and 90.08% for *Sesenduk* that are indicative of higher combustible properties, easier ignition and longer flame length than average energy crops with an extremely low ash content, namely 0.34% for *Sentang* and 0.23% for *Sesenduk,* respectively that indicates a negligible impurity and an environmentally-friendly property (Hossain & Jalil, 2015). Consequently, these species are desirable for experimental purposes to analyze calorific or heating values within different MC ranges.

According to McKendry (2002), potential energy crops usually contain some general characteristics, such as high yield and growth, low energy investment for production, low cost, composition with least contaminants, low nutrient requirement, water availability and soil texture, in order to be considered as ideal energy crops for commercial energy farming Both *E. malaccense* (*Sesenduk)* and *A. excelsa* (*Sentang)* wood species are fast growing with high yields; they require only conventional plantation costs under usual soil and climatic conditions in Malaysia. After planting, they do not need too much fertilizer or pesticides, which saves energy costs and they contain a lower degree of contaminants with negligible ash production after burning (Poopathy, 2002). Thus, these species are very effective in relation to added value and they produce quite a high calorific value with different ranges of moisture content. In summary, both of these trees can be projected as ideal energy crops.

4. CONCLUSION

This study implied the mitigation of high demand for and the usage of fossil fuels as well as environmental pollution by converting *E. malaccense* (*Sesenduk)* and *A. excelsa* (*Sentang)* trees into potential feedstock to be used as fuel for heat generation. A Bomb Calorimeter was capable of analyzing pure heating or calorific value with different ranges of moisture contents at a laboratory scale. For further utilization of this analysis in pilot or large scale projects, solid or liquid biofuel production processes are recommended. The maximum calorific values for both species were 17.3490 MJ/kg for *Sesenduk* and 17.1273 MJ/kg for *Sentang* with less than 20% MC. The maximum energy density were 2496.86 MJ/m^3 and 2611.91 MJ/m^3 for *E. malaccense* (*Sesenduk)* and *A. excelsa* (*Sentang),* respectively. When MC increased, CV and energy density reduced for both species following the Van Krevelen diagram.

We recommend reducing the MC to less than 10% to improve the heating value, as suggested by the Van Krevelen diagram, where coal contained a very high heating value because of its low O/C ratio or moisture content. So, both species are expected to become promising sources of wood fuel. The motivation to utilize these wood species for heat production was to discover an alternative source of fuel to reduce dependence on fossil fuels and CO_2 emissions as a step forward towards clean and bio-energy utilization. Setting up large scale, pilot scale and industrialization projects could attract the local market in cultivation of plantations for these trees in what would encourage local people for afforestation, which could decrease landslides and pollution, utilize barren lands and add more oxygen in the air.

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