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Characterization of Total Particulate Emission for Palm Oil Mill Boiler

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In Malaysia, more than four million hectares of land is used for oil palm cultivation. Malaysia palm oil industry has grown to become a very important biomass-based industry. This study investigates the emission from a palm waste biomass fired boiler of two studied palm oil mill plants – named as Plant A and Plant B. The finding shows that the total particulate emission of Plant A is 4,242 mg/Nm^3- exceeding the emission limit specified by the Department of Environment Malaysia (DOE) by 960 %, while the average total particulate emission of Plant B was 851 mg/Nm^3 (exceeds the limit by 113 %). This study also performed more detailed measurements on the emissions of PM_{10} and $PM_{2.5}$ in Plant B. It was found that the emitted PM_{10} and $PM_{2.5}$ is not significant compared to the total particulate emission in this plant, since both are less than 20 % of the total particulate emission.

1. Introduction

Over the last forty years, palm oil industry in Malaysia has grown by leaps and bounds to become the second world's largest biomass producer and exporter of palm oil and its products, replacing Nigeria as the chief producer since early seventies before overtaken by Indonesia since year 2006 (Yusoff, 2006).In Malaysia, more than four million hectares of land is used for oil palm cultivation and it is the main contributor to biomass resources. Biomass is produced through photosynthesis as plants convert solar energy into chemical energy. The chemical energy in biomass can be extracted through combustion to produce energy that can be used as heat or power. Biomass represents an attractive source both for energy recovery and valuable chemicals obtaining (Popa and Volf, 2008). Basically, palm oil industry is divided into two main businesses, which are palm oil mill and palm oil refinery. Palm oil mill processes fresh fruit bunches (FFB) received from the oil palm plantations into crude palm oil (CPO) and other by-products. Two products, which are crude palm oil (CPO) and palm kernel, are produced in palm oil mill. Meanwhile, palm oil refinery process is to convert the crude oil to quality edible oil by removing impurities that are forbidden in most oil. The research work presented in this paper focuses on palm oil mill because in principle, the mill is more significant in causing environmental air pollution due to dark smoke emission with carry-over of soot and partially carbonised fibrous particulates emitted from the boiler. Generally in palm oil mills, fresh fruit bunch (FFB) of palm will go through several processes such as sterilization, stripping, oil extraction, clarification, nutfiber separation as well as kernel extraction and drying to produce palm oil. The processing wastes (fibre and shell) are utilized as an alternative boiler fuel for steam and electricity generation for palm oil and kernel production processes. In 2009, there were 411 palm oil mills in Malaysia with total capacities of 95 Mt fresh fruit bunch (FFB) and average 90.53 % of capacity utilization rate (MPOB, 2010). Although palm oil mill industry has been in the country for many years, very limited studies have been done in investigating the characteristic and emission of pollutants from palm oil mills.

Generally, palm oil mills in Malaysia use fibre and shell wastes as fuel source in boiler to produce steam and electricity for palm oil and kernel oil production processes. The fibre and shell generated by the mill alone can supply more than enough electricity to meet the energy demand of a palm oil mill (Ma et al,

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2007). One t of FFB leaves 14 - 15 % fibre and 6 - 7 % shell; sufficient for a palm oil mill to self-generate energy for their internal use. However, there are some problems associated due to incomplete combustion of fuel such as the emissions of smoke and the carryover of particulate matters (Yusuff, 2006). Such activity will cause the emissions of dark smoke (particulate) and gaseous pollutant due to incomplete combustion of the solid fuels. High carbon in palm oil residual can be easily converted into particulate during the combustion process and thus, causing air pollution (Abdullah et al., 2007). Dark smoke which is caused by the palm oil mill boiler fly ash (POMBFA) is a by-product of the industry that is generated from the combustion of fuel (palm fiber and shell waste) in the form of empty fruit bunches, palm kernel shell and palm mesocarp fibre. It is estimated that 39 Mt of POMBFA will be generated by 2020 (Yusoff, 2006).
Other pollutants that may be emitted from incomplete agricultural burning among others are CO_2, CO, and hydrocarbons. According to Leong (1986), for every one t fresh fruit bunches (FFB) burnt, 1.5 g/Nm^3 particulate level is produced. For a typical 500,000 t of crude palm oil generally produced from a mill in a year, it may require the burning of 17,500,000 t of FFB. This may result to the release of the pollutant of 1 to 1.5 t particulate matter to atmosphere per mill annually. For an extended period, this level of pollution will certainly threat the lives of human animals, plants and buildings. From the palm oil combustion process, the pollutants released mainly consist of carbon monoxide (CO), particulate matter (PM), nitrogen oxide (NO_x) and sulphur dioxide (SO_2). This study presents the efforts made on the investigation of the emitted total particulate from a boiler of two studied palm oil mill plants in Malaysia. In addition, this study also discusses the health and environmental impacts due to the emissions.

2. Methodology

2.1 Description of the sampling location

The two palm oil mill plants selected for the study are located in two states – one is in the east coast of Malaysia (Pahang - Plant A) and another one is in the southern part of Malaysia (Johor - Plant B). The current processing capacity of Plant A mill is 60 t/h fresh fruit bunch (FFB). The mill burns oil palm fruit fibre in two boilers, with capacity of 30 t/h each, to generate steam for sterilisation of FFB, oil room, kernel plant sludge tank and press station. Each boiler is connected to separate cyclone and stack. However only one boiler is under operation at one time.
Meanwhile in Plant B, the 13.6 t/h steam capacity of water-tube typed boiler is used to process 800 t/d of fresh fruit bunch (FFB). This mill is equipped with two boilers and multi-dust cyclone as the air pollution control (APC) system. The two boilers are operating simultaneously at one time. Table 1 presents the details of the boilers' operating conditions for Plant A and Plant B. The stack diameter is 1.524 m for Plant A while for both boilers in Plant B, they are 2.5 m. The boiler temperature for Plant A is 543.15 K and for Plant B is 563.15 K. As shown in Table 1, the stack gas velocities in the two plants are almost similar; around 15.9 m/s.

Table 1:The tested palm oil mill boilers conditions in Plant A and Plant B

	PLANT A	PLANT B	
	Boilers 1 and 2	Boiler 1	Boiler 2
Boiler capacity, t/h	30	13.60	13.60
Fresh Fruit Bunch (FFB) processed, t/h	60	33.33	33.33
Stack diameter, m	1.524	2.5	2.5
Stack temperature, K	543.15	563.15	53.15
Stack gas velocity, m/s	15.90	15.97	15.94

2.2 Sampling method of the stack emission

For both plants, the particulate emission sampling was performed at the sampling port located after the separate cyclones unit. The sampling procedures were made according to the standard procedure USEPA Method 5 - "Determination of particulate emissions from stationary sources". The materials used for the sample collection are filters, silica gel, water, crushed ice, and stopcock grease. Particulate matter is withdrawn iso-kinetically from the source and collected on a glass fibre filter maintained at the stack temperature. Silica gels are used to determine the amount of moisture leaving the condenser. It is recommended to use silica gel in the last impinger before pump to avoid the corrections for moisture. During the test run, crushed ice was added into the impinger ice bath to maintain a temperature of below 293.15 K at the condenser outlet to prevent excessive moisture losses. The data (weight of the total particulate) was collected by using glass fibre filter papers for each boiler during, before, and after sampling. The data was collected more than once, specifically three times, for each boiler. The flue gas moisture content and volumetric flow rate were determined using the US EPA method 4 - “Determination of moisture content in stack gas” and US EPA method 2- “Determination of stack gas velocity and volumetric flow rate (Type S pitot tube)”.

2.3 Data analysis

The analysis procedures of the samples collected were performed using gravimetric analysis. Glass fibre filters papers (Whatman GF) were used as the collection medium in the sampling. First, the filters were dried in an oven for 24 hours before being used. The filters were carefully placed in the filter holders and used for sample collection. After sampling, the filters were taken out of the holder, desiccated for 24 h and weighed by analytical balance. The average values of the collected weights from the filter papers were then computed to obtain the average concentration of each gaseous component and particulate matter in order to increase the reliability of the data. The weight difference of the filter papers before and after sampling represents the amount of particulate collected on the filter media.

3. Results and Discussion

The results of stack sampling measurement for both Plants A and B are shown in Table 2. The emission limit of particulate matter as specified in the Environmental Quality (Clean Air) Regulations 1978 is 400 mg/Nm^3 at 12 % CO_2. Based on the stack measurement results, the total particulate emission of Plant A is 4,242 mg/Nm^3–exceeding the limit by 960 %. Whereas in Plant B the average total particulate emission was 113 % above the limit (851 mg/Nm^3).As expected, this study also shows that the total particulate emission from the boiler with bigger capacity (30 t/h)in Plant A was higher than the smaller boiler capacity of Plant B (13.6 t/h). As shown in Table 1, the emitted PM_{10} and $PM_{2.5}$ for Plant B is not significant compared to the emitted total particulate which are only 18 % and 3 %,(< 20 %). The fraction of the finer particle size of the total dust is difficult to be captured by the existing dust emission control unit.

Table 2: Comparison of emission data from Plant A and Plant B

	PLANT A	PLANT B		Limits*
	Boilers 1 and 2	Boiler 1	Boiler 2	
Boiler capacity (t/h)	30	13.6	13.6	-
Amount of FFB processed (t/h)	60	33	33	-
Total Particulate matter, PM (mg/Nm^3)	4,242	1,250	452	400
		Avg: 851		
PM_{10} (mg/Nm^3)	-	285.2	103.06	-
		Avg: 194.13		
$PM_{2.5}$ (mg/Nm^3)	-	47.7	17.23	-
		Avg: 32.47		

* Based on the Environmental Quality (Clean Air) Regulations 1978

3.1 Particle morphology

The morphology of the emitted total particulate for Plant A was also examined using the Hitachi Scanning Electron Microscope (SEM)/S 3400 apparatus. This technique allows particle morphology to be investigated. SEM analysis has been used for similar studies e.g. in investigating particle morphology such as the characterization of size and morphology of particles emitted from combustion of wood from three common Iberian trees (oak -Quercus pyrenaica-, beech -Fagus sylvatica and poplar -Populus nigra-), in a woodstove (Coz et al., 2014). The SEM images of the three samples of total particulate collected on the glass fiber filters are shown in Figures 1(a), (b) and (c). Figures1(a) and (b) show the size fractions for the first and second sampling. These figures depict that majority of the particulate size are above 10 μm; mainly consist of isolated spherical and irregularly shaped large particles of unburned carbon material. Meanwhile Figure 1(c) shows that majority of the total particulate matter shave particle size fraction between 2.5 μm and 10μm; they are mostly consisting of micrometer sized particles with some isolated spherical and irregularly shaped large particles are also observed in this sample. From the results of the SEM investigation, it was found that total particulate matter above10 μm does present in all the three samples. The results obtained from the SEM analysis support the findings of the emission data from Plants A and B, that is the concentration of total particulate matter are more significant compared to $PM_{2.5}$ and PM_{10} generated on combustion in palm oil mill boiler.

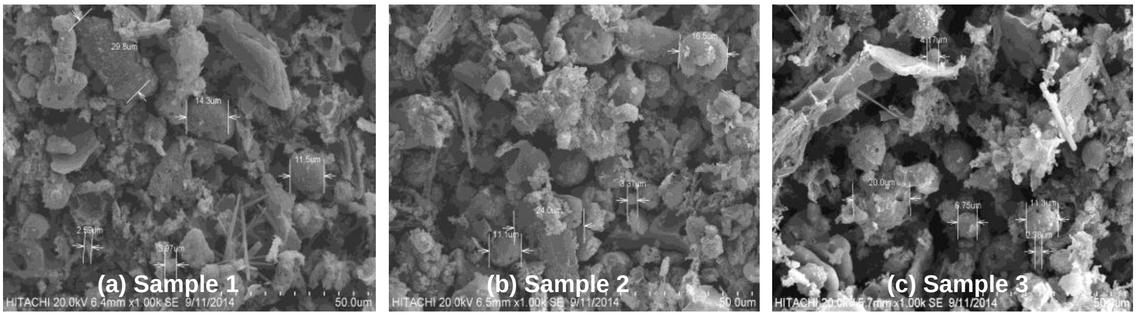

Figure1: SEM images of three particulate samples collected on the glass fibre filter for Plant A (a) particle size for first sampling; (b) particle size for second sampling; (c)particle size for third sampling

3.2 Recommendations for the preventive and control measures

The respiratory system is the major route of entry for airborne particulates. The deposition of particulates in different parts of the human respiratory system depends on particle size, shape, density, and individual breathing patterns such as mouth or nose breathing (PPAH, 1998).The effect on the human organism is also influenced by the chemical composition of the particles, duration of exposure, and individual susceptibility. Products of incomplete combustion (PIC), which form a significant portion of fine particulates, may enter deep into the lungs. PICs contribute significantly to health impacts associated with fine particulates. Elevated levels of particle air pollution have been associated with decreased lung function, increased respiratory symptoms such as cough, shortness of breath, wheezing and asthma attacks, as well as chronic obstructive pulmonary disease, cardiovascular diseases, and lung cancer (Mitra et al., 2002).Particles may also cause environmental impacts when they deposit on surfaces including plants, buildings, hydrological systems, and geological structures. Besides, vegetation exposed to wet and dry deposition of particulates may be injured when particulates are combined with other pollutants (PPAH, 1998).Coarse particles, such as dust, directly deposited on leaf surfaces can reduce gas exchange and photosynthesis, leading to reduced plant growth. Heavy metals that may be present in particulates, when deposited on soil, inhibit the process in soil that makes nutrients available to plants. This, combined with the effects of particulates on leaves, may contribute to reduction of plant growth and yields. In particular, the acidity of the particles can cause severe damage to plant structures, can affect building surfaces, including walls and exterior decorating designs, and can speed up weathering processes of rock structures (Mitra et al., 2002). However, the emission of particulates can be controlled basically using two approaches- 1) prevention of the emission itself and 2) through air pollution control system. The emission of particulate can be avoided by ensuring proper feeding of palm waste fuel (fibre and shell)and optimum conditions of the combustion process. Overloading of fuel (i.e. fibre and shell) could cause higher rate of particulate emission. The generation of particulate emission due to incomplete combustion as well as fly ash due to excessive carryover of bottom ash that will consequently contribute to high particulate emission, can be reduced by improving the combustion process as summaries in Table 3 below:

a) Control air fuel ratio

Air supply is very important in achieving complete combustion. Insufficient air supply may lead to poor combustion which results in black smoke. Meanwhile, too much air supply may result in excessive carryover of bottom ash and unburned fibre. The higher volume of combustion air reduces the flue gas temperature, thus reducing the efficiency of steam production. This in turn, requires more fuel which consequently resulting in higher emission level.

b) Control fuel feeding

The steam demand of the palm oil mill processes varies from time to time. Therefore automated fuel feed control is necessary to cope with the changing steam demand as well as to maintain steady-state combustion conditions. Beside, optimum fuel feeding rate to boiler capacity (F/B) should be determined for each boiler and maintained during the operation. Higher F/B ratio results in higher black smoke and particulate emission.

c) Sufficient time for complete combustion process

A good combustion process requires three ‘T’ factors i.e. temperature, turbulence and time. A combustion process cannot be completed if there is not enough time for the combustion reaction to take place even the process temperature and turbulence for proper mixing are adequate.

d) Boiler modification

There are several alternative approaches to modify a boiler system for control emission of particulate, including enlarging the capacity of draught fans to increase air injection, installing air nozzles for secondary air supply, replacing the manual fuel feed with automated feed system, and increasing stack height for improved pollutant dispersion. Besides, another alternative approach is to use the appropriate indicative boiler instrumentation. These include air pressure gauge, steam pressure gauge, carbon dioxide meter and smoke density monitor to indicate completeness of combustion. For instance, a carbon dioxide level of about 15 - 20% is indicative of complete combustion, hence the instrument would be a great help in guiding the process operator to attain for complete combustion process.

e) Air pollution controller (APC) system

In addition, particulate collection system (i.e. multicyclone) of suitable design with sufficient capacity should be installed to control particulate emission. High particulate emission from multicyclone system will occur in the event of failure of such system. Therefore, measures shall be undertaken to ensure the system is working properly, e.g. through:

i) Frequent monitoring of pressure drop of the multicyclone system.

ii) Conducting performance monitoring on the multicyclone system as recommended by the DOE in the *"Technical Guidance on Performance Monitoring of Air Pollution Control Systems"* (Technical Guidance Document Series Number: DOE-APCS-5, First Edition: December 2006). This includes daily, weekly, monthly, quarterly and annual monitoring procedures for the system.

Table 3: Preventive and control measures of particulate emission

Control Measures	Performance	Cost	Reliability
Control air fuel ratio	Insufficient air supply may results in black smoke. Too much air supply may result in excessive carryover of bottom ash and unburned fibre.	Inexpensive	Normally seek sensors, easy to install and maintain, and quick to respond.
Control fuel feeding	Higher F/B ratio results in higher black smoke and particulate emission.	Inexpensive	Reliable with the installation of a fully automated feeding system.
Sufficient time for complete combustion process	Insufficient time may lead to poor combustion.	Inexpensive	Furnace enclosures are built to allow sufficient time for complete combustion with slower and more complete heat release rate.
Boiler modification	enlarging the capacity of draught fans to increase air injection	Expensive	Including air pressure gauge, steam pressure gauge, carbon dioxide meter and smoke density monitor to indicate completeness of combustion.
Air pollution controller (APC) system; multi cyclone dust collector	Remove particles with an efficiency greater than 80% unless the particle size is 25µm or larger.	Inexpensive	Cyclone could remove big particles, dark smoke may still appear.

4. Conclusions

The particulate emission of palm biomass fired boiler from two studied palm oil mill plants in Malaysia have been investigated (namely Plant A which is located in the east coast of Malaysia (Pahang) and Plant B in the southern part of Malaysia (Johor)).The properties of the total particulate emission were examined by performing stack sampling. The study revealed that the total particulate emission of Plant A is 4,242 mg/Nm^3–exceeding the limit by 960 %. Whereas, in Plant B the average total particulate emission was 113 % above the limit (851 mg/Nm^3).Result from this study also indicates that the total particulate emission from a boiler with bigger capacity (30 t/h) in Plant A was higher than the smaller boiler capacity of Plant B (13.6 t/h).Besides, more extensive study on Plant B found that the emitted PM_{10} (18 %)and $PM_{2.5}$ (3 %) for this plant is not significant compared to the emitted total particulate. Further analysis on the particle morphology shows that the isolated shape of submicron particle produced after the combustion process is characterized by various particle sizes. In principle, the emission of particulates can be controlled basically using two approaches of emissions prevention as well as through the installation of particulate collection system (i.e. multicyclone).

References

Abdullah L.C., Wong L.I., Saari M., Salmiaton A., Abdul Rashid M.S., 2007, Particulate matter dispersion and haze occurrence potential studies at a local palm oil mill, Int. J. Environ. Sci. Tech., 4 (2), 271-278.

Chuah T.G., Abdul Ghani W.A., Robiah Y., Rozita O., 2006, Biomass as the renewable energy sources in malaysia: an overview, Int. J. of Green Energy, 3, 323-346.

Coz E., Perez-Guldris J., Calvo A., Alves C., Tarelho L., Ramos G., Artinano B., 2014, A study on the structural properties of aerosols from biomass combustion for domestic heating, Chemical Engineering Transactions, 37, 811-816.

Leong L.W., 1986, Air Pollution and Control in Palm Oil Mill, Technical report from PORIM, Malaysia Palm Oil Board, Kuala Lumpur, Malaysia.

Ma A.N., Choo Y.M., Cheah K.Y., Basiron Y., 2007, Chapter 14: Development of Renewable Energy in Malaysia, Part IV Trends, needs, and opportunities in developing countries, In: Graziani M., Fornasiero P. (Eds.) Renewable Resources and Renewable Energy: A Global Challenge, Second Edition, Taylor and Francis Group, United States of America.

Malaysia Palm Oil Board (MPOB), 2010, <econ.mpob.gov.my/economy/EIDweb.htm>, accessed 15.01.2010.

Mitra A.P., Morawska L., Sharma C., Zhang J., 2002, Chapter two: methodologies for characterization of combustion sources and for quantification of their emissions, Chemosphere, 49, 903-922.

Pollution Prevention and Abatement Handbook (PPAH), 1998, Airborne Particulate Matter, World Bank Group, Effective July 1998.

Popa V.I., Volf I., 2008, Contribution to the complex processing of biomass, Proceedings of the 2008 Nordic Wood Biorefinery Conference, Stockholm, 229.

Yusoff S., 2006, Renewable Energy From Palm Oil - Innovation on Effective Utilization of Waste, Journal of Cleaner Production, 14, 87-93.

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