

Characterizations of Solid Biomass Fuel Pellets

by

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23007

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CERTIFICATION OF APPROVAL

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Approved by,



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CERTIFICATION OF ORIGINALITY

This is to certify that I am fully responsible for the work submitted in this project. This work is my own and original. There are exceptions as I had mentioned in the references and acknowledgements. This original work contained herein have not been carried out or done by unspecified sources or persons.



(Izzat Sayyidi Bin Shafie)

ABSTRACT

Malaysia is second to Indonesia for being the largest producer and exporter of palm oil. When the fresh bunch had been pruned and harvested, the palm oil industries generate wastes which are biomass potential. One of them include oil palm frond (OPF). OPF makes up more than 50% of the total biomass generated. OPF has higher volatile matter, lower ash content, and fixed carbon when being compared with hardwood, which signifies better burning efficiency.

The objective of this final year project is to characterize the solid biomass fuel pellets which consist of different portion of oil palm frond (OPF) and sugarcane bagasse (SC). The study involves conducting several analyses; density determination, proximate analysis, ultimate analysis and calorific value determination. The OPF and SC was mixed with different blending ratio which are 90:10, 80:20, 70:30, 60:40 and 50:50. Hydraulic press was used to determine the density of different blending ratios of OPF and SC of different particle sizes. The samples were pressed into pellets under different compression pressure which are 50 MPa, 100 MPa, 150 MPa. The maximum compression pressure for particle size was determined to save energy consumption. The density of produced pellets which is significant in the heating value of pellets was calculated. The proximate analysis was carried out using thermo gravimetric analyser (TGA) to find the moisture content, volatile matter, fixed carbon and ash contents of the samples which can be used to calculate the higher heating value (HHV). Ultimate analysis was carried using Carbon Hydrogen Nitrogen Sulphur (CHNS) Elemental Analyzer to determine the data on carbon, hydrogen, nitrogen and sulphur of the samples which is important in determining the best sample for biomass pellets. Bomb calorimeter was used to find the calorific value of the samples. The best blending ratio of OPF and SC is 90:10 and their particle size is less than 600 μm to produce the biomass pellets with highest heating value.

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CHAPTER 1 : INTRODUCTION

1.1 Background of Study

Malaysia is one of the world largest producers of oil palm [1][2]. As in March 2012, Malaysia has five million hectares of oil palm planted area [1]. This number of plantation area gives huge potential of biomass as the oil palm processing will give lots of waste products; empty fruit bunch (EFB), oil palm shell (PS), oil palm fibre (PF) and palm frond (PFR). These waste products could be utilized as biomass fuel to generate heat for boilers. These wastes could be used directly as fuel for residential heating stoves, heating boilers and large-scale power plants [3].

Fuel pellets are compressed form of biomass materials into regular shapes. According to EN ISO 17225-2 [4], the maximum acceptable length of the pellet is 40mm. Biomass fuel pellets are commonly made from oil palm mills residue, bagasse, wood chips, sludge and many more.

For biomass materials to be made into pellets, there are many issues to be considered so that they are worth to be made and can be used safely. In terms of energy content, several analyses can be done to quantify the energy content of biomass materials, which are proximate analysis, ultimate analysis and using bomb calorimeter.

1.2 Problem Statement

The demand for power or electrical energy is high in the modern industrial world. The applications of generators such as internal combustion engines and steam turbines are known to utilize non-renewable sources of energy like hydrocarbons such as gasoline and diesel to operate in generating electricity. Other than gasoline and diesel, the spark or compression ignition engine also operates on propane, natural gas, hydrogen (H₂), liquefied petroleum gas (LPG), biogas or the mixture of the above gases. Natural gas has been on high demand since last two decades for its utilization in industries. Even though natural gas regarded as clean among fossil fuels, the reserves are expected to last for only five to six decades. Thus, the need to have much secure, abundant and environmentally friendly renewable alternatives as fuels such as biomass for these internal combustion (IC) engines and electrical generators are necessary. The criteria to be focused are high efficiency of energy conversion from fuels into useful energy, less pollution emissions including carbon footprints.

As Malaysia has abundant source of oil palm mill residues, these solid biomass fuel based on oil palm frond have high potential to be used as alternative energy, which is a renewable energy source. However, there are parameters that need to be studied so that these materials could be practically used in daily life. If these materials are to be pelletized, parameters that affect combustion characteristics need to be studied and they include density, energy content, and elemental compositions.

1.3 Objectives and Scopes of Study

The aim of the research is to characterize solid biomass fuel pellets of different blending ratio of oil palm frond (OPF) and sugarcane bagasse (SC). The detailed objectives of this study are as follows:

- 1) Produce oil palm frond pellets with sugarcane bagasse as binders
- 2) Analyse the effect of different particle sizes of powder of oil palm frond and sugarcane bagasse, binders blending ratio, and compression pressure during pelletization on combustion characteristics

Since Malaysia is one of the largest producers of oil palm in the world, the waste or by product of the production should be huge also. Thus, oil palm mill waste residue is selected to be material of interest here. The residue to be used in this study is oil palm frond (OPF). Apart from that, other waste material like sugarcane bagasse (SC) are also considered to be used as binder in fuel pellets.

The scopes of study in this research are the particle sizes of oil palm frond and the binder, which is sugarcane bagasse, the binder blending ratio and pelletization compression pressure. The analysis that will be carried out are proximate analysis, ultimate analysis, pellets density determination and calorific value determination.

1.4 Relevancy and Feasibility

This project is relevant and feasible in Malaysia. The waste materials to be used in fuel pellets are available in huge amount and readily available throughout Malaysia. The availability of the materials helps the research in finding the materials and the success of the research could be implemented in the industry in Malaysia directly.

CHAPTER 2 : LITERATURE REVIEWS

2.1 Pellet Size

According to Purwanto, Supramono, Nugroho, & Lestari [5], as the rice husk, straw, rubber wood, and camphor wood pellets diameter are increased, the bulk density of pellets decreased. They also found that these pellets with diameter of 1cm produce highest combustion temperature of 800°C for straw compared to 2cm diameter which produce 700°C. The reason is smaller pellets of smaller diameter than 1cm absorb less conduction heat from combustion, thus causing the thermocouple to detect large amount of remaining heat released. Diameter of pellets more than 1cm require longer time to react to produce high combustion temperature and with higher diameter, the lower the peak combustion temperature.

2.2 Biomass Composition

According to Purwanto et al. [5], the carbon percentage content in the biomass produce higher heating value based on this formula

$$\text{HHV (kJ/g)} = 0.3491\text{C} + 1.1783 \text{H} - 0.1034 \text{O} - 0.0211 \text{A} + 0.1005 \text{S} - 0.0151 \text{N} \quad (1)$$

This is supported by Harun & Afzan [6] where they found that carbon and hydrogen is the most significant element in determining the heating value since they are converted into carbon dioxide and water during combustion. High ash content inside the biomass can lead to pellet die erosion, thus negatively affect the binding phenomena of the pellets. The ash that stick to pellet die are made up of hard and sharp particles, the pellet die will erode as force is applied. Additional findings by Jamradloedluk & Lertsatitthanakorn [7], the higher ash content in eucalyptus barks, mangos teen shells and raw papaya peels will reduce the heating value. They also found that the higher the volatile matter content, the higher the reactivity rate of biomass pellets as fuel, the faster the combustion rate during devolatilization phase. Devolatilization is the removal of less strongly bonded in biomass (volatiles) which are H, C, and O that forms tar gasses and liquids during pyrolysis in gasification. High lignin content inside biomass leads to high heating value. The higher the amount of

hydrogen, carbon and sulphur, the higher the heating value which supports the findings by Harun & Afzan [6]. Meanwhile, the higher the content of nitrogen and oxygen reduces the value of heating value.

Table 1: Proximate analysis of biomass raw materials and binders. Reprinted from “Influences of Mixing Ratios and Binder Types on Properties of Biomass Pellets” by J. Jindaporn and L. Charoenporn, 2017, Energy Procedia, 138, p. 1147-1152. [7]

| Sample | Chemical composition | | | | Higher heating value (cal/g) |
|------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|---------------------------------|
| | Moisture (%) | Volatile matter (%) | Ash (%) | Fixed carbon (%) | |
| Eucalyptus bark | 7.85±0.18 ^b | 66.36±5.63 ^a | 13.11±0.24 ^c | 12.67±5.54 ^c | 3,394.86±38.16 ^a |
| Mangosteen shell | 8.53±0.24 ^b | 67.21±0.93 ^a | 3.22±0.03 ^a | 21.03±0.70 ^d | 4,505.30±9.07 ^c |
| Papaya peel | 12.18±1.44 ^c | 73.66±0.60 ^b | 8.71±0.34 ^b | 5.44±1.52 ^b | 3,817.85±34.69 ^b |
| <i>Persea kurzii</i> kosterm | 7.67±0.16 ^b | 64.32±1.80 ^a | 17.60±0.10 ^d | 10.39±1.74 ^c | 3,422.57±29.66 ^a |
| Dammar | 1.67±0.07 ^a | 80.55±0.04 ^c | 17.70±0.13 ^d | 0.07±0.17 ^a | 7,259.97±146.32 ^d |
| Cashew nut shell liquid | N/A | N/A | N/A | N/A | 7,382.02±133.76 ^d |

Different letters in the same column indicate that values are significantly different ($p < 0.05$)

Table 2: Ultimate analysis of biomass raw materials and binders. Reprinted from “Influences of Mixing Ratios and Binder Types on Properties of Biomass Pellets” by J. Jindaporn and L. Charoenporn, 2017, Energy Procedia, 138, p. 1147-1152. [7]

| Sample | Elemental composition | | | | |
|------------------------------|-----------------------|-------|-------|-------|-------|
| | C (%) | H (%) | O (%) | N (%) | S (%) |
| Mangosteen shell | 47.399 | 5.945 | 46.00 | 0.460 | 0.196 |
| Papaya peel | 38.797 | 6.271 | 53.00 | 3.161 | 0.802 |
| Eucalyptus bark | 42.921 | 5.606 | 51.11 | 0.222 | 0.141 |
| <i>Persea kurzii</i> kosterm | 38.952 | 5.211 | 54.35 | 1.343 | 0.140 |
| Dammar | 61.145 | 7.945 | 30.69 | 7.945 | 0.130 |
| Cashew nut shell liquid | N/A | N/A | N/A | N/A | N/A |

Different letters in the same column indicate that values are significantly different ($p < 0.05$)

However, a study by Commeh, Kemausuor, Badger, & Osei [8] argued that too high volatile matter of 82.77% found in wood pellets compared to 12.15% in teak, 15.32% in kane, 13.98% in bamboo will generate more unwanted tar in gasification.

2.3 Single and Bulk Densities of Pellets

The pellets' bulk density is based on the volume of the pore. According to Emadi, Iroba, & Tabil [9], the normal acceptable range of singular pellet's density is within the range of 1000-1400 kg/m³. High bulk density is needed for very efficient storage and transportation. Other than that, according to Purwanto et al. [5], higher bulk density of straw pellet of 6006 kg/m³ has higher mass per surface area that reacts with oxygen during combustion thus producing higher heating value with diameter of 1cm and moisture content of 4%.

2.4 Effect of Applied Pressure

According to Kaliyan & Morey [10], Gilbert, Ryu, Sharifi, & Swithenbank [11], Rhen, Gref, Sjostrom, & Wasterlund [12], and Arshadi, Gref, Giladi, Dahlqvist, & Lestander [13], by changing the applied pressure, the mechanical and physical properties of the pellets can be altered. According to Jiang et al. [14], Kaliyan & Morey [15], Zakir, Suzana, & Murni [16], and Carone, Pantalio, & Pellerano [17], there exists natural binders like lignin, starch, protein and water-soluble carbohydrates in all the potential biomass materials. The pressure being applied during pellet making can affect the natural binders. According to Kaliyan & Morey [15], Jiang et al. [18], and Samuelsson, Larsson, Thyrel, & Lestander [19], when pressure being applied during pelletization is increased, the binding components are squeezed forming solid bridges, hydrogen bonding and van der Waals' forces. Solid bridges are formed within biomass particles by the diffusion of molecules of one particle to another. Natural binders inside biomass form hydrogen bonding, one of the three types of molecular forces, at the surface areas of lignin and cellulose. Van der Waals' force is one of the three types of molecular forces responsible for adhesion between particles less than 1 μm .

2.5 Effect of Applied Pressure on Density of Pellets

There is a positive relationship between the density of pellets and the applied pressure during pelletization. According to Adapa, Tabil, & Schoenau [20], by increasing the applied pressure from 31.6 MPa until 138.9 MPa, the density of barley straw, canola straw, oat straw and wheat straw pellets can also be increased until a maximum point where any further increase in the applied pressure will have no effects on the density of pellets. This is found when they studied the relationship between density and applied pressure for the different materials at different operating conditions. Jiang et al. [18] found that protein and lignin which are found in the Chinese fir, rice straw, and camphor materials are being rejected out and the void fractions of biomass materials are now filled with sewage sludge, further enhancing the density of pellets at high pressure of 110 MPa and temperature of 110°C. Above 110°C, which is from 130°C – 150°C, the density dropped is explained by the moisture content almost completely vaporised.

2.6 Moisture Content of Pellet

According to Jiang et al. [14], Samuelsson et al. [19] and Filbakk, Skjevraak, Hoibo, Dibdiakova, & Jirjis [21], quality of pellets is deeply connected with moisture content of water. Water content can fill the pore spaces between particles, increasing the mass and density of pellets before maximum point of moisture content. According to Kaliyan & Morey [10], the optimum moisture content for biomass pellets is to be in the range of 5-28%. Higher moisture content will disturb the combustion or gasification process. The excess water fills the volume of materials, enhancing the volume expansion and reduce the density of pellets. Too low moisture content will cause the pellets to easily break [10].

2.7 Effect of Particle Size of Pellets

The density of pellets relates to the particle size of the biomass. According to Stelte et al. [22], when they studied using particle size between 1 mm and 2.8 mm, the larger the particle size of biomass materials, the lower the density of biomass pellets. This can be explained that during densification, there exists inter-molecular attractive forces which can be recognized as hydrogen bonds and van der Waals'. The bigger the particle size of biomass materials, the weaker the van der Waals' forces. This is supported by Jiang et al. [18] when the study using particle sizes of less than 0.20mm, 0.20-0.30 mm, 0.30-0.45 mm, 0.45-0.85 mm and 0.85-1.18 mm, found that smaller particle size can fill the empty spaces better than large particle size thus increases the surface area producing high density pellets. Greater surface area has better heat and moisture absorption which enhances the binding properties of chemical components.

2.8 Effect of Binders

According to Said, Mahmoud, Garcia-Maraver, & Zamorano [23] and Sui Lam, Sokhansanj, Bi, Lim, & Melin [24], the lignocellulose matrix that contains low amount of lignin, proteins and starches sometimes requires extra binders to improve the inter-particle bonding thus producing high quality pellets with high density. This is supported by Lu, Tabil, Decheng, Guanghui, & Emami[25] that found the particle bonding is stronger because the bentonite and lignosulfonate binders which are small size particles now fill the voids and form films around biomass particles. According to Jamradloedluk & Lertsatitthanakorn [7], they found that *Persea kurzii* kosterm (Lauraceae plant) powder managed to produce the eucalyptus bark, mangos teen shells, and papaya peels pellets with higher density than the other binders ($p < 0.05$). This is due to the *Persea kurzii* kosterm solution is found to be more viscous than dammar solution and cashew nutshell liquid. Considering the high pressure being applied during pelletization, it is believed that stronger particle bonding is produced as results of films around biomass particles. The pellet density is higher. The composition of the raw materials does affect the higher heating value of the pellet. The highest higher heating value which can be produced is by using cashew nutshell liquid as a binder when compared with the other two. This is due to the cashew nutshell liquid had the higher heating value. However, the pellets produced with the binder of cashew nutshell liquid has the worst mechanical characteristics compared to the other two.

Table 3: Properties of pellets prepared at different biomass mixing ratios and binder types. Reprinted from "Influences of Mixing Ratios and Binder Types on Properties of Biomass Pellets" by J. Jindaporn and L. Charoenporn, 2017, Energy Procedia, 138, p. 1147-1152. [7]

| Binder type | Mixing ratio | Density (kg/m ³) | Higher heating value (cal/g) | Compressive strength (N/mm ²) | Maximum force (N) |
|---------------------------------|--------------|---------------------------------|---------------------------------|--|-----------------------------|
| <i>Persea kurzii</i> kosterm | 1:1:1 | 1,792.36±33.19 ^g | 4,080.93±158.77 ^{ab} | 4.97±0.99 ^{cd} | 97.50±19.50 ^{cd} |
| | 2:1:1 | 1,728.71±50.30 ^f | 3,990.11±12.84 ^{ab} | 5.69±1.09 ^{de} | 111.67±21.50 ^{de} |
| | 1:2:1 | 1,587.33±70.39 ^e | 4,014.09±7.23 ^{ab} | 7.45±1.14 ^g | 146.29±22.39 ^g |
| Dammar | 1:1:2 | 1,683.20±14.49 ^f | 3,825.25±125.06 ^a | 8.93±1.96 ^h | 175.26±38.52 ^h |
| | 1:1:1 | 1,554.13±9.00 ^{de} | 4,433.11±74.02 ^{bcd} | 6.49±1.36 ^f | 127.36±26.6 ^f |
| | 2:1:1 | 1,1436.84±9.89 ^b | 4,720.88±43.34 ^{cde} | 5.37±0.63 ^{cde} | 105.55±12.33 ^{cde} |
| Cashew nut shell liquid | 1:2:1 | 1,317.02±62.20 ^a | 4,669.03±11.30 ^{cde} | 5.85±0.98 ^f | 114.79±19.25 ^{ef} |
| | 1:1:2 | 1,432.05±4.67 ^b | 4,345.26±84.70 ^{bc} | 4.77±0.66 ^c | 93.71±12.93 ^c |
| | 1:1:1 | 1,516.87±9.62 ^{cd} | 4,903.58±209.08 ^{de} | 2.19±0.75 ^b | 42.92±14.78 ^b |
| Cashew nut shell liquid | 2:1:1 | 1,532.01±4.49 ^{cde} | 4,910.51±19.74 ^{de} | 1.32±0.32 ^a | 25.92±6.29 ^a |
| | 1:2:1 | 1,563.32±6.95 ^{de} | 5,068.60±7.74 ^e | 0.70±0.20 ^a | 13.73±3.90 ^a |
| | 1:1:2 | 1,477.70±34.55 ^{bc} | 4,928.86±38.16 ^{de} | 0.84±0.38 ^a | 16.42±7.53 ^a |

Different letters in the same column indicate that values are significantly different ($p < 0.05$)

2.9 Summary of Literature Reviews

The optimum biomass pellets diameter is 1 cm. According to the EN ISO 17225-2 [4], the optimum length is 40 mm. High carbon, hydrogen, and sulphur content in biomass leads to high heating value. The heating value is inversely proportional with the ash, oxygen and nitrogen content percentage in biomass. High volatile matter but no more than 80% is favourable since it produces high reactivity of biomass pellets as fuel. The optimum moisture content is 5-28%. Normal bulk density of pellets is 1000 – 1400 kg/m³, the higher the bulk density, the higher the heating value, but higher bulk density means heavier in storage and transportation. Density of pellets is found to be increased when compression pressure during pelletization is from 30 MPa – 110 MPa, above the range, the density will begin to decrease. Small size of biomass particles leads to high density pellets. Binders with high amount of lignin, proteins, and starches and higher heating value can produce pellets with higher heating value.

CHAPTER 3 : METHODOLOGY

3.1 Research Methodology

The project was initiated by knowing the problem statement first. After that, information was gathered further to know the background of the project or anything related to the problem statement. By understanding the information about the problem statement leads to material gathering and materials preparation. After all materials were prepared, experiments were carried out. From results obtained, data were then analysed and compared with previous works done by other researchers. After that, a conclusion was obtained in which meeting the objective of this research or not. The process flow chart of this research was simplified as in figure follows:

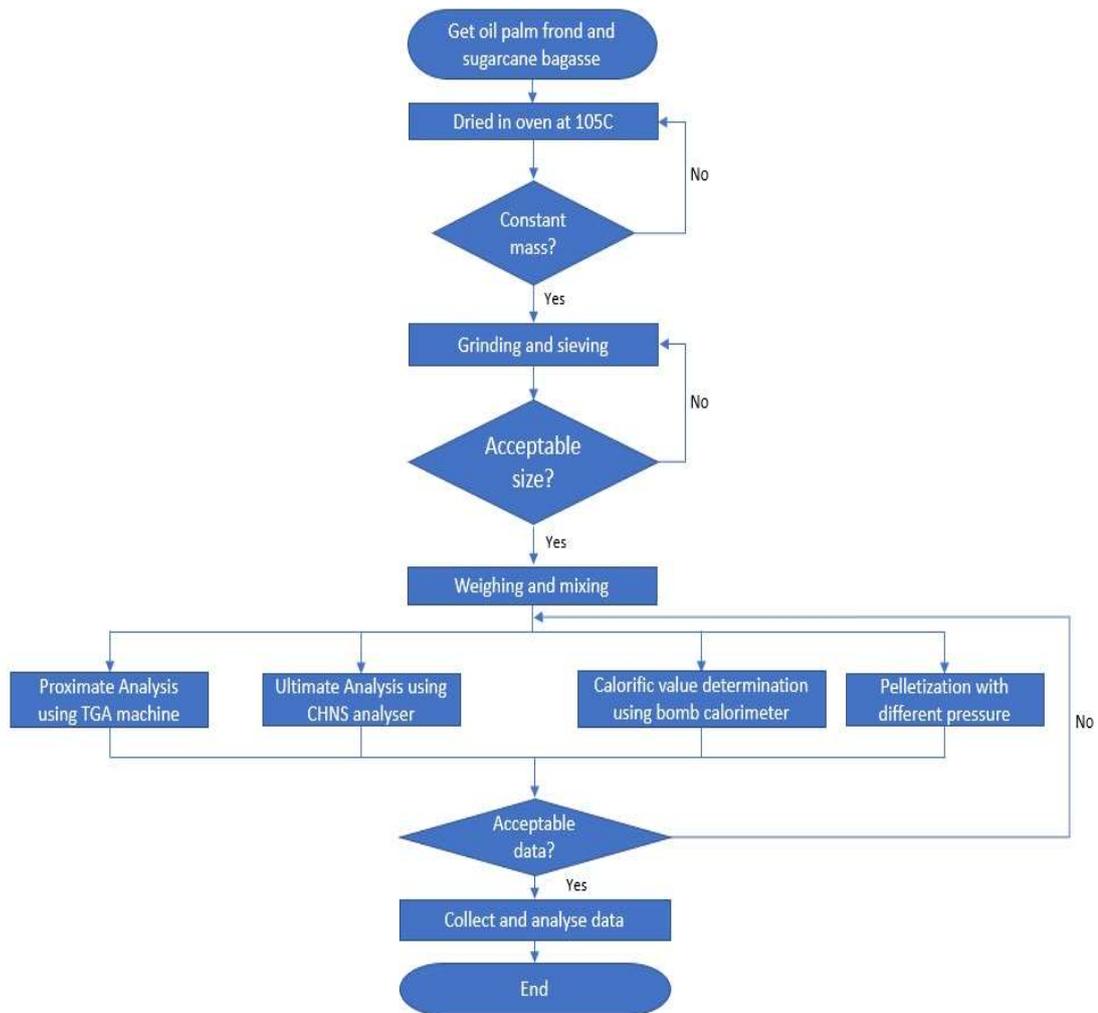


Figure 1: Flowchart

3.2 Project Activities

In doing this research, there were many activities to be done. After understanding problem statement, literature review was done first to get more information on the project. In conducting this project, it was found that many analyses should be done to assess the materials to be used as fuel pellets. They included density determination, proximate analysis, ultimate analysis, and calorific value determination. Prior to testing, material preparation was also discussed in detail.

Table 4: Manipulated Variables

| Manipulated Variables | |
|------------------------------------|---|
| Particle Size | <ol style="list-style-type: none"> 1. Group 1 (Small particles) Oil palm frond (OPF) smaller than 600μm Sugarcane bagasse (SC) smaller than 600 μm 2. Group 2 (Big particles) Oil palm frond (OPF) bigger than 600 μm Sugarcane bagasse (SC) bigger than 600 μm |
| Binder blending ratio | <ol style="list-style-type: none"> 1. OPF: SC (90:10) 2. OPF: SC (80:20) 3. OPF: SC (70:30) 4. OPF: SC (60:40) 5. OPF: SC (50:50) |
| Pelletization compression pressure | <ol style="list-style-type: none"> 1. 50 MPa 2. 100 MPa 3. 150 MPa |

3.2.1 Materials Gathering

Raw material to be used for biomass pellets in this research is oil palm frond (OPF) which was obtained from Kilang Sawit Felcra Nasaruddin in Bota, Perak. Other material collected was sugarcane bagasse purchased from stalls selling drinks.



Figure 2: Sugarcane and Oil Palm Frond

3.2.2 Drying

To prepare the materials, both oil palm frond (OPF) and sugarcane bagasse (SC) were dried in oven in Block 05-00-10 in UTP under Chemical Engineering department at 105 °C until constant mass was obtained, and they were subjected to sun drying before oven was used. Sun drying was done by exposing the materials under direct sunlight so that they can be dried. However, care was to be taken as they could be wet if they are not protected or moved away when rain falls.

3.2.3 Grinding and Sieving

After drying the materials, they were grounded into fine particles using granulator, mortar grinder and analytical mill grinder. After that, they were sieved into two groups which are group 1 and group 2. Group 1 (small particle) comprised of oil palm frond (OPF) and sugarcane as binder less than 600 μ m. Group 2 (big particle) comprised of oil palm frond (OPF) and sugarcane as binder bigger than 600 μ m.

3.2.4 Weighing and Mixing

Fuel pellets are to be made from different blending ratio between oil palm frond (OPF) as main material and sugarcane bagasse (SC) as binder. The OPF and SC were weighed and mixed together with blending ratio of 90:10, 80:20, 70:30, 60:40 and 50:50.

3.2.5 Materials Analysing

A) Proximate Analysis

To study the combustion characteristics of the materials, several analyses were carried out. Proximate analysis was done by using thermo gravimetric analyser (TGA) in UTP, 04-00-05. This experiment is carried out by CAL. From this analysis, data of moisture content, volatile matter, fixed carbon and ash contents of the materials was obtained. These data were used to estimate HHV value based on correlation by Parikh et al [20].

$$\text{HHV} = 0.3536\text{FC} + 0.1559\text{VM} - 0.0078\text{ASH} \text{ (MJ/kg)} \quad (2)$$

The actual data obtained from TGA was data of weight change against time and temperature. From these, further analysis was done, and proximate analysis is one of them.

B) Ultimate Analysis

Ultimate analysis was done to obtain data on carbon, hydrogen, nitrogen and sulphur content. Equipment used in this study was from LECO CHNS-932 in UTP, 04-00-05 where the standard chemical for CHNS for carbon was 51.78%, hydrogen 5.07%, nitrogen 20.13% and sulphur 11.52%. This known reference material was called sulfamethazine. This experiment is carried out by CAL.

C) Calorific Value Determination

To determine calorific value, a device called bomb calorimeter was used in UTP, 04-00-05. From this experiment, higher heating values (HHV) was obtained. This experiment is carried out by CAL.

D) Pelletizing

From here, pelletizing was done using Hydraulic Press in UTP, 04-02-09. Pelletizing process were done using different compression pressure, which are 50 MPa, 100 MPa and finally 150 MPa. The dimension of pellet was kept constant which is 1.3 cm in diameter. After that, the density was measured and calculated from the length and volume of the produced pellets.

3.3 Gantt Chart and Key Milestones

| ITEMS | WEEK (FYP 1) | | | | | | | | | | | | | |
|--------------------------------|--------------|---|---|---|---|---|---|---|---|----|----|----|----|----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Topic Selection and Allocation | | | | | | | | | | | | | | |
| Literature Reviews | | | | | | | | | | | | | | |
| Proposal Defense | | | | | | | | | | | | | | |
| Material Gathering | | | | | | | | | | | | | | |
| Material Preparation | | | | | | | | | | | | | | |
| Submission of Interim Report | | | | | | | | | | | | | | |

| ITEMS | WEEK (FYP 2) | | | | | | | | | | | | | |
|--|--------------|---|---|---|---|---|---|---|---|----|----|----|----|----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Material Preparation | | | | | | | | | | | | | | |
| Proximate Analysis | | | | | | | | | | | | | | |
| Ultimate Analysis | | | | | | | | | | | | | | |
| Calorific Value Determination | | | | | | | | | | | | | | |
| Pelletizing | | | | | | | | | | | | | | |
| Submission of Progress Report 1 | | | | | | | | | | | | | | |
| Submission of Progress Report 2 | | | | | | | | | | | | | | |
| Submission of Dissertation (softbound) | | | | | | | | | | | | | | |
| Video Presentation | | | | | | | | | | | | | | |
| VIVA | | | | | | | | | | | | | | |

Key Milestone 

1. Completion of ultimate analysis (28 Feb 2020)

3. Completion of producing pellets (13 March 2020)

2. Completion of calorific value determination (6 March 2020)

4. Completion of dissertation and video presentation (10 April 2020)

3.4 Equipment and tools

The machines being used are all available in Universiti Teknologi PETRONAS. Below are the details of the machines being used:

Table 5: Analysis equipment and its purpose

| No. | Equipment/Tools | Purpose |
|-----|--|--|
| 1 | <p>Oven</p>  | <p>To remove and reduce moisture content from materials. Location: UTP, 05-00-10</p> |
| 2 | <p>Granulator</p>  | <p>To grind raw materials into smaller pieces 3-5mm, but not in powder form. Location: UTP, Block STP</p> |
| 3 | <p>Analytical Mill Grinder</p>  | <p>To grind materials and sieve or filter automatically to desired particle size. Minimum size 425 μm Location: UTP, 05-00-05</p> |
| 4 | <p>Sieve</p>  | <p>To sieve powdered form materials into desired groups of particle sizes. Location: UTP, 13-00-06</p> |

| | | |
|---|--|---|
| 5 | <p>Mass Balance</p>  | <p>To weigh powdered form materials precisely to make accurate combination of materials for analysis and pelletization. To weight produced pellets</p> <p>Location: UTP, 17-02-08</p> |
| 6 | <p>TGA machine</p>  | <p>To conduct thermo gravimetric analysis or TGA analysis. Data obtained are used to plot graph of weight and derivative weight against time and temperature. From this, MC, VM, FC, and AC can be obtained.</p> <p>Location: UTP, 04-00-05</p> |
| 7 | <p>CHNS Analyzer</p>  | <p>To conduct ultimate analysis. Data obtained are the elemental composition of carbon, hydrogen, nitrogen and sulphur.</p> <p>Location: UTP, 04-00-05</p> |
| 8 | <p>Auto Pellet Machine</p>  | <p>To compress biomass powders into pellets</p> <p>Location: UTP, 04-02-09</p> |
| 9 | <p>Bomb Calorimeter</p>  | <p>To find calorific value or actual high heating value (HHV) of produced pellets</p> <p>Location: UTP, 04-02-09</p> |

CHAPTER 4 : RESULTS AND DISCUSSIONS

4.1 Proximate Analysis

As indicated in table 6, the ash contents of the oil palm frond (OPF) is the second lowest after western hemlock. The OPF which has low ash content of 1.3% means lower risk of pellet die erosion and increase the heating value. The ash content will bring negative effects on the gasification process and the environment when being disposed. Higher ash content means more slag being formed by the formation of clinkers in the gasifier. OPF with low ash content will require much simple handling system in the gasification process. The ash content of sugarcane bagasse (SC) is the third lowest after OPF. The ash content of both OPF and SC proves that both are suitable to be used as biomass fuel pellets.

From table 6, both OPF and SC has the average amount of fixed carbon which are 15.2% and 14.3%. The values are within the same range as other biomass materials such as rice husk, rice straw, wheat straw, and corn straw. The values are much lower as compared to bituminous coal and wood (acacia mangium) which are 57% and 45.5%. Size and temperature of char flame depends on the value of fixed carbon. Higher fixed carbon leads to bigger size and higher temperature of char flame.

After that, both OPF and SC are among the highest in the value of volatile matter which are 83.5% and 82.3%. The higher the volatile matter content, the higher the reactivity rate of biomass pellets as fuel, the faster the combustion rate during devolatilization. However, too high volatile matter content around 80% will lead to unwanted tar in gasification. When comparing both OPF and SC in volatile matter content with other biomass materials, the values are within the same range. Only bituminous coal scores the lowest volatile matter content which is 35%.

The value of Higher Heating Value (HHV) using Parikh et al [20] formula:

$$\text{HHV} = 0.3536\text{FC} + 0.1559\text{VM} - 0.0078\text{ASH} \text{ (MJ/kg)}$$

$$\text{HHV (OPF)} = 0.3563(15.2) + 0.1559(83.5) - 0.0078(1.3)$$

$$\text{HHV (OPF)} = 18.42 \text{ MJ/kg} = 18.42 \text{ kJ/kg}$$

$$\text{HHV (SC)} = 0.3563(14.3) + 0.1559(82.3) - 0.0078(3.3)$$

$$\text{HHV (SC)} = 17.9 \text{ MJ/kg} = 17.9 \text{ kJ/kg}$$

Table 6: Proximate analysis comparison of date palm frond (DPF) with other biomass (dry basis).
Reprinted from “Characterization of date palm fronds as a fuel for energy production” by Sulaiman, S.A., Inayat, M., Tamili, S.M.A., & Bamufleh, H.S., & Naz M.Y., 2017, Bulletin of the Chemical Society of Ethiopia, 30(3), p. 465-472. [26]

| Sample | Type of biomass | Volatile matter (%) | Fixed carbon (%) | Ash content (%) | Reference |
|-------------------|--------------------------------|---------------------|------------------|-----------------|----------------|
| DPF Samples | Ajwah | 78.2 | 14.1 | 7.7 | Present result |
| | Sukariah | 82.5 | 13.6 | 3.6 | Present result |
| | Jeddah | 83.0 | 5.2 | 11.7 | Present result |
| Date palm biomass | Seed | 76.6 | 7.7 | 10.8 | [11] |
| | Leaf | 78.1 | 5.2 | 11.7 | [11] |
| | Leaf stem | 55.3 | 7.8 | 19.2 | [11] |
| Other biomass | Sugar cane bagasse | 82.3 | 14.3 | 3.3 | [13] |
| | Oil palm fronds (OPF) | 83.5 | 15.2 | 1.3 | [7] |
| | Wood (<i>Acacia mangium</i>) | 45.5 | 45.5 | 9.0 | [13] |
| | Rice husk | 75.4 | 12.3 | 13.2 | [7] |
| | Rice straw | 66.5 | 16.9 | 16.6 | [9] |
| | Wheat straw | 70.0 | 16.4 | 16.6 | [9] |
| | Corn straw | 69.0 | 16.4 | 14.5 | [9] |
| | Sesame stalk | 72.2 | 17.0 | 6.6 | [9] |
| Western hemlock | 84.8 | 15.0 | 0.2 | [10] | |
| Coal | Bituminous coal | 35 | 57 | 8 | [11] |

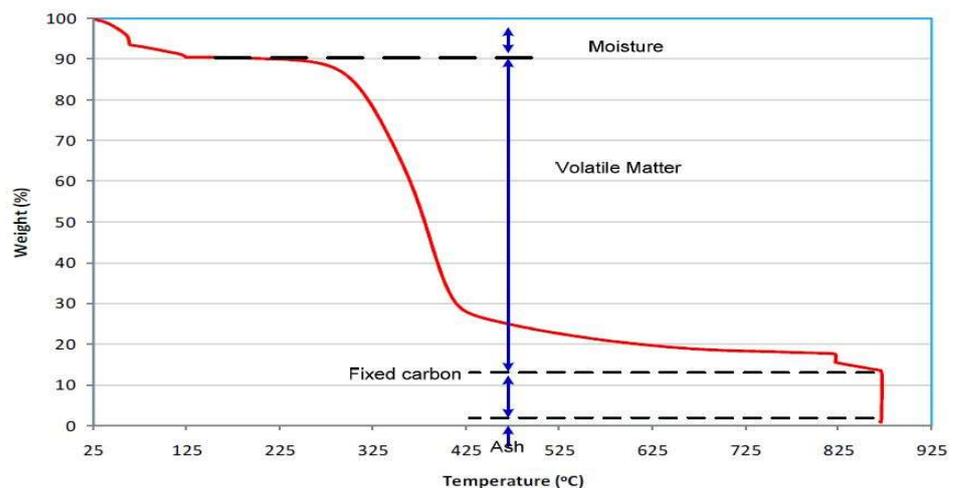


Figure 3: A Typical Proximate Analysis Graph of OPF Obtained from Pyris 1 TGA Experiment.
Reprinted from “Elemental and thermo-chemical analysis of oil palm fronds for biomass energy conversion” by Guangul, F.M., Sulaiman, S.A., & Raghavan, V.R., 2012, AIP Conf. Proc. 1440, p. 1197-1205. [27]

4.2 Ultimate Analysis

From the data shown in table 7 and figure 4, the carbon content for both biomass samples are different which is 42.49% for oil palm frond (OPF) and 40.87% for sugarcane bagasse (SC). The OPF has higher carbon, hydrogen and sulphur percentage content compared to SC as displayed in table 7. Based on the findings by Harun & Afzan [6], higher carbon, hydrogen and sulphur percentage content leads to the increase in heating value of the biomass sample. This shows that OPF has higher heating value than SC based on the component's percentage in ultimate analysis. From the table, OPF has higher potential for char burning as compared with the SC as OPF has higher carbon content. The hydrogen and nitrogen of SC is slightly varied with OPF value, but with the lower carbon content, that leads the SC to have the lower heating value. The low value of nitrogen and sulphur means less harmful effect to the environment and requires less treatment during the conversion process.

Table 7: Ultimate Analysis Data

| Components (wt%) | Oil Palm Frond (OPF) | Sugarcane Bagasse (SC) |
|------------------|----------------------|------------------------|
| Carbon | 42.49 | 40.87 |
| Hydrogen | 6.36 | 6.17 |
| Nitrogen | 0.42 | 0.34 |
| Sulphur | 0.20 | 0.15 |

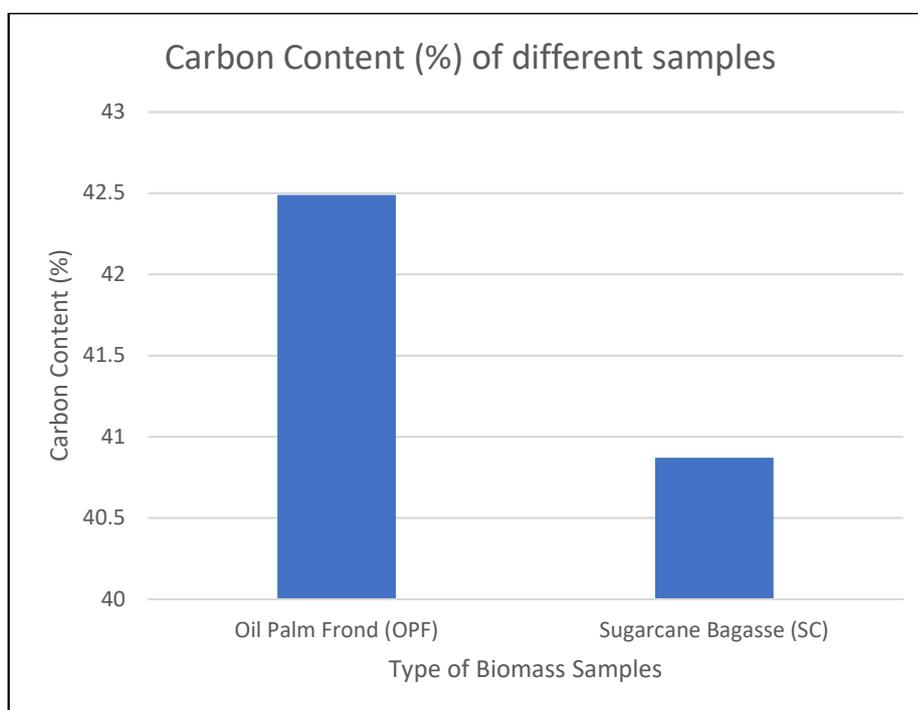


Figure 4: Percentage of carbon content for different type of biomass samples.

4.2.1 Experimental vs Correlation Ultimate Analysis

From table 8, the value of carbon content for both oil palm frond (OPF) and sugarcane bagasse (SC) from the experiment and journal paper not much different. The hydrogen content deviates by 2%. Meanwhile, the difference in nitrogen and sulphur for both OPF and SC from experiment and journal paper is quite significant. The higher value of nitrogen and sulphur content for SC from other biomass materials means it releases more harmful gases to the environment such as nitrogen dioxide and sulphur dioxide and requires additional treatment during the conversion process. The same goes with OPF which has higher nitrogen content than other biomass materials. However, OPF and SC has much higher carbon content and hydrogen than most of the other biomass materials. Higher carbon, hydrogen and sulphur content lead to higher heating value.

Table 8: Ultimate Analysis Comparison of DPF with other biomass. Reprinted from “Characterization of date palm fronds as a fuel for energy production” by Sulaiman, S.A., Inayat, M., Tamili, S.M.A, & Bamufleh, H.S., & Naz M.Y., 2017, Bulletin of the Chemical Society of Ethiopia, 30(3), p. 465-472. [26]

| Sample | Type of biomass | Carbon (%) | Hydrogen (%) | Nitrogen (%) | Sulfur (%) | Reference |
|-------------------|--------------------------------|------------|--------------|--------------|------------|----------------|
| DPF samples | Ajwah | 36.3 | 5.38 | 0.28 | 0.33 | Present result |
| | Sukariah | 38.9 | 5.70 | 0.32 | 0.66 | Present result |
| | Jeddah | 37.9 | 5.66 | 0.47 | 0.60 | Present result |
| Date palm biomass | Seed | 45.3 | 5.6 | 1.0 | 0.8 | [11] |
| | Leaf | 49.4 | 5.8 | 1.2 | 1.3 | [11] |
| | Leaf stem | 36.1 | 5.2 | 0.7 | 0.7 | [11] |
| | Sugar cane bagasse | 42.0 | 4.01 | 1.28 | 0.74 | [13] |
| | Oil palm fronds (OPF) | 44.6 | 4.53 | 0.71 | 0.07 | [7] |
| | Oil palm fronds (OPF) | 44.6 | 4.53 | 0.71 | 0.07 | [7] |
| Other biomass | Wood (<i>Acacia mangium</i>) | 43.5 | 3.59 | 1.00 | 0.16 | [13] |
| | Rice husk | 39.8 | 4.18 | 1.35 | 0.06 | [7] |
| | Rice straw | 39.2 | 5.10 | 0.60 | 0.10 | [9] |
| | Wheat straw | 42.1 | 6.53 | 0.58 | 0.32 | [9] |
| | Corn straw | 42.7 | 6.16 | 0.99 | 0.21 | [9] |
| | Sesame stalk | 41.3 | 6.57 | 0.81 | 0.29 | [9] |
| Coal | Bituminous coal | 73.1 | 5.50 | 1.40 | 1.70 | [11] |

4.3 CALORIFIC VALUE DETERMINATION

The calorific values for all the samples were obtained from the bomb calorimeter. The test was repeated three times to get the average results. The average results were more reliable and accurate. Based on figure 5, the highest value of HHV could be found in the mixture of oil palm frond and sugarcane bagasse with the blending ratio of 90:10. The value is 16.51 kJ/g. This is followed by blending ratio of 80:20 with HHV value of 16.38 kJ/g, 70:30 with HHV value of 16.33 kJ/g, 60:40 with HHV value of 16.29 kJ/g and finally 50:50 with HHV value of 16.15 kJ/g. This shows that as the mass of sugarcane bagasse is increased in the mixture of pellets alongside oil palm frond, the value of HHV will be decreased.

The best blending ratio to produce biomass pellets using oil palm frond (OPF) with sugarcane bagasse (SC) as binders is the 90:10. It produces the highest higher heating value (HHV) which is 16.51 kJ/g.

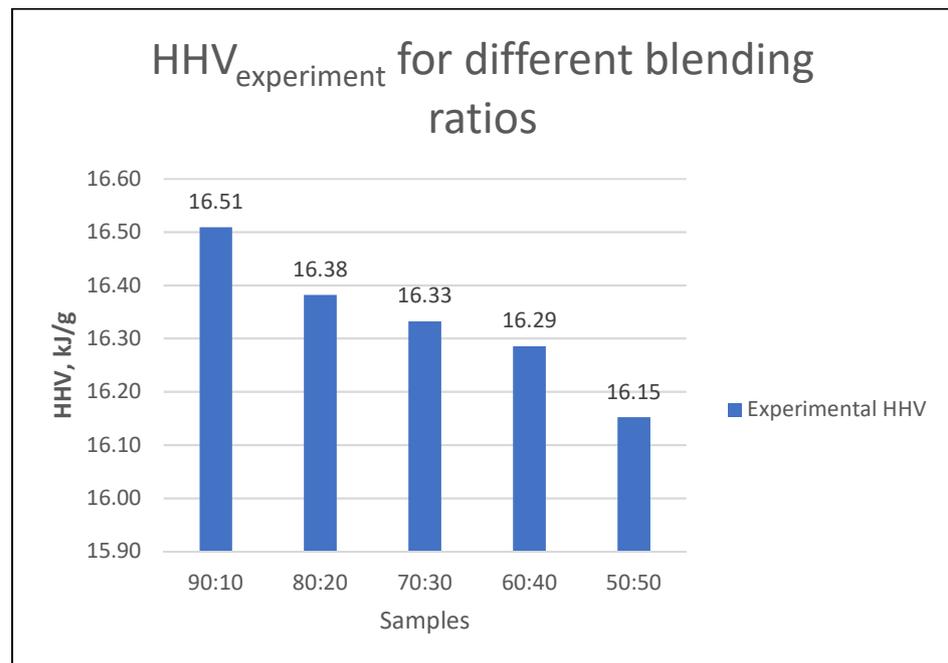


Figure 5: Experimental Higher Heating Value (HHV) obtained from bomb calorimeter.

4.3.1 Experimental vs Correlation Higher Heating Value (HHV)

From table 9, the sugarcane bagasse (SC) higher heating value (HHV) is 17485 kJ/kg which is equivalent to 17.3 kJ/g. The oil palm frond (OPF) has HHV of 17280 kJ/kg which is equivalent to 17.28 kJ/g. Both OPF and SC have much higher HHV than other biomass materials like date palm fronds samples, rice straw, and others. However, they are very low compared to HHV of bituminous coal which is 34000 kJ/kg.

From figure 6, the HHV value of oil palm frond (OPF) is 17.28 MJ/kg equivalent to 17.28 kJ/g. From these tables, the oil palm frond (OPF) has higher HHV as compared to agricultural biomass like corn straw, wheat straw and others. When compared with forestry biomass wastes like sawdust, paper and others, the value of HHV for OPF is lower. In terms of environment friendly, agricultural biomass is preferable than forestry biomass.

Table 9: Heating value of DPF and other biomass materials. Reprinted from “Characterization of date palm fronds as a fuel for energy production” by Sulaiman, S.A., Inayat, M., Tamili, S.M.A., & Bamufleh, H.S., & Naz M.Y., 2017, Bulletin of the Chemical Society of Ethiopia, 30(3), p. 465-472. [26]

| Sample | Type of biomass | Heating value (kJ/kg) | Reference |
|-------------------|--------------------------------|-----------------------|----------------|
| DPF samples | Ajwah | 16670 | Present result |
| | Sukariah | 16809 | Present result |
| | Jeddah | 16418 | Present result |
| Date palm biomass | Seed | 18970 | [11] |
| | Leaf | 17900 | [11] |
| | Leaf stem | 10900 | [11] |
| Other biomass | Sugar cane bagasse | 17485 | [13] |
| | Oil palm fronds (OPF) | 17280 | [7] |
| | Wood (<i>Acacia mangium</i>) | 17525 | [13] |
| | Rice husk | 15300 | [7] |
| | Rice straw | 15800 | [9] |
| | Wheat straw | 16500 | [9] |
| | Corn straw | 16640 | [9] |
| | Sesame stalk | 15920 | [9] |
| Coal | Bituminous coal | 34000 | [16] |

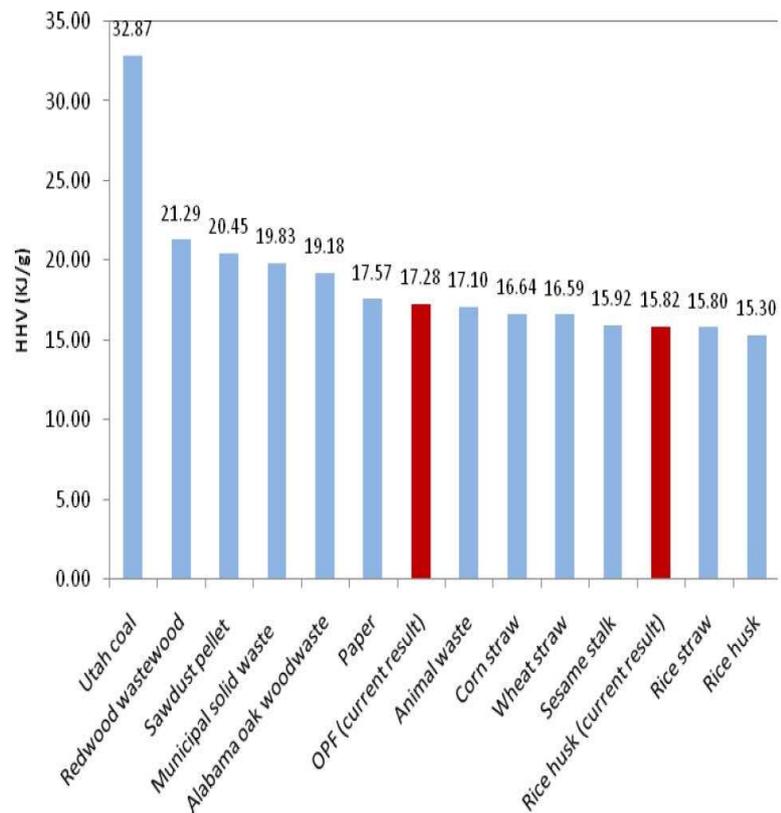


Figure 6: Comparison of OPF Higher Heating Value (HHV) with other feedstock. Reprinted from “Elemental and thermo-chemical analysis of oil palm fronds for biomass energy conversion” by Guangul, F.M., Sulaiman, S.A., & Raghavan, V.R., 2012, AIP Conf. Proc. 1440, p. 1197-1205. [27]

4.4 APPLIED PRESSURE AND PARTICLE SIZE OF BIOMASS ON DENSITY OF PELLETS

The oil palm frond (OPF) and sugarcane bagasse (SC) of different blending ratio of particles size smaller than 600 μm were subjugated to applied pressure of 50 MPa, 100 MPa, and 150 MPa. The density of each produced pellets was calculated as shown in table 10, table 11 and table 12.

Table 10: The density of produced pellets for particle size <600 μm and applied pressure of 50 MPa

| Sample Powder < 600 μm | | | | | | |
|-----------------------------------|--------|----------------|-------------|-------------------------|----------|------------------------------------|
| Applied Pressure = 50 MPa | | | | | | |
| No. | Sample | Blending Ratio | Length (cm) | Volume (m^3) | Mass (g) | Density (kg/m^3) |
| 1 | OPF:SC | 90:10 | 0.8 | 1.062E-06 | 0.9720 | 915.26 |
| 2 | OPF:SC | 80:20 | 0.8 | 1.062E-06 | 0.9840 | 926.56 |
| 3 | OPF:SC | 70:30 | 0.8 | 1.062E-06 | 0.9870 | 929.38 |
| 4 | OPF:SC | 60:40 | 0.8 | 1.062E-06 | 0.9780 | 920.91 |
| 5 | OPF:SC | 50:50 | 0.8 | 1.062E-06 | 0.9870 | 929.38 |

Table 11: The density of produced pellets for particle size <600 μm and applied pressure of 100 MPa

| Sample Powder < 600 μm | | | | | | |
|-----------------------------------|--------|----------------|-------------|-------------------------|----------|------------------------------------|
| Applied Pressure = 100 MPa | | | | | | |
| No. | Sample | Blending Ratio | Length (cm) | Volume (m^3) | Mass (g) | Density (kg/m^3) |
| 1 | OPF:SC | 90:10 | 0.7 | 9.292E-07 | 0.9930 | 1068.61 |
| 2 | OPF:SC | 80:20 | 0.7 | 9.292E-07 | 0.9926 | 1068.18 |
| 3 | OPF:SC | 70:30 | 0.7 | 9.292E-07 | 0.9893 | 1064.63 |
| 4 | OPF:SC | 60:40 | 0.7 | 9.292E-07 | 0.9784 | 1052.90 |
| 5 | OPF:SC | 50:50 | 0.7 | 9.292E-07 | 0.9982 | 1074.20 |

Table 12: The density of produced pellets for particle size <600 μm and applied pressure of 150 MPa

| Sample Powder < 600 μm | | | | | | |
|-----------------------------------|--------|----------------|-------------|-------------------------|----------|------------------------------------|
| Applied Pressure = 150 MPa | | | | | | |
| No. | Sample | Blending Ratio | Length (cm) | Volume (m^3) | Mass (g) | Density (kg/m^3) |
| 1 | OPF:SC | 90:10 | 0.7 | 9.292E-07 | 0.9721 | 1046.12 |
| 2 | OPF:SC | 80:20 | 0.7 | 9.292E-07 | 0.9960 | 1071.84 |
| 3 | OPF:SC | 70:30 | 0.7 | 9.292E-07 | 0.9839 | 1058.81 |
| 4 | OPF:SC | 60:40 | 0.7 | 9.292E-07 | 0.9920 | 1067.53 |
| 5 | OPF:SC | 50:50 | 0.7 | 9.292E-07 | 0.9849 | 1059.89 |

Based on figure 7, biomass samples with smaller particle size of less than 600 μm when being applied pressure of 50 MPa, the produced pellets' density are within 900 – 950 kg/m^3 . The produced pellets' length is 0.8 cm. As the applied pressure is increased to 100 MPa, the density of produced pellets increased to within 1000 – 1100 kg/m^3 , the length decreased to 0.7 cm. As the applied pressure further increased to 150 MPa, there are no significant changes in the density and length of produced pellets. This indicates that the maximum applied pressure required for biomass samples with particle size of less than 600 μm is 100 MPa to produce the pellets with highest density. Thus, less energy is required to produce the pressure required to produce the biomass pellets with the optimum density. For the different blending ratio of OPF:SC, there were no significant effects on the density of produced pellets and the applied pressure required.

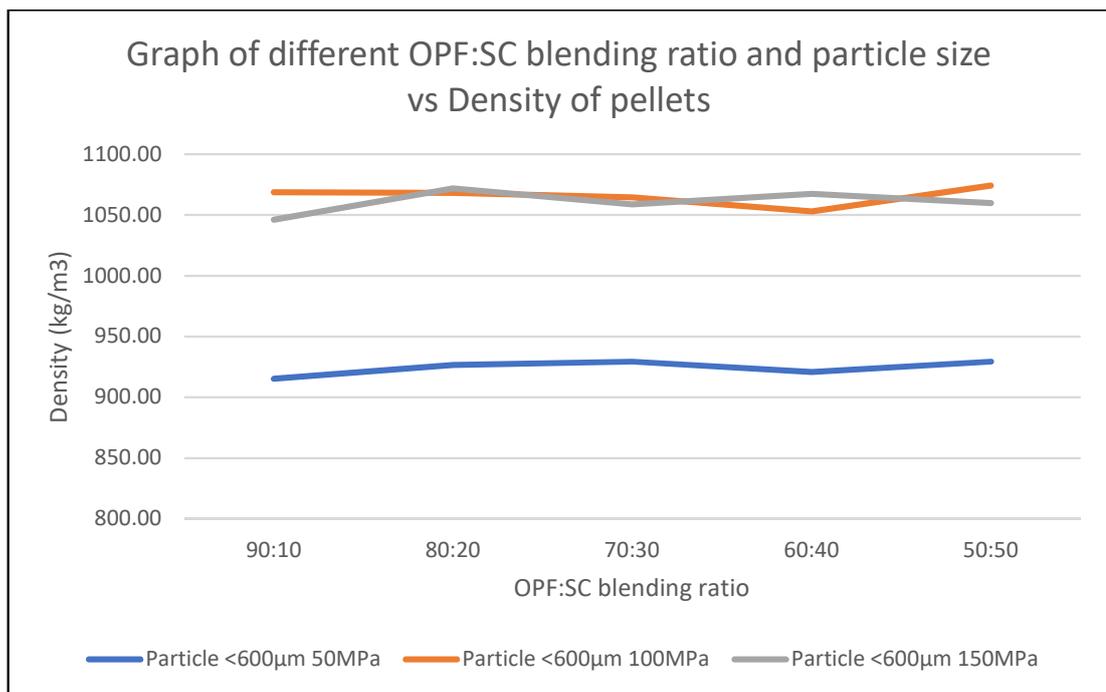


Figure 7: Graph of different OPF:SC blending ratio and particle size vs density of pellets

The oil palm frond (OPF) and sugarcane bagasse (SC) of different blending ratio of particles size larger than 600 μm were subjected to applied pressure of 50 MPa, 100 MPa, and 150 MPa. The density of each produced pellets was calculated as shown in table 13, table 14 and table 15.

Table 13: The density of produced pellets for particle size $>600 \mu\text{m}$ and applied pressure of 50 MPa

| Sample Powder $> 600 \mu\text{m}$ | | | | | | |
|-----------------------------------|--------|----------------|-------------|-------------------------|----------|------------------------------------|
| Applied Pressure = 50 MPa | | | | | | |
| No. | Sample | Blending Ratio | Length (cm) | Volume (m^3) | Mass (g) | Density (kg/m^3) |
| 1 | OPF:SC | 90:10 | 0.9 | 1.195E-06 | 0.9786 | 819.09 |
| 2 | OPF:SC | 80:20 | 0.9 | 1.195E-06 | 1.0023 | 838.92 |
| 3 | OPF:SC | 70:30 | 0.9 | 1.195E-06 | 0.9852 | 824.61 |
| 4 | OPF:SC | 60:40 | 0.9 | 1.195E-06 | 0.9986 | 835.83 |
| 5 | OPF:SC | 50:50 | 0.9 | 1.195E-06 | 0.9840 | 823.61 |

Table 14: The density of produced pellets for particle size $>600 \mu\text{m}$ and applied pressure of 100 MPa

| Sample Powder $> 600 \mu\text{m}$ | | | | | | |
|-----------------------------------|--------|----------------|-------------|-------------------------|----------|------------------------------------|
| Applied Pressure = 100 MPa | | | | | | |
| No. | Sample | Blending Ratio | Length (cm) | Volume (m^3) | Mass (g) | Density (kg/m^3) |
| 1 | OPF:SC | 90:10 | 0.8 | 1.062E-06 | 0.9865 | 928.91 |
| 2 | OPF:SC | 80:20 | 0.8 | 1.062E-06 | 0.9898 | 932.02 |
| 3 | OPF:SC | 70:30 | 0.8 | 1.062E-06 | 0.9940 | 935.97 |
| 4 | OPF:SC | 60:40 | 0.8 | 1.062E-06 | 0.9860 | 928.44 |
| 5 | OPF:SC | 50:50 | 0.8 | 1.062E-06 | 0.9941 | 936.07 |

Table 15: The density of produced pellets for particle size $>600 \mu\text{m}$ and applied pressure of 150 MPa

| Sample Powder $> 600 \mu\text{m}$ | | | | | | |
|-----------------------------------|--------|----------------|-------------|-------------------------|----------|------------------------------------|
| Applied Pressure = 150 MPa | | | | | | |
| No. | Sample | Blending Ratio | Length (cm) | Volume (m^3) | Mass (g) | Density (kg/m^3) |
| 1 | OPF:SC | 90:10 | 0.7 | 9.292E-07 | 0.9932 | 1068.82 |
| 2 | OPF:SC | 80:20 | 0.7 | 9.292E-07 | 0.9835 | 1058.38 |
| 3 | OPF:SC | 70:30 | 0.7 | 9.292E-07 | 0.9840 | 1058.92 |
| 4 | OPF:SC | 60:40 | 0.7 | 9.292E-07 | 1.0100 | 1086.90 |
| 5 | OPF:SC | 50:50 | 0.7 | 9.292E-07 | 1.0150 | 1092.28 |

Based on figure 8, biomass samples with larger particle size of more than 600 μm when being applied pressure of 50 MPa, the produced pellets' density are within 800 – 850 kg/m^3 , lower than the density for particle size less than 600 μm . The produced pellets' length is 0.9 cm, longer than when the particle size is less than 600 μm . As the applied pressure was increased to 100 MPa, the density of produced pellets increased to within 900 – 950 kg/m^3 , and the length decreased to 0.8 cm. The density is lower, and the length is longer compared to particle size of less than 600 μm . As the applied pressure further increased to 150 MPa, the density increases to its maximum which is within 1000 – 1100 kg/m^3 and the length decreased to 0.7 cm. This indicates that the biomass samples with particle size of more than 600 μm requires much higher maximum applied pressure which is 150 MPa to produce the pellets with highest density. This shows that it is required for more energy to produce higher pressure to produce the biomass pellets with optimum density. For the different blending ratio of OPF:SC, there were no significant effects on the density of produced pellets and the applied pressure required.

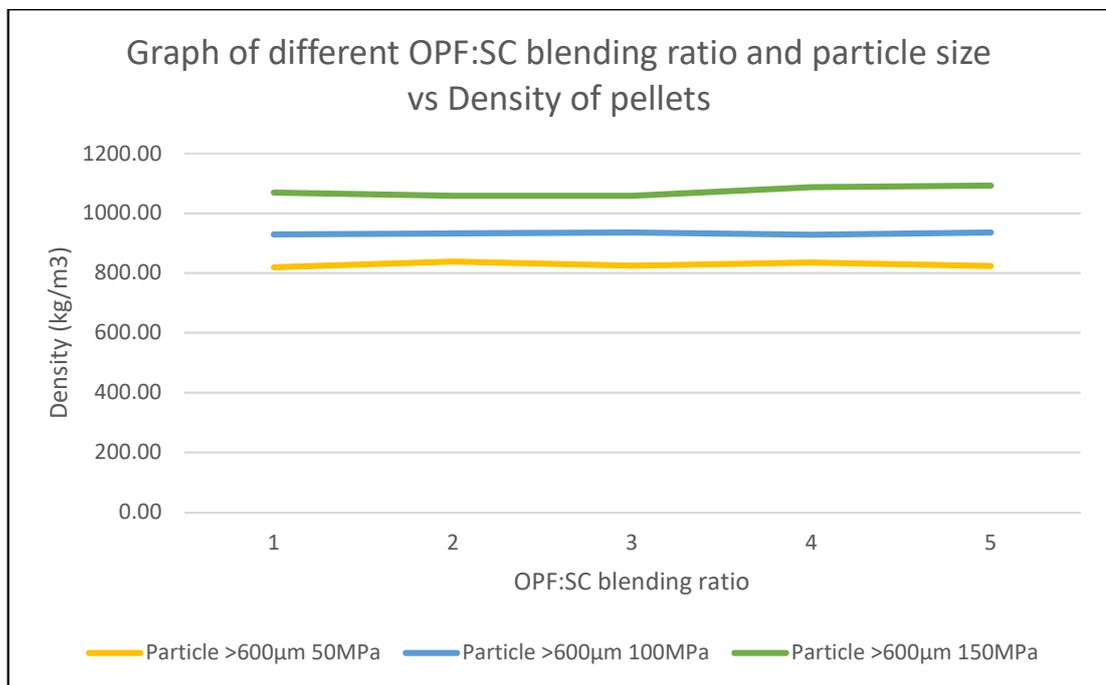


Figure 8: Graph of different OPF:SC blending ratio and particle size vs density of pellets

CHAPTER 5 : CONCLUSION AND FUTURE WORK

Both oil palm frond (OPF) and sugarcane bagasse (SC) has low ash content that lead to lower risk of pellet die erosion, less slag formation in gasification process. OPF and SC has high amount of fixed carbon which leads to bigger size and higher temperature of char flame. OPF and SC has high volatile matter content which leads to faster reactivity rate of biomass pellets as fuel. However, high volatile matter can lead to more unwanted tar during gasification.

OPF and SC has higher amount of carbon, hydrogen and sulphur compared to other biomass materials which lead to higher heating value. Low amount of nitrogen leads to lower harmful gas emissions to the environment, thus requires simple treatment process during conversion.

OPF and SC has higher heating value (HHV) which are higher than most other biomass materials. They are suitable to be used as biomass fuel pellets. The best blending ratio using OPF with SC as binder is 90:10 which has the highest HHV of 16.51 kJ/kg.

When particle size of biomass is smaller, less energy and less optimum applied pressure are required to produce biomass fuel pellets with the highest density. Biomass fuel pellets with highest density have higher heating value. For the different blending ratio of mass between OPF and SC, there is no significant effect on the applied pressure required to produce biomass fuel pellets with highest density.

The recommendation for future work would be to study other types potential biomass like wood, empty fruit bunch (EFB) and many more. The potential study would include the types of binders being used, the viscosity of the binders, and the blending ratio of the binders in producing biomass pellets. The work should also include torrefaction as it prevents the biomass materials from absorbing surrounding moisture, thus increasing the heating value of the biomass pellets.

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APPENDICES

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APPENDIX A: TGA ANALYSIS PROCEDURE

Procedure A

1. Weigh sample using mass balance about 5 mg and put in crucible.
2. Carefully place the crucible in the holder for hang down pan.
3. Start the program. Procedure of program:
 - a) Hold for 1 minute at 29 °C
 - b) Heat from 29 °C to 800 °C at 20 20 °C/min
4. End program.
5. Clean crucible and repeat step 1 until 5 for next set of experiment.

Procedure B

1. Weigh sample using mass balance about 5 mg and put in crucible.
2. Carefully place the crucible in the holder for hang down pan.
3. Start the program. Procedure of program:
 - a) a. Sample is heated from initial temperature of 50°C C to 110°C, at heating rate of 60 °C /min with nitrogen gas flow rate of 30 ml/min.
 - b) b. Sample is held isothermally for 5 minutes.
 - c) c. Sample is heated until 800°C at heating rate of 100 °C min with same nitrogen flow rate
 - d) d. Sample is held for another 3 minutes.
 - e) e. Sample is heated from 800 °C to 850 °C at a rate of 20 °C /min.
 - f) f. The gas used was changed to oxygen.
 - g) g. Sample temperature was held constant for 10 minutes at 850 °C
4. End program.
5. Clean crucible and repeat step 1 until 5 for next set of experiment.

APPENDIX B: ULTIMATE ANALYSIS PROCEDURE

1. Prepare the instrument as written in the instruction manual (perform checks).
2. Analyse blanks until the instrument is completely stable, then analyse 3-5 crimped 502-206 Silver Capsules. Set weight to be 2.0 mg. Set blank using results from these capsules.
3. Analyse 3-5 standards using the steps:
 - a) Weigh ~ 2 mg of standard material into a 502-206 Silver Capsule, crimp capsule, and analyse.
 - b) Calibrate using the values from the manual
4. Mix the sample well, weigh ~ 2 mg sample into a 502-206 Silver Capsule, crimp capsule, and analyse.
5. Set a standard to verify calibration.

APPENDIX C: BOMB CALORIMETER PROCEDURE

1. Turn on oxygen gas regulator. Adjust the outlet pressure 30 PSI.
2. Turn on controller unit and cooling system, wait 20 minutes for WAITING STABLE.
3. Prepare sample (weighing below 1.0 gram)
4. Place sample into crucible, secure a cotton thread with a loop in it on the middle of the ignition wire. Place into the decomposition vessel.
5. Open the SAMPLE dialog window to enter parameter.
6. The decomposition vessel is suspended into the filling head of the measurement cell cover.
7. Press START. The measurement cell cover will close the decomposition vessel and the oxygen fills in. The water will fill the inner vessel. As the experiment begins, the display will show a graph of the change over time in temperature of the inner vessel.
8. When the measurement is complete, remove the decomposition vessel, clean, dry and prepare for the next experiment.