Study on the Potential of Pelletisation of Empty Fruit Bunch with Sago as Binding Agent for Power Generation

N. Abdul Rahman, M.F. Atan, C. M. Low, R. Baini, N.F. Che Mat and S.F. Salleh

Abstract

The aim of this study is to pelletise oil palm empty fruit bunch (EFB) with binding agent at low compression pressure for power generation purposes. The pellets are tested for bulk density, moisture content, amount of fines and calorific value. This study has proven that pelletisation of pulverised EFB and pulverised EFB + mesocarp fibre with sago starch reduce the breakage and fibrous loose as well as the amount of fines for EFB pellets at low compression pressure. Due to sago starch higher moisture content, the produced pellets moisture content is slightly higher than the pellets without the addition of sago starch. Consequently, the calorific value of the produced pellets is lower and the ash content is also found to be slightly higher. Therefore, sago starch addition improves the physical characteristics of the EFB pellets but optimisation of the sago starch addition proportion need to be performed accordingly as excessive addition of sago starch degrade combustion characteristics of the pellet.

Keywords: Pelletisation, Pellet, Oil Palm Empty Fruit Bunch, Binding Agent

1. INTRODUCTION

The forestry and agricultural industry in Malaysia is producing large volumes of residues. In the past, these residues are left in the field and in some circumstances are wastefully burnt away which causing problems to the industries. Moreover, due to the expansion of agriculture plantation area, the biomass wastes generated create a number of issues such as bulkiness in term of storage and if improperly disposed could cause serious air and water pollution in which degrade the environmental quality [1]. Therefore, there are strong motivations to utilise these wastes as renewable energy sources for power generation as the amount of agricultural biomass waste is in abundant supply in Malaysia especially from palm oil industry [2]. Palm oil wastes in Malaysia are disused due to their high moisture content and normally unsaleable such as empty fruit bunch (EFB)[3]. Therefore, the main aim of this research is to pelletise pulverised EFB and Mesocarp fibre as fuel for power generation at low compression pressure. In addition, the study also examines the effect of sago starch as binding agent for pelletisation. As such, the study investigates the produced pellets physical and combustion characteristics especially on (i) bulk density, (ii) moisture content, (ii) amount of fines produced, (iii) calorific value, and (iv) ash content after combustion.

2. METHODOLOGY

The methodology of this study is divided into three parts, namely, (i) Material Preparation, (ii) Pelleting Process, and (iii) Experimental Testing.

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N. Abdul Rahman, M.F. Atan, R. Baini, N.F. Che Mat and S.F. Salleh are with the Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, SARAWAK (Phone: +60162085591 e-mail: amfarid@feng.unimas.my).

C. M. Low was with the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, SARAWAK.

2.1. Material Preparation

Material preparation includes the collection of raw materials which are EFB and mesocarp fibres from nearby palm oil plantations and soiled sago starch from sago processing mill. The EFB are shredded and cut into small pieces for convenient of drying and grinding purposes. The EFB are then sun dried for a few days in order to remove most moisture content. The sorting process is also carried out in order to remove the impurities from the raw material. These procedures are taken as to improve the quality of the produced pellets. The final step is to pulverise the raw materials prior to pelletisation process.

2.2. Pelleting Process

Six types of pellets are produced for this study with varying composition of EFB, Mesocarp fibre and Sago starch. Two pellet diameters, 6mm and 8mm, are choose in this study as these are the most common commercially available pellet sizes. The various types of the pellet produced are depicted by Table 1.

Table 1 Composition of Pellets Produced

Pellet Diameter	**Pellet Type**	**Composition Percentage (%) by weight**		
		Empty Fruit Bunches	**Mesocarp Fibres**	**Sago Starch**
6 mm and 8mm	100% Pulverized EFB	100	-	
	Pulverized EFB + Sago starch (90:10)	90	-	10
	Pulverized EFB + Sago starch (95+5)	95	-	5
	Pulverized EFB + Mesocarp (90+10)	90	10	-
	Pulverized EFB + Mesocarp + Sago starch (80+10+10)	80	10	10
	Pulverized EFB + Mesocarp (85+10+5)	85	10	5

Due to unavailability of pelletiser, the study has designed a male and female mould for pelletisation. In the pelletisation process, the blended raw mix is inserted and pre-compressed manually into the female mould. The pre-compressed particles in female mould are then compressed by using the male mould at 120°C ± 2°C temperature and 50 kg/cm^2 (5MPa) pressure by using a Hot Press Machine for about 10 minutes. After the compression process, the produced pellets are removed from the mould manually and then cooled to the room temperature prior to experimental testings.

2.3. Experimental Testing

In this study, five types of experimental testing have been conducted in order to determine the properties of the pellets produced. The testings are as follow:

2.3.1. Bulk Density Testing

Bulk density is defined as the weight per unit volume of the material. The weight of the pellets is measured by using a digital analytical balance with an accuracy of 0.01g and the volume are measured by using a graduated cylinder. The calculation of bulk density can be carried out by using (1) as follow:

$$\text{Pellet Density (kg/m}^3) = \frac{\text{weight (kg)}}{\text{volume (m}^3)} \quad (1)$$

2.3.2. Moisture Content Testing

Two types of moisture content testing are conducted; oven dry and moisture analyser machine. In the oven dry moisture content testing, the weight of the pellets is measured by using a digital analytical balance with an accuracy of 0.01g before and after the drying process. In this testing, the pellets are dried in the oven at 80°C for 24 hours. The measurement of moisture content is carried out by using (2).

$$\text{Moisture content (dry basis)(\%)} = \frac{\text{Wet Weight (g) - Dry Weight (g)}}{\text{Dry Weight (g)}} \times 100\% \quad (2)$$

Pellet moisture content is also measured by means of moisture analyser in which the temperature is set at 130°C as recommended by the manufacturer. The moisture content of the pellets is automatically measured by the analyser.

2.3.3. Amount of Fines Testing

For the amount of fines testing, the sample pellets are shaken lightly and continuously for 10 minutes in order to simulate loading and unloading of pellets during transportation. After the procedure, the pellets are separated from its fines. The produced fines are measured by using a digital analytical balance in which the percentage amount of fines in the sample is determined by using (3)

$$\text{Amount of Fines (\%)} = \frac{\text{Mass of amount of fines(g)}}{\text{Mass of sample (g)}} \times 100\% \quad (3)$$

2.3.4. Calorific value Testing

This test determines the total heat release by the pellets when complete combustion occurs. Automated Bomb Calorimeter is used in determining the calorific value of the produced pellets. The calorific value of pellet is automatically measured and calculated by the machine by using (4) as follow:

$$\text{Combustion Heat (J/g)} = \frac{\text{Measured value (J) - Complete Combustion (J)}}{\text{Sample size (g)}} \quad (4)$$

2.3.5. Ash Content Testing

This test determines the ash produced which is expressed as the percentage of residue remaining after combustion in 700°C oven for about 4 hours. The weight of pellets is recorded before and after combustion by using a digital analytical balance. The measurements of ash content are carried out by using (5).

$$\text{Ash,\%} = \frac{\text{Weight of ash (g)}}{\text{Initial weight of dried sample (g)}} \quad (5)$$

3. Results and Discussion

The results obtained from the experimental testing are depicted in Table 2 and 3 for 6mm and 8mm diameters pellets respectively.

Table 2 Overall Characteristic of Different Type of 6mm Pellet

Pellets (Blending ratio)	Bulk density, kg/m^3	Moisture content, %	Ash content, %	Fines content, %	Calorific value, kJ/kg
100% Pulverized EFB	908	10.03	0.42	0.19	-
Pulverized EFB + Sago starch (90:10)	1105	10.86	0.50	0.09	-
Pulverized EFB + Sago starch (95+5)	1017	10.79	0.43	0.14	-
Pulverized EFB + Mesocarp (90+10)	724	15.74	0.41	2.59	-
Pulverized EFB + Mesocarp + sago (80+10+10)	896	17.90	0.49	0.92	-
Pulverized EFB + Mesocarp +sago (85+10+5)	864	15.17	0.43	1.33	-

Table 3 Overall Characteristic of Different Type of 8mm Pellet

Pellets (Blending ratio)	Bulk density, kg/m^3	Moisture content, %	Ash content, %	Fines content, %	Calorific value, kJ/kg
100% Pulverized EFB	607	10.17	0.47	0.35	17000
Pulverized EFB + Sago starch (90:10)	735	13.28	0.53	0.21	16860
Pulverized EFB + Sago starch (95+5)	695	12.36	0.49	0.27	16890
Pulverized EFB + Mesocarp (90+10)	480	13.63	0.56	2.54	16855
Pulverized EFB + Mesocarp + sago (80+10+10)	596	14.86	0.63	1.24	16850
Pulverized EFB + Mesocarp +sago (85+10+5)	553	13.51	0.58	1.66	16880

3.1. Pellet Physical characteristics

The compression strength is a direct factor affecting the size and density of the pellets. The high temperature (at least up to 144°C) at the start of compression increases the dry density of the pellets [4]. Size of the pellets also plays an important role for convenient of storage and efficient transport. For that reason, pellets with the size of 6mm and 8mm in diameter are mostly produced commercially in ensuring it able to flow, handle, and even fed to boiler and furnace easily. However, due to unavailability of suitable pelletiser in this study, the pellets are produced at much lower pressure and temperature of $50kg/cm^2$ or 5MPa and temperature 120°C as compare to commercial standard production at around 100Mpa to 150 Mpa and at least 144°C. The results at these study lower pressure and temperature pelletisation shows that 6mm pellets exhibit some structure breakages and produce significant amount of loose fibrous ends as compare to 8mm pellets. In addition, it is also observed that pellets with higher percentage of sago starch demonstrates better particle bonding as compare to pellets without sago addition to its raw material composition. Therefore, in term of better bonding observation, pellets with 8mm diameter and higher percentage of sago demonstrated better bonding structure as depicted by Figure 1, 2, 3 and 4.

(a) **(b)** **(c)**

Figure 1 Oil palm EFB pellet 8mm diameter (a) 100%EFB, (b) EFB+Sago (95+5) and (c) EFB+Sago (90+10)

(a) **(b)** **(c)**

Figure 2 Oil palm EFB pellet 8mm diameter (a) EFB+ Mesocarp fibre, (b) EFB+ Mesocarp fibre+ Sago (85+10+5)
and (c) EFB+ Mesocarp fibre+ Sago (80+10+10)

(a) **(b)** **(c)**

Figure 3 Oil palm EFB pellet 6mm diameter (a) 100%EFB, (b) EFB+Sago (95+5) and (c) EFB+Sago (90+10)

(a) **(b)** **(c)**

Figure 4 Oil palm EFB pellet 8mm diameter (a) EFB+ Mesocarp fibre, (b) EFB+ Mesocarp fibre+ Sago (85+10+5)
and (c) EFB+ Mesocarp fibre+ Sago (80+10+10)

3.2. Bulk Density

The study has show that addition of sago starch to the pellet composition increases the bulk density of the pellets. This is made evident by comparing pellets with 100% pulverised EFB to pulverised EFB + Sago starch (90:10) for both 8mm and 6 mm pellets. The addition of 10% sago starch increases the bulk density of the pellet by about 20 percent. This is possibly due to the fact that the particles are bonding better with the addition of sago starch and maintaining their compacting form after the pressure has been released in the compression process. This is agreeing to the observation that less loose fibrous end and pellet breakage for pellets with sago starch addition. This observation is also observed for pellet with the composition of Pulverised EFB + Mesocarp fibre and sago in which the bulk density increases by about 24%. Therefore, it can be deduced that addition of sage starch increases the bulk density of the pellet.

3.3. Moisture Content

The results show that addition of 10% sago starch into the composition of pellet significantly increases the moisture content of the pellets. For 6mm pellets, at both 10% and 5% addition of sago starch causes about 10% higher moisture content as compared to pellet without the addition of sago starch. For 8mm diameter pellets, addition of 10 and 5% sago starch causing the pellet moisture content to increase excessively to around 30 and 20% respectively. Similar results are also observed for Pulverised EFB + Mesocarp fibre and sago pellets. This finding is due the fact that sago starch used in this study is in wet starch form in which it has a very high moisture content. The moisture content in wet starch can be up to 50% w/w of starch to water [5]. As such, it can be concluded that addition of wet sago starch increases the moisture content of the pellet.

3.4. Amount of Fines

The result shows that the amounts of fines produced by pellets with addition of sago starch are lower than pellets without the addition of sago starch for both pulverised EFB and pulverised EFB + mesocarp fibre pellets. Overall, the percentage amounts of fines for pulverised EFB pellets are acceptable to European standard which is less than 1% [6]. However, for pulverised EFB + mesocarp fibre pellet, addition of sago starch reduces the amount of fines significantly but it is still higher than the limit set by European standard. Only pulverised EFB + mesocarp fibre with the addition of 10% sago starch pellets meet the requirement for the produced amount of fines standard.

3.5. Ash Content

For ash content experimental testing, it is found that the addition of sago starch to the pellet composition increases the ash content of pellets for both pulverised EFB and pulverised EFB + mesocarp fibre pellets. Addition of 10% sago starch by weight, increase the ash content produced by almost 20%. However, the ash percentage produced by all types of pellet produced in this study are between 0.42 to 0.63 and these are within the European standard which is should be less than 0.7% in dry weight basis [6]. This is due to the fact that higher addition of sago starch increases the moisture content of the pellet which eventually reduced that completeness of pellet combustion.

3.6. Calorific Value

As in Table 4, 100% pulverized EFB pellets have the highest calorific value. On average, 100% pulverized EFB pellets calorific value is 17kJ/kg which is double the calorific value of undensified EFB at 8160kJ/g [7]. The other two types of pulverised EFB pellets exhibit slightly lower calorific at approximately 16.9kJ/kg. Higher additions of sago starch in the pellet composition witness some reduction in calorific value. This is the result of higher moisture content in sago starch as observed in moisture content testing mentioned earlier. The same observation is also witnessed for pulverised EFB + mesocarp fibre pellets. As such, it can be deduced that existence of higher moisture content in sago starch significantly affects the amount of energy emitted during the combustion of the pellets. In term of comparison to other densified biomass fuel, all produced pellets in this study exhibits higher calorific values as compare to oil palm fibre and shell briquette conducted by previous researchers but approximately 7% and 13% lower than normal wood and pine wood pellet respectively.

Table 4 Pellet Calorific Values

Pellets (Blending ratio)	**Calorific value, kJ/kg**
Oil Palm EFB [7]	8160
100% Pulverized EFB	17000
Pulverized EFB + Sago starch (90:10)	16860
Pulverized EFB + Sago starch (95+5)	16890
Pulverized EFB + Mesocarp (90+10)	16880
Pulverized EFB + Mesocarp + sago (80+10+10)	16850
Pulverized EFB + Mesocarp +sago (85+10+5)	16855
Oil Palm Fibre and Shell Briquette[8]	16380
Normal Wood Pellet [9]	18000
Pine wood Pellet [9]	19300

4. Conclusion

The addition of sago starch into the pulverised raw material prior to pelletisation is observed to improve the physical characteristics of pulverised EFB and Pulverised EFB + mesocarp fibre pellets. This will undoubtedly reduce the breakage and generation of fines during the handling and transporting of pellets from production plant to power plant. This is also confirmed by the amount of fines experimental testing in this study. Conversely, due to higher moisture content of sago starch use in this study, the produced pellets with addition of sago starch are found to have higher moisture content in which all the produce pellet have moisture content higher than 10% (w -% of dry basis) as specified by European Standard for pellet [6]. As such, it is recommended that the raw material for pelletisation, as in this case EFB and mesocarp fibre, to be sufficiently dried prior to pelletisation as to compensate the high moisture content in wet sago starch in order to produce pellets comply with international standard. Such measure will also improve the calorific value of the produced pellets as the study found that higher addition percentage of sago starch reduces the calorific value of the produced pellets. Therefore, it can be concluded that addition of sago starch into the raw pelletisation material will improve the physical structure of the produced pellet. However, the optimum percentage of sago addition needs to be determined prior to pelletisation process as excessive addition of sago starch increases pellet moisture content. High moisture content reduces the combustion characteristics of the pellets especially on the reduction of calorific value and the increase of ash content.

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