Analysis of the Characteristics of Palm Oil Trunk Waste as Co-firing Fuel for Power Plant

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Abstract. Indonesia palm oil plantations have an area 15.08 million hectares in 2021 which provide huge potential of biomass from replanting waste including palm oil trunks. This study aims to determine the characteristics of palm oil trunks and its potential for co-firing fuel with coal in power plant. The palm oil trunks were analyzed and evaluated by theoretical prediction calculation to find the risk potential of slagging, fouling, corrosion, abrasion, and agglomeration. AFT analysis result of the three parts of palm oil trunk samples were showed low values. It was due to the high SiO_2/Al_2O_3 and K_2O composition which made the ash melted easier. Furthermore, high K_2O and chlorine contents in palm oil trunks can accelerate the production of ash deposits in convection area, increase the risk of fouling, and enhance high thermal corrosion. In addition, there is also high risk of agglomeration from palm oil trunk due to high K_2O contents. Need to consider the coal characteristic for utilization of palm oil trunk as co-firing fuel to minimize the problem especially risk of corrosion and agglomeration.

Keywords: Palm · Oil · Waste · Fuel · Power Plant

1 Introduction

The target for the energy mix, new and renewable energy (NRE) of Indonesia in the general plan of national energy (RUEN) is 23% by 2025, including biomass use in the fuel sector [1]. One of the efforts to increase the percentage of NRE is cofiring biomass and coal in existing coal-fired power plants (CFPP) [2]. Co-firing can be carried out on all type of boilers, namely Stocker, Pulverized Coal (PC), and Circulated Fluidized Bed (CFB) [3]. Due to its lower sulfur and nitrogen content, biomass as renewable carbon source can be used as a fuel with fewer emissions than fossil fuels value [4, 5].

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In Indonesia, some biomass sources have not been fully utilized for NRE including palm oil trunks as waste from palm oil plantation. Based on data from the ministry of agriculture, the area of palm oil plantations in Indonesia reach 15.08 million hectares in 2021 spread over 26 province in Indonesia [6]. Palm oil trees over 25 years old will experience a decline in productivity and necessary to be replanted [7]. The replanting process will produce solid waste such as trunks, fronds, fruit fibers, and shells [8]. The average replanting area required to achieve the desired composition is 4% of the existing plantation area. So nationally, with an area of 15.08 million ha, there will be around 603,000 ha of oil palm land consider annually replanted [9, 10]. Assuming the number of oil palm trees is 100 trees per hectares, then there are 60.3 million trees to be replanted that produce waste including trunk. The potential energy contained in palm oil trunks is around 260,000 TJ/year [11]. With this potential, palm oil trunks can be utilized as biomass material for co-firing fuel.

Biomass usage as a coal blended in CFPP can cause ash deposition problems, including slagging and fouling, that can interfere with boiler performance [4]. In addition, biomass also has other challenges, such as type, age, growing conditions, physical properties, and chemical content, that will affect the characteristics [12]. High concentrations of Cl and alkali metals (K and Na) contained in palm oil biomass accelerate the ash deposition formed in the furnace and heat conduction walls, inhibiting heat exchange, and reducing efficiency boiler [13, 14]. The content of alkali metals and chlorine in biomass also increasing the corrosion potential [4]. Blending this type of biomass and certain type of coal can minimize the problems. However, analysis of characteristics of biomass from palm oil especially palm oil trunk before blending with coal is needed. Palm oil trunk converted to biochar has potential to be solid biofuel, but it still has the risk of low ash fusion [12]. Co-firing between palm oil trunk and sub- bituminous coal also improve the combustion efficiency and emission of CO2 and SO2 [15]. So far, there are few studies about utilization of Indonesian palm oil trunk as co-firing fuel which focused on slagging fouling problems. This study aims to determine the characteristics and potentials of palm oil trunks as co-firing fuel regarding ash deposition problems by theoretical prediction calculation. In this study, proximate analysis was carried out to determine the solid fuel content of the moisture, ash content, volatiles, and fixed carbon, while ultimate analysis was used to determine the organic elements of solid fuels, such as carbon, hydrogen, oxygen, nitrogen, and sulfur [16]. Furthermore, analysis of total chlorine, ash fusion temperature, and ash composition had been carried out [13].

2 Material and Method

2.1 Materials and Sampel Preparation

Figure 1 shows the material used in this study is a palm oil trunk with a length of 12–15 m over 25 years old. The samples were divided into three parts, the upper part (BA), middle part (BT), and lower part (BB) of trunk. The palm oil trunks obtained from Palm Oil Plantation in Serdang Bedagai, North Sumatra. Each part is chopped into small pieces for air-dried. Then crushed with mixer mill into powder form and sieved to obtain 60 mesh sample with 6–10% moisture content.

Fig. 1. (a) sample of the upper palm trunk (BA), (b) the middle palm trunk (BT), (c) the lower palm trunk (BB)

2.2 Characteristics Analysis

Characteristic of sample is analyzed with standard of coal. For proximate analysis is according to ASTM D3172-D3175. Total sulfur and total chlorine are according to ASTM D4239 and D4208. Analysis of ash content to determine composition in each part of the palm oil trunk is carried out according to ASTM D3682-2013 and ASTM D5016-2016 [17].

2.3 Ash Fusion Temperature

The ash fusion temperature (AFT) test method is based on ASTM D1857-2017. This method describes the ash's melting properties by measuring and observing the ash's form changes. The ash sample prepared in the form of a cone, 3/4" in height and 1/4" in width at each side of the equilateral triangle base, is then heated in a controlled combustion chamber. The changes of cone shape are observed and recorded during heating. The change in the shape of the cone is shown in Fig. 2. Based on this standard, there are four characteristics of the deformation temperature, such as Initial Deformation Temperature (IT, the temperature at which the cone peaks rounding off for each sample), Softening Temperature (ST, the temperature at which a cone transforms into a sphere whose height is equal to the width of the base), Hemispherical Temperature (HT, the temperature at which the cone has fused into a hemispherical lump that is half the height of the base width), and the Fluid Temperature (FT is the temperature at which the fused ash has dispersed to a maximum height of 1/16") [18].

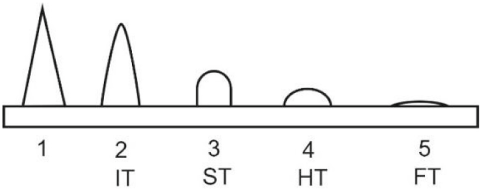

Fig. 2. Conditions of the cone in the analysis of ash melting temperature

2.4 Theoretical Prediction Calculation

Theoretical predictions can be calculated using general indices such as base acid ratio (B/A), silica ratio (Sr), slagging index (Fs), ash fusibility index (AFI), iron in ash (Fe), composite index (Rz), silica/aluminum (Si/Al), iron/calcium (Fe/Ca), fouling index (Ff), sodium in ash (Na), total alkali (Na + K), abrasion index (AI), chlorine in fuel (CI), sulfur/chlorine (S/CI), bed agglomeration index (BAI), alkali/sulfur chlorine (Na + K)/(2S + Cl), and alkali index (Alk). For each parameter, the risk criteria is shown at Table 1 quantified with score of 0.0 indicates low-risk, 0.50 indicates moderate-risk, and 1.0 indicates high-risk [26]. Slagging predictions using eight parameters, if value $<$3.5 categorized as low-risk, 3.5–5.0 as medium-risk, and $>$5.0 as high-risk. For fouling prediction with three parameters, if value $<$1.0 categorized as low-risk, 1.0–2.0 as medium-risk, and $>$2.0 as high-risk. For corrosion prediction $<$1.0 as low-risk, 1.0 as medium-risk, and $>$1.0 as high-risk. Abrasion uses only one prediction where if value is 0.0, shows low-risk, 0.5 medium-risk, and 1.0 then the risk is high. Furthermore, for the corrosion and agglomeration risk criteria, if the value is 0.0 then the risk is low, 0.5 the risk is medium, and if the value $>$0.5 the risk is high.

3 Result and Discussion

Table 2 show the characteristics of the palm oil trunk samples. Upper part of trunk has higher ash and SiO_2 content but lower sulfur, calorific value, and K_2O content than the middle and lower part. It shows how much different characteristics between each part of trunk that will affect in slagging and fouling tendency. The chemical composition of the sample with the tendency of the ash sample to produce slag consists of two types of oxides, namely basic oxides (Na_2O, CaO, Fe_2O_3, K_2O, and MgO) and acidic oxides (Al_2O_3, SiO_2, and TiO_2) [27]. High content of SiO_2 in each part of palm oil trunk may cause the problem of abrasion in preparation equipment or boiler wall. High K_2O content of palm oil trunks can produce low-melting compounds in form of sticking ash that accumulate on the heat-conducting walls, especially during reheating [28]. In addition, with high chlorine content it will enhance fouling and heat thermal corrosion. The corrosion rate caused will inhibit the heat exchange that occurs in the boiler process [13, 29]. Predictions of slagging, fouling, abrasion, corrosion, and agglomeration are calculated based on the results of the characteristic analysis in Table 2 with criteria from Table 1.

Table 1. Parameter, formula, and risk criteria of prediction calculation

Parameter	Formula	Risk Criteria			Ref
		LOW	MEDIUM	HIGH	
Slagging Indication					
B/A	$BA = Fe_2O_3 + CaO + MgO + Na2O + K_2OSiO_2 + AI_2O_3 + TiO_2$	<0.206	0.206–0.4	>0.4	[19]
Sr	$SiR = SiO_2SiO_2 + Fe_2O_3 + CaO + MgO \cdot 100$	>72	65–72	<65	[13]
Fs	$Rs = BA \cdot S$	<0.6	0.6–<2	2–<2.6	[19]
AFI	$TAFI = 4\ IT + HT5$	>1343	1343–>1232	1232–>1149	[16]
Fe		<8	8–<15	15–<23	[20]
Rz	$Rz = 1.24RB/A + 0.28RS/A - 0.0023ST - 0.019G + 5.4$	<1.5	1.5–2.5	>2.5	[19]
Si/Al		<0.7 or >3.5		0.7–3.5	[21]
Fe/Ca		<0.3 or >3.0		0.3–3.0	[22]
Fouling Indication					
Ff	$Rf = BANa_2O$	<0.2	<0.5	<1	[16]
Na		<2	2–6	6–8	[19]
Na + K		<2	2–3	3–4	[4]
Abrasion Indication	$AI = qc + 0.5pc + 0.2\ Ac$				
AI		<4	<8	<= 12.0	[20]
Corrosion Indication					
Cl		<0.3	0.3–0.5	> 0.5	[20]
S/Cl		>4	2–4	<2	[23]
Agglomeration Indication					
BAI	$(Fe_2O_3)/(Na_2O + K_2O)$	<0.15 or >0.15		>0.15	[24]
(Na + K)/(2S + Cl)		<0 or >		>0.1	[25]
Alk	$(Na_2O + K_2O)ArHHV$	<0.17 or >0.34		>0.34	[13]

Table 2. Result of characteristics sample analysis

Parameters	Unit	Basis	Sample		
			BA	**BT**	**BB**
Proximate					
Total Moisture	%	ar	63.04	65.22	57.94
Inherent Moisture	%	adb	12.25	19.95	11.66
Ash Content	%	adb	6.15	4.83	2.32
Volatile Matter	%	adb	64.77	60.62	70.91
Fixed Carbon	%	adb	3572	3395	3853
Ultimate					
Carbon	%	adb	40.21	37.1	42.21
Hydrogen	%	adb	5.00	4.55	5.22
Nitrogen	%	adb	1.89	0.55	0.26
Oxygen	%	adb	51.61	52.84	49,95
Sulphur	%	adb	0.14	0.13	0.04
Ash Analysis					
SiO_2	%	in ash	72.80	57.26	50.06
Al_2O_3	%	in ash	5.02	8.78	7.63
Fe_2O_3	%	in ash	1.08	4.61	4.85
CaO	%	in ash	4.46	7.37	10.00
MgO	%	in ash	3.82	7.69	11.16
TiO_2	%	in ash	0.05	0.12	0.09
Na_2O	%	in ash	0.18	0.19	0.19
K_2O	%	in ash	11.07	13.15	14.85
Mn_3O_4	%	in ash	0.16	0.27	0.35
P_2O_5	%	in ash	0.10	0.10	0.10
SO_3	%	in ash	0.18	0.18	0.21
Gross Calorific Value	kcal/kg	db	4071	4241	4362
Chlorine	ppm		4028	3849	4028

ar: as received; adb: air-dried based; db: dried based

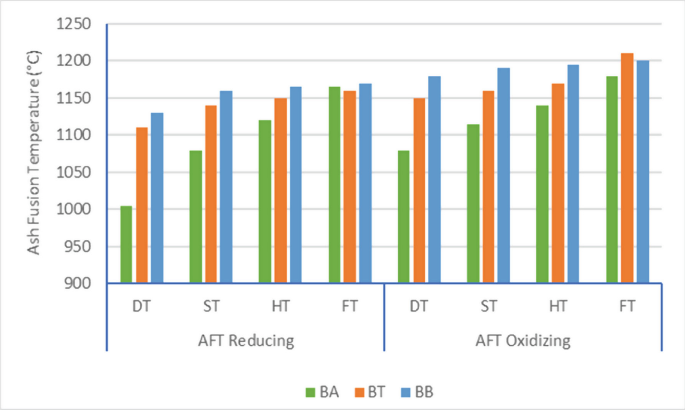

Fig. 3. Result of ash fusion temperature analysis of palm oil trunk

Figure 3 show the AFT reducing test conditions, the DT on the samples showed different values. The BA sample shows a lower temperature of 1005 °C, the BT is 1110 °C, and the BB sample shows the highest value of 1130 °C. ST is a key parameters because at this temperature the melting of ash occurs [30]. The melting of ash in the BA sample occurred at a temperature of 1080 °C lower than in other samples, while the BB sample was the highest at 1160 °C. Overall, palm oil trunk samples have low ash fusion temperature. This condition might be caused by content of ash in samples [21]. According to research [31] a high SiO_2/Al_2O_3 will reduce the AFT value. High content of SO_2 also contribute low temperature on IT value [21, 32]. K_2O also tend to form low-melting ash that affect low temperature of IT [31, 33]. Chlorine also directly affect the low AFT value because it facilitate alkali compound to form low eutectic compound with silicate that reduce AFT value sharply [24].

BA, BT, and BB sample belongs to lignite ash type because it has more Fe_2O_3 content than CaO and MgO. Based on Table 3, the slagging indication of the BA and BT sample has a medium risk of the B/A ratio parameter, while BB samples have high values. The fusibility and composite index parameters in all samples were high due to the high SiO_2 content. Overall, the slagging potential of BA and BT is medium-risk while BB has high-risk. Fouling potential in all samples are high, this is due to the high content of K_2O that affect total alkali parameter [34]. Chlorine content and S/Cl which relatively high have tendency to causes high temperature corrosion and accelerate the ash deposit. The abrasion index in each sample did not show a high value due to the low ash content and total sulfur. Regarding agglomeration, the bad agglomeration index and alkali index show high values in all samples due to the high K_2O content.

Table 3. Result of prediction calculation

Parameters		BA	BT	BB
Slagging Indication				
B/A	calc	0.26	0.50	0.71
S/r	calc	88.61	74.43	65.81
AFI	calc	1032	1122	1143
Rz	calc	5.62	3.81	4.20
Fs	calc	0.04	0.07	0.03
Fe	calc	1.08	4.61	4.85
Si/Al	calc	14.50	6.52	6.56
Fe/Ca	calc	0.24	0.63	0.49
Score		4.0	4.5	5.0
Criteria		Medium	Medium	High
Fouling Indication				
Ff	calc	0.05	0.09	0.13
Na	calc	0.18	0.19	0.19
Na+K	calc	11.25	13.34	15.04
Score		1.0	1.0	1.0
Criteria		Medium	Medium	Medium
Abrasion Indication				
AI	calc	4.52	2.36	1.03
Score		0.5	0.0	0.0
Criteria		Medium	Low	Low
Corrosion Indication				
CI	calc	0.403	0.385	0.403
S/Cl	calc	0.29	0.26	0.09
Score		1.5	1.5	1.5
Criteria		High	High	High
Agglomeration Indication				
BAI	calc	0.10	0.35	0.32
(Na+K)/2S+CI)	calc	0.92	0.85	0.64
Alk	calc	0.41	0.36	0.19
Score		1.0	2.0	1.5
Criteria		High	High	High

4 Conclusion

The results of the analysis of the characteristics of the palm oil trunk can be used as the basis for early prediction of the risk of ash deposition problems. The results showed that the SiO_2, K_2O, chlorine content, and SiO_2/Al_2O_3 have high values. The high content of SiO_2 high value SiO_2/Al_2O_3 causes the AFT value to be low, especially in the IT parameter. The high K_2O content causes a medium-risk of fouling and high-risk agglomeration potential. The chlorine content showed a high value in the three samples that causes high-risk of corrosion potential. From this study, for utilization of palm oil trunk to be blended as co-firing fuel need to consider the coal characteristics to minimize the problem especially risk on corrosion and agglomeration.

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