Characteristics of Palm Oil Solid Waste and Its Potency for Bio-Oil Raw Material

Rusdianasari Rusdianasari [1,*] Leila Kalsum[1], Nelly Masnila[2], Leila Utarina[1]

Daya Wulandari[1]

[1] *Department of Renewable Energy Engineering, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar Palembang, 30139, Indonesia*·
[2] *Department of Public Sector Accounting, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar Palembang, 30139, Indonesia*·
Corresponding author. Email: rusdianasari@polsri.ac.id

ABSTRACT
The qualities of the raw materials utilized have a significant impact on the features of vegetable oil-based fuel products. The goal of this study is to find out what features palm oil solid waste has as a raw material for bio-oil production. In this study, shell and Empty Fruit Bunch (EFB) waste are compared to earlier research. The proximate analysis was carried out on a Carbolite Furnace, and the ultimate analysis on a Lecco CHN628 instrument, both in accordance with the ASTM test method. The findings of the typical tests reveal that the lower the O/C and H/C ratios, the higher the calorific value of a certain fuel, and vice versa. Palm oil solid waste has the potential to be employed as a raw material in the manufacturing of bio-oil, according to both ultimate and proximate studies.

Keywords: *Bio-Oil, EFB, Palm Oil, Shell*

1. INTRODUCTION

The number of fuel consumption recently from gasoline, kerosene, and also diesel are increasing. Data from the Ministry of Energy and Mineral Resources states that oil production in Indonesia is currently 55 million tons, where this production is estimated to only be able to meet Indonesia's fuel oil needs for the next 10 years [1][2]. Along with the lowering in oil production, national oil exploration activities encourage the research for alternative fuels as a substitute for petroleum-based energy supplies. The majority of the energy sources used in the world today are non-renewable natural resources, specifically fossil fuels in the form of oil and natural gas, with petroleum being widely used as a fuel in the power generation and transportation sectors. Bio-oil production is one of promising process to reduce dependence on fossil fuels [3][4].

Bio-oil is a type of fuel oil made from different organic oxygenate compounds and does not mix with fuel oils in general. They are called emulsions because of the high water content, which is around 15–20 percent and also serves as a binder for hundreds of distinct molecules [5][6]. Bio-oil can be used for household heating, boiler fuel, or direct drying fuel, and when filtered or improved, it becomes a purer and higher calorie fuel that can be utilized for a variety of chemical industry demands, including petroleum fuel. Bio-oil is made from vegetable materials, especially from lignocellulosic materials, such as biomass from forestry waste, forest products industry, and agriculture [7][8].

There are many different types of vegetable oil-producing plants that can be utilized as raw materials for bio-oil with lignocellulosic content. However, these requirements frequently conflict with the community's production and food requirements. As a result, selecting raw materials for bio-oil is critical in order to avoid demand distortions between food and bio-energy needs. In Indonesia, several vegetable oil-producing plants are grown, one of which is palm oil. As is well known, the expansion of the palm oil region in Indonesia has tended to increase since the 1980s [9][10]. With an area of 1.22 million hectares and a plantation area capable of producing roughly 4.3 million tons of CPO, South Sumatra is one of Indonesia's top six largest oil palm plantations provinces. [11][12].

The palm oil industry produces waste every day consisting of liquid waste in the form of sludge oil and solid trash in the form of empty palm fruit bunches, fibers, and palm shells. Each ton of EFB (Empty Fruit

Bunches) will yield 22–23 percent, or roughly 220–230 kg of empty bunches, 6.5 percent, or 65 kg of shell waste, and 13 percent, or 130 kg of coir, from each process. There will be 23 tons of EFB produced in the palm oil sector with a processing capacity of 100 tons/hour and a 1 hour operation time.. However, so far the waste usually used as animal feed or boiler fuel. Utilization of this type of palm oil waste is constrained by processing technology that is relatively inexpensive in preparing materials and requires a process to reduce the water content which is still quite high, even though the lignocellulose content of both shells and EFB is quite high, namely cellulose (41-46.5%), hemicellulose (25.3-33.8%), and lignin (27.6-32.5%) [13][14]. Based on these chemical components, both shells and EFB have the potential as raw materials for making biofuels through the pyrolysis process.

This study aims to determine the proximate and ultimate characteristics of palm oil solid waste and compare it with previous research that also has the potential as raw material for bio-oil production.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this research are Palm Kernel Shell (PKS) and EFB. Both PKS and EFB was obtained from one of plantation in South Sumatera, Indonesia.

2.2. Methods

2.2.1. Sample Preparation

Each PKS and EFB were weighed as much as 100 grams, then washed and dried under the direct sunlight. After drying process, the sample which is still in the form of chunks is crushed first using a Hammer Crusher to make it smaller. Furthermore, PKS and EFB were ground using a Raymond Mill tool to a size of 0.25 mm. Samples were stored in bottles and labeled. Further will be analyzed according to their functions at PT Carsurin.

(a) (b)

Figure 1 PKS in form of (a) chunks and (b) smaller pieces

Figure 2 EFB (a) before size reducing and (b) after size reducing

2.2.2. Proximate analysis

2.2.2.1. Moisture

Empty crucible is weighed and recorded, then 1 gram of the sample is put into the crucible. After that, the crucible containing the sample is put into a furnace at a temperature of 104-110 ^{0}C for 1 hour. After reaching 1 hour, the crucible was removed and cooled in a desiccator for 10 minutes. Then proceed to the crucible weighing stage and the result is recorded to calculate the data analysis with the formula:

$$IM = \frac{m2-m3}{m2-m1}\ x\ 100\ \% \tag{1}$$

Note:
IM: Inherent Moisture
m1: Empty Crucible + Cover
m2: Empty Crucible + Cover + Sample
m3: Empty Crucible + Cover + Sample (From the Furnace)

2.2.2.2. Ash Content

Empty crucible is weighed and recorded, then 1 gram of the sample is put into the crucible. After that, crucible containing the sample was put into a furnace at a temperature of 500 ^{0}C for 1 hour. After reaching 1 hour, the temperature was raised to 750 ^{0}C for 1 hour. After the heating process is complete, the crucible is removed and cooled. Then proceed to the weighing stage which crucible containing the ash was weighed and the results are recorded to be calculated for the analysis data using the formula:

$$ASH = \frac{m3-m1}{m2-m1}\ x\ 100\ \% \tag{2}$$

Note:
Ash : Ash Content
m1 : Empty Crusible
m2 : Empty Crusible + Sample
m3 : Empty Crusible +Residu (From the Furnace)

2.2.2.3. Volatile Matter

Empty platinum crucible is weighed and recorded, then 1 gram of the sample is put into the platinum crucible. After that, platinum crucible containing the sample was put into a furnace at a temperature of 950 ^{0}C for 7 minutes. After reaching 2-3 minutes make sure that the platinum crucible is tightly closed. After heated for 7 minutes, the platinum crucible was removed and cooled in a desiccator. Then proceed to the weighing stage of the platinum crucible containing ash, and the results are recorded for calculation of the analysis data using the formula:

$$VM = \frac{m2-m3}{m2-m1} \, x \, 100\,\% \qquad (3)$$

Keterangan:
VM: Volatile Matter
m1 : Empty Platinum Crusible + Cover
m2 : Empty Platinum Crusible + Cover + Sample
m3 : Empty Platinum Crusible + Cover +Residu (From the Furnace)

2.2.2.4. Fixed Carbon

After the inherent moisture, ash content, and volatile matter have been obtained, the final calculation in the proximate analysis is to calculate the fixed carbon. Fixed Carbon cannot be calculated by direct testing in the laboratory, but by subtracting its impurity content, namely water content, ash content, and volatile matter with the formula:

$$\%FC = 100\% - (IM+ASH+VM)\ 100\% \qquad (4)$$

2.2.2.5. Calorific Value

Each sample was weighed as much as 1 gram into a crucible, then put into a combustion vessel and then filled the bomb with oxygen gas to 2-3 mPa. The combustion vessel is placed into the bomb bucket, then close the bucket cover and the sample is analyzed using a Caloric Value Isoperbol tool. After the sample is burned, the caloric value will automatically appear on the monitor.

2.2.3. Ultimate analysis

2.2.3.1. Carbon, Nitrogen, and Hydrogen

The sample is weighed as much as 0.1 grams into tin foil, then the tin foil containing the sample is folded in a circle and then inserted into the Carousel, input the weight and sample ID on the Leco CHN628 instrument, then click "Analyze". The graph and analysis results will automatically appear on the monitor screen.

2.2.3.2. Sulfur

The sample is weighed as much as 0.2 grams into the crucible boat, then inserted into the Leco S832 instrument, input the weight and sample ID on the monitor screen, then click "Analyze". the graph and analysis results will automatically appear on the monitor screen.

3. RESULT AND DISCUSSION

The suitability of biomass as a fuel is influenced by moisture content, the material included (C, H, N, S, and O), volatile matter, and ash concentration [15]. The gravimetric method is used to determine the water content, volatile matter, ash content, and fixed carbon in proximate analysis. The final goal of EFB was to determine the percentage of carbon, hydrogen nitrogen, and oxygen in the shells, and the Leco CHN628 device was used to do it. The Parr 6200 Bomb Calorimeter was used to determine the calorific value of raw materials.

fuel classification is fundamental in determining its characteristics. Fuels can be divided into several groups that have the same properties regardless of their type and origin. Therefore, when biomass is considered for pyrolysis or other thermochemical conversions, its classification can be traced, then from these characteristics, we can assess its conversion potential [16].

Both PKS and EFB should be dried before further examination. The drying procedure is required for the next phase, which is to reduce the sample size using hammer mill tools. Table 1 and Table 2 show the results of the ultimate-proximate analysis and the calorific value of the shells and EFB of palm oil employed in this study in comparison to numerous other studies. Tables 1 and 2 are a comparison table of the findings of the investigation of PKS and EFB characteristics with the attributes of the same material collected from some literature. The literature was chosen based on a similar characteristic test of PKS and EFB, which would be employed as raw materials in the pyrolysis step to produce Bio-oil.

The atomic ratios of O/C and H/C obtained from the ultimate analysis can be used to show the amount of calorific value that can be used for certain fuels. The smaller the O/C and H/C, the more significant the calorific value in particular fuel, and vice versa. The results showed that the shell had a C content of 47.53%, and H content of 5.11%, and an O content of 36.14%. When viewed from the comparison in table 1, the ratio of C, H, and O in the shell research results is still in the range of C, H, and O ratios in the comparative literature. This shows that the ratio of O/C and H/C atoms owned by the shell is suitable for use as raw material for Bio-Oil. Likewise, the research results on TKKS are still within the range of ratios in the comparative literature. The C level in EFB is 54.5%, the H content is 5%, and the O content is 16.27%. The shell has a higher O and H ratio compared to EFB. Meanwhile, EFB has a higher C ratio than the shell.

Table 1. Results of Shell Analysis and Comparative Literature

Content	Unit	Method	Results	Comparative Literature			
				A	B	C	D
Proximate Analysis							
Moisture	%	ASTM D 3173-17a	19.58	-	3.87	11.9	6.3
Ash Content	%	ASTM D 3174-12	2.75	11.08	7.06	3.4	11.8
Volatile Matter	%	ASTM D 3175-18	69.78	73.77	72.34	66.8	62.8
Fixed Carbon	%	ASTM D 3172-13	19.37	15.15	20.61	17.9	19.1
Gross Calorific Value	MJ/kg	ASTM D 5865-13	19.20	16.3	19.15	15.89	17.02
Net Calorific Value	MJ/kg	ASTM D 5865-13	17.56				
Ultimate Analysis							
Carbon (C)	%	ASTM D 5373-16	47.53	48.68	68.45	55.82	46.7
Hydrogen (H)	%	ASTM D 5373-16	5.11	4.77	9.52	5.62	5.9
Nitrogen (N)	%	ASTM D 5373-16	0.32	1.17	0.2	0.84	1
Potassium (K)	%	ASTM D 3682-13	3.64	-	-	-	-
Sulfur (S)	%	ASTM D 4239-18e1	0.05	0.2	0.74	-	0.06
Oxygen (O)	%	ASTM D 3176-15	36.14	45.27	20.99	37.73	42

^{A} Idris et al (2012) [17] ,^{B} Raju(2016) [18], ^{C} Lee *et al* (2013) [19], ^{D} Ahmad (2014) [20]

Table 2. EFB Analysis Results and Comparative Literature

Content	Unit	Method	Results	Comparative Literature			
				E	F	G	H
Proximate Analysis							
Moisture	%	ASTM D 3173-17a	13.66	6,17	7,95	-	5.18
Ash Content	%	ASTM D 3174-12	8.74	5,80	5,36	3,11	3.45
Volatile Matter	%	ASTM D 3175-18	58.66	76,09	83,86	81,9	82.58
Fixed Carbon	%	ASTM D 3172-13	18.90	18,15	10,78	12,6	8.79
Gross Calorific Value	MJ/kg	ASTM D 5865-13	15.49	18,72	17,08	-	17.02
Net Calorific Value	MJ/kg	ASTM D 5865-13	12.44				
Ultimate Analysis							
Carbon (C)	%	ASTM D 5373-16	54.45	66.17	49,07	53.78	46.62
Hydrogen (H)	%	ASTM D 5373-16	5.00	9.54	6,48	4.37	6.45
Nitrogen (N)	%	ASTM D 5373-16	1.83	1.51	0,7	0.35	1.21
Potassium (K)	%	ASTM D 3682-13	0	-	-	-	-
Sulfur (S)	%	ASTM D 4239-18e1	0.05	0.06	0,10	0	0.04
Oxygen (O)	%	ASTM D 3176-15	16.27	22.72	38,29	41.5	45.7

^{E} Raju (2016) [18], ^{F} Yang *et al* (2006) [21], ^{G} Abdulah and Gerhauser (2008) [22], ^{H} Mohammed (2012) [23]

Proximate analysis is used as an indicator to show how well the biomass is converted into energy. The greater the ratio between fixed carbon and volatile matter, the more it can release chemical energy [8]. Based on the research results, the shell has a fixed carbon value of 19.37% and a volatile matter value of 69.78%. Both are still included in the range of research results from the comparative literature. As for the EFB, the volatile matter value it has is 58.66%, where this value is relatively small and outside the range of research results in the comparative literature. Then for the fixed carbon value owned by EFB itself is 18.90%, where this value is slightly larger than the range found in other studies. This means EFB itself is not necessarily unable to release chemical energy.

Based on the comparison in Tables 1 and 2, it can be seen that the %moisture in the shell and EFB is greater than the %moisture in the comparative literature. The range of shell moisture % obtained from the literature ranged from 3.87 to 11.9, while the EFB moisture % ranged from 5.18-7.95. The research shell had %moisture 19.58, and the EFB from the study had %moisture of 13.66. This is because the drying process on the material has not run perfectly. High moisture content can hamper the pyrolysis process due to the presence of moisture in the raw material. Then for the ash content, the shell has an ash content of 2.75%, where this value is relatively minimal compared to the amount of ash content found in other studies, namely 3.4% - 11.8%. As for EFB, the ash content is 8.74%, where this value is relatively more significant than other studies, namely 3.11%-5.8%. Moisture content and ash content are two parameters that are detrimental to fuel quality. High moisture content reduces the calorific value of fuel, while high ash content can increase operating costs [24].

For the calorific value, the results showed that the calorific value of PKS 19.20 MJ/kg and EFB 15.49 MJ/kg were among the values in the comparison literature due to the high percentage of C atoms contained in them. This shows that PKS and EFB have good combustion capabilities, so that they are suitable for use as raw materials for making Bio-oil through the pyrolysis stage.

4. CONCLUSION

From the results of proximate and ultimate analysis, it is seen that most of PKS and EFB consist of volatile materials. With high levels of volatile materials, it is hoped that large quantities of gas and liquid from the pyrolysis process can be obtained. The carbon and oxygen content in the PKS are greater than the EFB, this indicates that the bio-oil from the PKS during pyrolysis will have more oxygen levels than the EFB. The sulphur content in the PKS and EFB is the same, namely 0.05 according to fuel standards below 1-2%, so the bio-oil produced will be environmentally friendly. Meanwhile, the calorific value of the PKS is greater, namely 19.20 MJ/kg and EFB 15.49 MJ/kg. This shows that PKS have a greater heat than EFB. Both PKS and EFB of palm oil have the potential to produce bio-oil through the pyrolysis process.

AUTHORS' CONTRIBUTIONS

Rusdianasari participated in the conception and design of the study. Leila Kalsum and Nelly Masnila contribute in manuscript preparation. Leila Utarina analyzed the data and wrote the paper. Daya Wulandari conducted the experiments and calculated the data. All authors read the manuscript, contributed to manuscript changes, accepted the final version of the work, and agreed to be held responsible for its content.

ACKNOWLEDGMENTS

This research would never be possible without the support of many parties, such as the supervisor and also PT. Carsurin, therefore the expression of gratitude goes to them. Although without reducing the gratitude to other parties who cannot be mentioned one by one.

REFERENCES

[1] R Ploetz, R Rusdianasari, E Eviliana, Renewable Energy: Advantages and Disadvantages Proceeding Forum in Research, Science, and Technology (FIRST), pp. E1-E4, 2016.

[2] Sukiran, Mohamad Azri, Soh Kheang, Bakar, Nasrin Abu. Production of bio-oil from fast pyrolysis of oil palm biomass using fluidised bed reactor. J. Energy Technol. Policy, 2016, 6: 52-62.

[3] Terry, L. M., Li, C., Chew, J. J., Aqsha, A., How, B. S., Loy, A. C. M., and Sunarso, J. Bio-oil production from pyrolysis of oil palm biomass and the upgrading technologies: A review. Carbon Resources Conversion. 2021.

[4] Alias, Amirah Farhana, et al. Simulation of co-processing bio-oil and vgo in fluid catalytic cracking units. Platform: A Journal of Engineering, 2020, 4.1: 12-19.

[5] Vasu, Harvindran, Insight into Co-pyrolysis of palm kernel shell (PKS) with palm oil sludge (POS): effect on bio-oil yield and properties. Waste and Biomass Valorization, 11.11: 2020, pp. 5877-5889.

[6] Chan, Y. H., Yusup, S., Quitain, A. T., Tan, R. R., Sasaki, M., Lam, H. L., & Uemura, Y. Effect of process parameters on hydrothermal liquefaction of oil palm biomass for bio-oil production and its life cycle assessment. Energy Conversion and Management, 104, 2015. pp. 180-188.

[7] Mohammed, M.A.A, Salmiaton, A, Azlina, WAKGW & Amran, MSM Gasification of oil palm empty fruit bunches : A characterization and kinetic study', Bioresource Technology, vol. 110, 2012.

[8] Asadieraghi, M., & Daud, W. M. A. W. In-depth investigation on thermochemical characteristics of palm oil biomasses as potential biofuel sources. Journal of analytical and applied pyrolysis, 115, 2015, pp. 379-391.

[9] Mohammed, M. A. A, Salmiaton, A, Azlina, WAKGW &Amran, MSM 2012, 'Gasification of oil palm empty fruit bunches : A characterization and kinetic study, Bioresource Technology, vol. 110

[10] Miyata, Y., Sagata, K., Hirose, M., Yamazaki, Y., Nishimura, A., Okuda, N. & Kita, Y. Fe-assisted hydrothermal liquefaction of lignocellulosic biomass for producing high-grade bio-oil. ACS Sustainable Chemistry & Engineering, 5(4), 2017, 3562-3569.

[11] Sangjan, A., Ngamsiri, P., Klomkliang, N., Wu, K. C. W., Matsagar, B. M., Ratchahat, S., & Sakdaronnarong, C. Effect of microwave-assisted wet torrefaction on liquefaction of biomass from palm oil and sugarcane wastes to bio-oil and carbon nanodots/nanoflakes by hydrothermolysis and solvothermolysis. Renewable Energy, 154, 2020, 1204-1217.

[12] S Yunsari, Rusdianasari, A Husaini, CPO Based Biodiesel Production using Microwaves Assisted Method, Journal of Physics: Conf. Series 1167(1) 012036, 2019

[13] Yim, S. C., Quitain, A. T., Yusup, S., Sasaki, M., Uemura, Y., & Kida, T. Metal oxide-catalyzed hydrothermal liquefaction of Malaysian oil palm biomass to bio-oil under supercritical condition. The Journal of Supercritical Fluids, 120, 2017, 384-394.

[14] Qarizada, D., Mohammadian, E., Alis, A. B., Yusuf, S. M., Dollah, A., Rahimi, H. A, & Azizi, M. Thermo Distillation and Characterization of Bio Oil from Fast Pyrolysis of Palm Kernel Shell (PKS). In Key Engineering Materials Vol. 797, 2019, pp. 359-364. Trans Tech Publications Ltd.

[15] Sukiran, M. A., Loh, S. K., & Bakar, N. A. Conversion of pre-treated oil palm empty fruit bunches into bio-oil and bio-char via fast pyrolysis. J. Oil Palm Res, 30(1), 2018, 121-129.

[16] Kasim, N. N., Ismail, K., Ishak, M. A. M., Ahmad, R., Mohamed, A. R., & Nawawi, W. I. (2016, November). Demineralization of oil palm empty fruit bunch (EFB) intended as a high quality bio-oil feedstock. In 4th IET Clean Energy and Technology Conference (CEAT 2016*)* (pp. 1-6). IET.

[17] Idris, R., Chong, W. W. F., Ali, A., Idris, S., Hasan, M. F., Ani, F. N., & Chong, C. T. Phenol-rich bio-oil derivation via microwave-induced fast pyrolysis of oil palm empty fruit bunch with activated carbon. Environmental Technology & Innovation, 21, 101291, 2021.

[18] S. Yunsari, A. Husaini, and Rusdianasari, Effect of Variation of Catalyst Concentration in the Producing of Biodiesel from Crude Palm Oil using Induction Heater, Asian Journal of Applied Research and Community Development and Empowerment, Vo. 3(1), pp. 24-27., 2019

[19] Idris, S.S., N.A. Rahman dan K. Ismail. Bioresource technology combustion characteristics of Malaysian oil palm biomass, sub-bituminous coal, and their respective blends via thermogravimetric analysis (TGA). Bioresource Technology Vol. 123:2012, 581–591.

[20] Raju, M., Tambunan, A. H., and Setiawan, R. P. A. Karakterisasi Arang dan Gas-gas Hasil Pirolisis Limbah Kelapa Sawit. Jurnal Keteknikan Pertanian, 4(2). 2016.

[21] Lee, Y., J. Park , C. Ryu, K.S. Gang, W. Yang, Y. Park dan S. Hyun. Bioresource technology comparison of biochar properties from biomass residues produced by slow pyrolysis at 500°C. Bioresource Technology Vol. 148:2013, 196–201

[22] Ahmad, R, Hamidin, N, Ali, UFM & Abidin, CZA, Characterization of bio- oil from palm kernel shell pyrolysis, Journal of Mechanical Engineering and Sciences (JMES), Univerity Putra Malaysia, vol. 7, no. December 2014, pp. 1134-40.

[23] Yang, H., R. Yan, H. Chen, D.H. Lee, D.T. Liang dan C. Zheng. Pyrolysis of palm oil wastes for enhanced production of hydrogen rich gases. Fuel Processing Technology Vol. 87: 2006, 935–942.

[24] Abdullah, N. and H. Gerhauser. Bio-oil derived from empty fruit bunches. Fuel Vol. 87: 2008, 2606–2613.