Estimation of Particulate Emission Generation in Palm Oil Mill Boiler

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Abstract. The palm oil industries in Malaysia has been positively growth throughout the year, for it sustainable approach in terms of production and environmental protection. However, this industry also producing considerable amount of particulate emission from the process of burning its biomass waste of palm fibre and shell in the boiler. This study present a method to estimate the particulate emission that are being generated from the boiler. The method were done by analyzing the proximate analysis value of the ash content of palm fibre and shell found in this study. The particulate emission were physically collected from five palm oil mill boilers with boiler capacity ranging from 18-45 tonne/hour. The particulate stack fly ash was collected from the stack gas downstream of a multi-cyclones particulate arrestor according to the USEPA Method 17- Determination of particulate matter emissions from stationary sources. Meanwhile the sample of palm fibre and shell were collected to determine the proximate value. The estimation were then being further analyzed according to the particulate emission that were obtained by the real-stack sampling. In summary, the average moisture content, ash content, volatile matter and fixed carbon for palm shell found in this study are $19.3 \pm 5.7\%$, $2.79 \pm 2.2\%$, 74.3 ± 3.0, and 11.3 ± 4.3, respectively.). The average particulate concentration for these five mills is $2.2 \pm 0.9 g/Nm^3$ and the air pollution control requirement are between 64 and 96% with reference to Clean Air Regulations 2014 of $0.15 g/Nm^3$ which is very high to be achieve. It also can be estimated that 26% of the ash generated from the combustion of palm fibre and shell in palm oil mill boiler are being released at the stack.

1. Introduction

Biomass fuel from agricultural sector is recognized as having high potential to promote biomass residue to wealth. Five different biomass residues in Malaysia that contributes to this effort, including, forestry, rubber, cocoa, sugarcane and palm [1]. Biomass residue from palm oil production such as empty fruit brunch (EFB), fibre and shell have the highest potential in electricity generation compared to other biomass residue in the country such as coconut, paddy and sugarcane [2]. As interest in developing biomass conversion technology is rapid, detail characteristics on the combustion process of

biomass fuel towards emission generation are not well understood. The biomass fuels having wide range of characteristics with poor air pollution control system were identified as some of the factors influencing the particulate emissions during combustion.

A few studies have been done related to the particulate emission from the palm oil mill boiler. the average particle emission concentration obtained at stack was 5.84 ±1.88 g/Nm3 @ corrected to 7% oxygen from a 13,600 kg steam/hour palm oil mill boiler [3]. The study also found that 26% of the particulate matter with diameter less than 10 micron (PM_{10}) concentration is accounted by the finer size fraction of $PM_{2.5}$, which is not easily removed by the existing particulate control device such as the multi-cyclone. In 2009, it is estimated that an average of 51.67 g/s of dust load are being emitted from 417 palm oil mills in Malaysia, making the minimum removal efficiency by the multi-cyclone at 91%. The high particulate emission from palm oil mills are generated from incomplete combustion of the fuels, due to several factors, including high moisture content of the palm fibre and shell, improper mixing of the palm fibre and shell, lack of control in air feeding and air to fuel (A/F) [4]. In addition, ow efficiency of the multi-cyclone in the palm oil mills due to improper design, lack of quality control and also poor maintenance from the millers [5].

In this regard, this study present a method to estimate the particulate emission generated from palm fibre and shell combustion in palm oil mill boiler, based on the ash content and the amount of fuel being burned. This estimation can further predict the stack particulate emission that are being released to the environment.

2. Materials & Methods

2.1. Palm Fibre & Shell Sampling

Figure 1 shows a typical schematic diagram arrangement of the boiler, multi-cyclone and stack of a mill where palm fibre and shell (F&S) are burned in the boiler at a certain ratio. Bottom ash were collected at the bottom of the boiler. Meanwhile, coarse particles collected at the hopper of multi-cyclone, known as retained fly ash and the fine particulates leaving the stack known as stack fly ash were sampled. The bottom ash and retained fly ash were grab sampled on hourly basis for a period of five hours on cumulative basis. Meanwhile, the stack fly ash and gases emission sampling was carried out at the stack sampling port. The sampling method is briefly discussed in the following section.
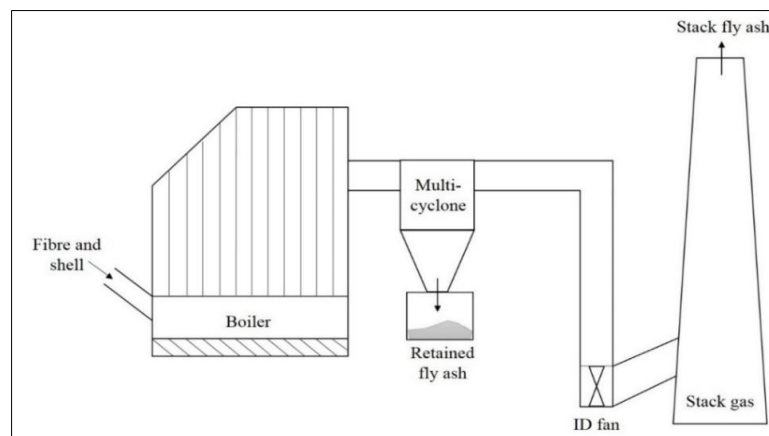

Figure 1. The schematic diagram of the boiler, multi-cyclone, and stack gas in the palm oil mill plan.

2.2. Palm Oil Mill Boiler Characterization

Table 1 summarizes the characteristics of the selected palm oil mills and their boiler operating conditions. Boiler C has the oldest boiler manufactured at 1983 while Boiler D and E operating with boiler manufactured at 2009. In terms of boiler rated steam capacity, Boiler B and D has the largest

steam capacity of 45,000kg/hr while Boiler A has the lowest steam capacity of 25,000kg/hr. Meanwhile, the mills running at different steam capacity varies from 17,000kg/hr (Boiler C) to 35,000kg/hr (Boiler D). The boiler is operating on average temperature of 231^0C and pressure of 303psi. Boiler B processed the largest amount of FFB per boiler at 54,000kg/hr while Boiler A and C processed the lowest amount of FFB per boiler at 40,000kg/hr. Most of the mills burned the F&S at 80:20 ratio with the F&S feeding varies from 6,000-12,000kg/hr. All boilers were equipped with multi-cyclone as their particulate arrestor.

Table 1. Characteristics of five palm oil mill boilers and their operating conditions

Boiler	**A**	**B**	**C**	**D**	**E**
Boiler manufactured year	2004	2002	1983	2009	2009
Boiler rated steam capacity (t/hr)	25	45	18	45	40
Boiler actual steam capacity (t/hr)	24	26	17	35	30
Boiler steam outlet temperature (^{o}C)	247	247	215	215	215
Boiler pressure (psi)	300	310	300	312	300
FFB processed per boiler (t/hr)	30	54	30	45	40
F&S feeding (t/hr)	8	9	6	12	10
Ratio of F&S	80:20	70:30	80:20	80:20	80:20
Air pollution control system	Multi-cyclone	Multi-cyclone	Multi-cyclone	Multi-cyclone	Multi-cyclone

2.3. Particulate Emission Sampling

The particulate emission sampling was performed at the sampling port in the stack gas downstream of a multiple-cyclones particulate arrestor. Figure 2 presents the particulate sampling train set up that follow the standard USEPA Method 17- Determination of particulate matter emissions from stationary sources were used in this study. Appropriate nozzle sizes were determined in order to get an isokinetic sampling. Set of impingers in ice bath container were used to place the distilled water and silica gel. The probe and the impingers were connected to the isokinetic control console using umbilical cable. The isokinetic control console display the measurement of parameters such as temperature, pressure drop, and air volume. The sampling time was taken on average of 40 minutes for each sample. Glass microfibre thimble canister were used as a collection medium due to its ability to stand for high temperature. The thimble was stored in a desiccator and weighed gravimetrically before and after samplings.

The sampling was carried out isokinetically, where the velocity of the particulate's extraction equal to the actual velocity of the stack gas in the duct within 90-110 % difference. This is to ensure the collected particulate concentration represent the actual condition in the duct. The percent isokinetic sampling rate was calculated using Equation 1.

$$\% \, I = \frac{100 \, T_s \left[K \, V_{wc} + \left(\frac{V_m}{T_m} \right) \left(P_{bar} + \frac{\Delta H}{13.6} \right) \right]}{60 \, P_s \, V_s \, A_n \, t} \tag{1}$$

Where; % I   = Isokinetic percent, 90-110%

T_s = absolute stack gas temperature, ^{o}K

K   = constant, 0.003454

V_{wc} = volume of water collected, m^3

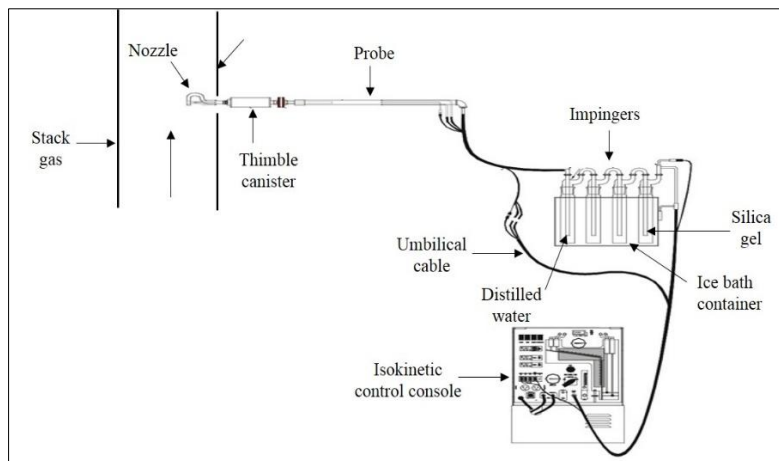|	
V_m	= dry gas volume sampled, m^3
T_m	= metered temperature, $^o K$
P_{bar}	= barometric pressure, 760 mmHg
P_s	= absolute stack gas pressure, mmHg
ΔH	= pressure drop across orifice meter, mmH_2O
A_n	= area of nozzle used, m^2
V_s	= stack gas velocity, m/s
t	= sampling time, min

Figure 2. US EPA Method 17 sampling train layout.

2.4. Proximate Analysis
Proximate analysis were done for palm F&S samples from all five mills. The analysis includes, moisture content, volatile matter, ash content and fixed carbon were repeated three times, each. All result were reported in percentage. Moisture content of the palm F&S were was determined according to the methods specified in ASTME871-82(2006), "Standard Method for Moisture Analysis of Particulate Wood Fuels". Volatile matter were determined according to ASTMD872 (2013), "Standard Test Method for Volatile Matter in the Analysis of Particulate Wood Fuels". Ash content were determined according to ASTME1755-01 (2007) "Standard Test Method for Ash in Biomass". Fixed carbon were calculated based on Equation 2.

$$Fixed\ Carbon(\%) = 100 - (Moisture + Volatile\ Matter + Ash) \qquad (2)$$

3. Results & Discussion

3.1. Proximate Analysis of Palm Fibre and Shell
Table 2 presents the proximate analysis for palm fibre and shell from five different palm oil mills, obtained in this study compare to the literature, which showed that the average moisture content, ash content, volatile matter and fixed carbon for palm fibre found in this study are 40.3 ± 21.6 %, 6.8 ± 6.8 %, 49.8 ± 24.5, and 3.6 ± 3.9, respectively Three samples of palm fibre and shell from each palm oil mills were analysed for their proximate component as received in order to get the average value. Meanwhile the average moisture content, ash content, volatile matter and fixed carbon for palm shell found in this study are 19.3 ± 5.7%, 2.79 ± 2.2%, 74.3 ± 3.0, and 11.3 ± 4.3, respectively. For a comparison purpose, proximate analysis of palm fibre and shell from five different literature were added in Table 2, which showed the moisture content of palm fibre and shell obtained from this study is slightly higher than reported in the literatures. Meanwhile, the other proximate component of ash content, volatile matter and fixed carbon, showed a closed figure with the average value obtained in the study.

It can be seen that each proximate component diverse in a wide range of value. Generally, the palm fibre has higher moisture content and ash content compared to the palm shell. Meanwhile, the volatile matter for both material is high, compared to other proximate components. In this study, the five palm oil mill boilers are processing the FFB from different plantation, which harvested at different time. Based on the sampling date information in Table 2, the samples of palm F&S for Boiler A and B were taken in June 2014, meanwhile, for Boiler C, D and E, the samples were taken in September 2014. This could influence the wide range of palm F&S characteristics, especially the moisture content.

Table 2. The proximate analysis of palm fibre and shell from five different palm oil mills (as received) and from the literatures (% by mass)

Boilers	Moisture Content	Ash Content	Volatile Matter	Fixed Carbon
		Palm Fibre		
A	55.8	5.9	36.8	1.5
B	39.4	5.3	55.0	2.7
C	36.9	7.9	49.9	5.3
D	22.7	7.8	62.5	7.0
E	46.5	6.9	45.1	1.6
Ranges	39.4-55.8	5.3-7.9	36.8-62.5	1.5-7.0
[6]	13.9	3.6	84.8	11.6
[7]	24.0	5.8	78.0	-
[8]	5.2	4.8	75.1	14.9
[9]	6.6	5.0	76.0	12.4
[10]	5.0	11.8	79.0	9.3
Boilers		**Palm Shell**		
A	21.9	7.4	60.0	10.6
B	29.9	1.1	59.5	9.6
C	15.4	0.6	71.7	12.4
D	17.7	2.1	72.4	7.8
E	11.6	2.8	74.3	11.3
Ranges	1.6-29.9	0.6-7.4	59.5-74.3	7.8-12.4
[6]	12.2	1.9	79.2	18.8
[7]	11.0	5.0	74.0	10.0
[8]	8.5	2.6	73.2	15.7
[9]	5.7	2.2	73.7	18.4
[10]	8.4	4.6	75.4	20.0

3.2. Stack Particulate Emission

Table 3 shows the stack emission data obtained in this study where the stack gas temperature were found ranging from 248-286^{0}C and the stack gas volumetric flowrate varied between 22.2 and 38.3m^3/s. Meanwhile, the stack gas velocity varies from 15.4 to 17.2m/s. In addition, the stack gas moisture content varied between 4.3 between 7.0% and the oxygen and carbon dioxide concentration varies between 10.3-17.9% and 2.9-8.5%, respectively. The average particulate concentration for these five mills is 2.2±0.9g/Nm^3 and the air pollution control requirement are between 64 and 96% with reference to Clean Air Regulations 2014 of 0.15g/Nm^3 which is very high to be achieve.

3.3. Prediction of Stack Particulate Emission in Palm Oil Mill Boiler

Figure 3 shows the relationship of predicted particulate concentration released without control from the boiler and the palm fibre and shell mixture ratio. The estimation were done based on palm fibre and shell ash content of 6.8% and 2.8%, respectively, which were obtained from this study. In

addition, 15% of clinker formation in the boiler were assumed [11].Based from this graph, it is estimated more particulate are being generated as the amount of palm fibre that are being burned is increases due to the ash content of palm fibre is approximately three times higher than palm shell. This graph can also be used to estimate the percentage of ash released at the stack based on the total ash generated in the boiler. Based from this graph, is it estimated that Boiler A, B, C, D, and E released 26%, 23%, 5%, 45% and 29% stack fly ash from the total ash generated in the boiler. From this result it can be estimated that in average, 26% of ash that are generated in the boiler, were released at the stack of a palm oil mill boiler equipped with an air pollution control system.

Table 3. Stack emission data for five palm oil mill boilers

| Parameters	Boilers				
	A	**B**	**C**	**D**	**E**
Stack diameter (m)	1.5	1.5	1.5	1.7	1.7
Stack gas temperature (^{o}C)	268	286	264	248	252
Stack gas volumetric flow rate (m^3/s)	29.2	22.2	29.0	37.5	38.3
Stack gas velocity (m/s)	16.2	17.2	15.6	15.4	15.8
Moisture content (%v/v)	4.3	7.0	4.9	5.4	11.2
Oxygen concentration (%)	17.9	11.2	11.0	10.3	13.5
Carbon dioxide concentration (%)	2.9	8.5	7.3	7.9	6.7
Particulate concentration (g/Nm^3)*	0.5±0.2	1.3±0.0	0.3±0.1	2.9±0.5	1.4±0.1
Particulate concentration (g/Nm^3) @ 7%O_2	2.4±1.0	1.9±0.0	0.4±0.1	3.8±0.7	2.5±0.2
Particulate emission rate (g/s)	7.5±3.0	13.8±0.1	4.2±0.9	53.6±9.8	23.9±2.2
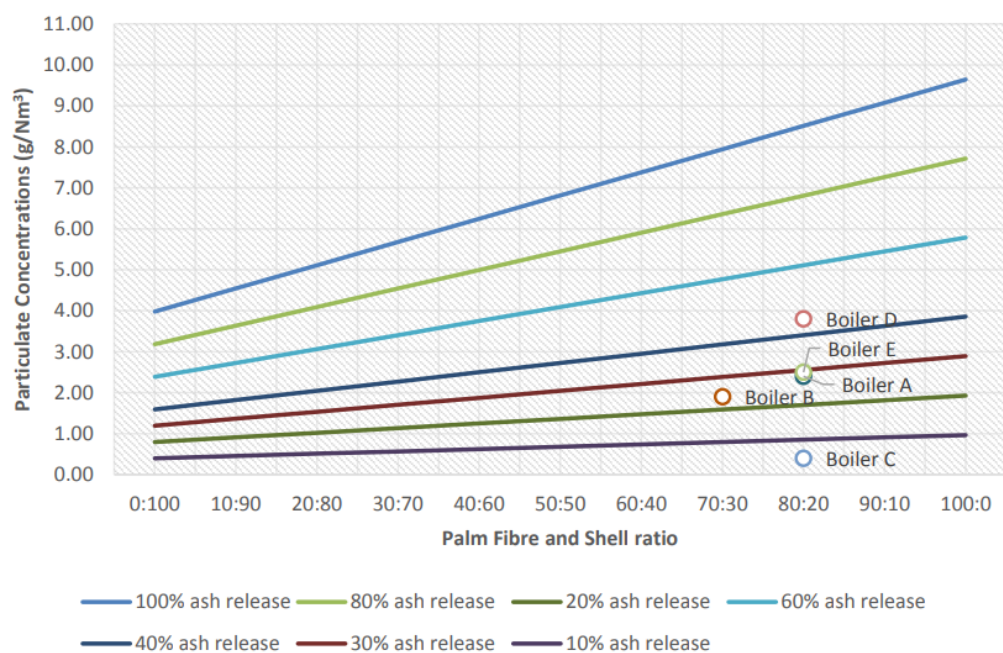
Figure 3 Relationship between estimated particulate concentrations (without control) and palm fibre and shell ratio.

4. Summary

The particulate emission from palm oil mill boilers were estimated based on the ash content of the palm fibre and shell found in this study. The result were further analysed with the particulate emission concentration obtained from the real stack emission sampling. It can be concluded that in average, 26% of ash that are generated in the boiler, were released at the stack of a palm oil mill boiler equipped with an APC system. This study would provide an estimate value of the particulate emission concentration at the stack of a palm oil mill boiler. Further recommendation in order to validate the estimation is by having a particulate emission sampling at the boiler, before the air pollution control system.

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