

“ST26943”, 2nd International Conference on Agricultural and Food Engineering, CAFEi2014”

Characteristics of Particulate Emission from a Biomass Fired Boiler

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Abstract

This study evaluates the emission characteristics of particulate emission from a palm waste biomass fired boiler with a capacity of 13,600 kg steam/hr. The average particle emission concentration obtained at stack was $5.84 \pm 1.88 \text{ g/Nm}^3$ @ corrected to 7% oxygen. It was found that 3.22% and 12.5% of the average particulate concentration is attributed to PM_{2.5} and PM₁₀ *i.e* particulate size fraction of less than 2.5 and 10 microns, respectively. Notably, 26% of the PM₁₀ concentration is accounted by the finer size fraction of PM_{2.5}, which is not easily removed by the existing particulate control device. Meanwhile, the SEM analysis revealed the presence of different shaped particles.

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Peer-review under responsibility of the Scientific Committee of CAFEi2014

Keywords: Air pollution; emission factor; fine particle; fly ash; stack sample; multi-cyclone

1. Introduction

Malaysia is the world's largest producer and exporter of palm oil, replacing Nigeria as the chief producer since early seventies (Yusoff, 2006). There are more than four million hectares of land under palm tree cultivation and it is the main contributor to biomass resources in Malaysia. The country alone contributes 41% of the world vegetable oil production. Approximately 368 palm oil mills are operating in the country that produce substantial amount of biomass in the form of empty fruit bunches (EFB), palm fiber and shell (FS). The government has encouraged the use of renewable energy through its Five Fuels Policy plan in 1999 with the estimation of 5% with the utilization of renewable energy for year 2008 and increases to 35% in 2030 (Idris et al., 2010).

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Biomass energy sources consist of residues from agriculture or forestry, and the organic component of municipal and industrial wastes. Each type of biomass has some distinct properties that determine its performance as a fuel (Razuan et al., 2010). Biomass production and utilization is growing considerably and play a very important role in the future world energy balance especially in the current fuel and economic crisis. Several biomass resources are used to generate electricity and heat through thermochemical process such as combustion. Palm solid wastes (including palm fiber, shell and empty fruit bunches) are abandoned materials produced during palm oil milling process. For each bunch of the fresh palm fruit, approximately 21% of palm oil, 6 – 7% of palm kernels, 14 – 15% of palm fibers, 6 – 7% of palm shells and 23% of empty fruit bunches are obtained which can meet the energy demand, if properly managed (Dalimin, 1995).

Many studies were performed in order to characterize and quantify gaseous emissions resulting from biomass combustion where various gasifying agents including air, steam, oxygen-steam, air-steam, O₂-enriched air and oxygen-air-steam had been studied (Campoy et al., 2009). Use of oxygen or steam as the gasifying agent improves the quality of producer gas in terms of heating value or hydrogen content. But the high cost and energy consumption of O₂ or steam generation makes the process unfavorable. Palm oil mill boiler fly ash (POMBFA) is a by-product of palm oil industry that is generated from the combustion of palm fiber and shell in the form of empty fruit bunches, palm kernel shell and palm mesocarp fibre. It is estimated that 39 million tons of POMBFA will be generated by 2020 (Yusoff, 2006).

The evaluation of particulate emission from a boiler of a palm oil mill plant with a boiler steam capacity of 8,000 kg/h had been reported elsewhere (Rashid et al., 2013; Chong et al., 2014). As a continuation of the previous studies, the emission characteristics of stack particulate sampled from a palm oil mill boiler with capacity of 13600 kg steam/h was investigated and reported in this paper.

2. Methodology

2.1 Background of the plant

A typical palm oil mill plant processing about 30,000 kg/h of fresh fruit bunches (FFB) was selected in this study. The mill is equipped with a two similar boilers with a steam capacity of 13,600 kg steam/h each and consumed approximately 9,000 kg/h of fibre and shell as fuel. Table 1 presents characteristics of the biomass fired boiler of the mill and its operating conditions during the study period.

2.2 Particulate sampling

The particulate emission sampling was performed at the sampling port in the stack gas downstream of a multiple-cyclones particulate arrestor. Particulate matter was sampled iso-kinetically following the USEPA Method 17: ‘Determination of in-stack particulate emissions from stationary sources’. A micro fiber thimble filter was used to collect the particulates. The flue gas moisture content was determined using the USEPA Method 4: ‘Determination of moisture content in stack gas’ and volumetric flow rate was determined according to USEPA Method 2: ‘Determination of stack gas velocity and volumetric flow rate (Type S-pitot tube)’. In situ measurement of gaseous emission was also carried out using a portable gas analyzer (Telegan, Model 100). A total of four samples were collected at the stack.

Table 1. Palm oil mill biomass boiler characteristics and its operating conditions.

Parameter	Value
Boiler model	TukamaN450
Boiler manufactured year	Late 80s
Boiler type	Water Tube Boiler
Maximum steam capacity (kg/h)	13,600
Fresh fruit bunch processed (kg/h)	30,000
Fiber and shell burned (kg/h)	9,000
Boiler exit temperature (°C)	300
Boiler pressure (psi)	290

2.3 Particulate mass concentration

The thimble type filter paper used in the study was dried in oven and weighted before and after sampling, where the net particulate mass collected was finally obtained. The concentration of particulate (in terms of g/Nm^3 at $T = 0^\circ\text{C}$, $P = 101.325\text{ kPa}$ and corrected to 7% oxygen as a standard reference) was calculated based on the difference in the amount of particulate collected divided by the volume of stack gas sampled in normal meter cubic. While, the particulate mass flow rate in g/s was calculated by the multiplying the volumetric flow rates of the stack gas per second with the concentration of particulate per meter cubic of the stack gas.

2.4 Particulate size distribution

The particulate size distribution of the collected sample was determined using a Laser Diffraction Particle Size Analyzer (SHIMADZU, SALD-2201). The thimble filter was ultra-sonicated in a water bath for a period of thirty minutes to disengage the particle which was later dried in an oven. Then, a small amount of the particulate sample suspended in solution and analyzed for particulate size distribution. In addition, the morphology of the particulate matter was determined using a scanning electron microscopy (HITACHI S-3400N).

2.5 Emission factor

Emission Factor (EF) of particulate emission at stack with particulate control device *i.e* multi-cyclone presented as g/kg of boiler capacity (BC) was calculated in the study. The stack particulate emission factor (EF) based on the boiler capacity (BC) was determined using equation (1);

$$EF_{BC} = \text{Stack particulate mass flow rates (g/h)} / \text{Boiler capacity (kg/h)} \quad (1)$$

where EF_{BC} is the stack particulate emission factor with after the particulate control unit installed downstream of the boiler.

3. Results and discussion

3.1 Particulate mass concentration

Table 2 presents the physical stack parameters and its emission characteristics obtained in this study, which includes the average stack gas temperature, velocity, moisture content, oxygen, carbon dioxide and particulate concentration, which showed that the total particulate (TP) emitted at stack from the palm fiber and shell biomass fired boiler was $5.84 \pm 1.88\text{ g}/\text{Nm}^3$, ranging from 4.08 to $8.34\text{ g}/\text{Nm}^3$ @ corrected to 7% oxygen concentration. The coefficient of variation of the particulate emission concentration of 32% indicates that variability of the particulate emitted from the boiler was consistent during the sampling.

Fig. 1 shows the particulate size distribution of the collected sample illustrating that 3.22% and 12.5% of the total particulate (TP) mass concentration was represented by particulate mass less than 2.5 and 10 microns (or PM2.5 and PM10), respectively. The finding indicates that 0.19 and $0.73\text{ g}/\text{Nm}^3$ of the TP mass concentration is accounted by the PM2.5 and PM10 size fraction, respectively. This means 26% of the PM10 mass concentration is represented by PM2.5, the finer size fraction which difficult to capture by the existing multi-cyclone particulate unit which generally has collection efficiency of not more than 80%.

In addition, as depicted in Fig. 1, the 50% cumulative particle size distribution obtained was 38 microns, which means that particle size collected at 50% collection efficiency (or cut-diameter) by the particulate arrestor *i.e* multi-cyclone installed downstream of the boiler is considerably large. In other words, a lower cut-diameter means that the particulate emission control system is efficient. Thus, in this case a more efficient particulate control system is warranted to be able to meet the newly imposed emission limits of $0.15\text{ g}/\text{Nm}^3$. It is almost impossible that the existing multi-cyclone be able to meet the new limits for the fact that $0.19\text{ g}/\text{Nm}^3$ found to be the PM2.5 particulate

mass size fraction already exceeded the prescribed limits. Furthermore, it was reported that having to comply with the existing limits of 0.4 g/Nm^3 warrants that the particulate control system must be well above 90% efficient (Kun and Abdullah, 2013; Rashid et al., 2013).

Table 2. Physical parameters of the stack and its emission characteristics of the palm fiber and shell biom assifired boiler.

Parameter	Value
Stack diameter at sampling plane (m)	2.4
Stack height (m)	30
Ave. stack gas temperature ($^{\circ}\text{C}$)	290
Ave. stack gas velocity (m/s)	16
Moisture content (%v/v)	4.5
Ave. CO_2 concentration (%v/v)	2
Ave. O_2 concentration (%v/v)	18
Particular emission concentration at stack (g/Nm^3 @corrected to 7% O_2)	5.84 ± 1.88

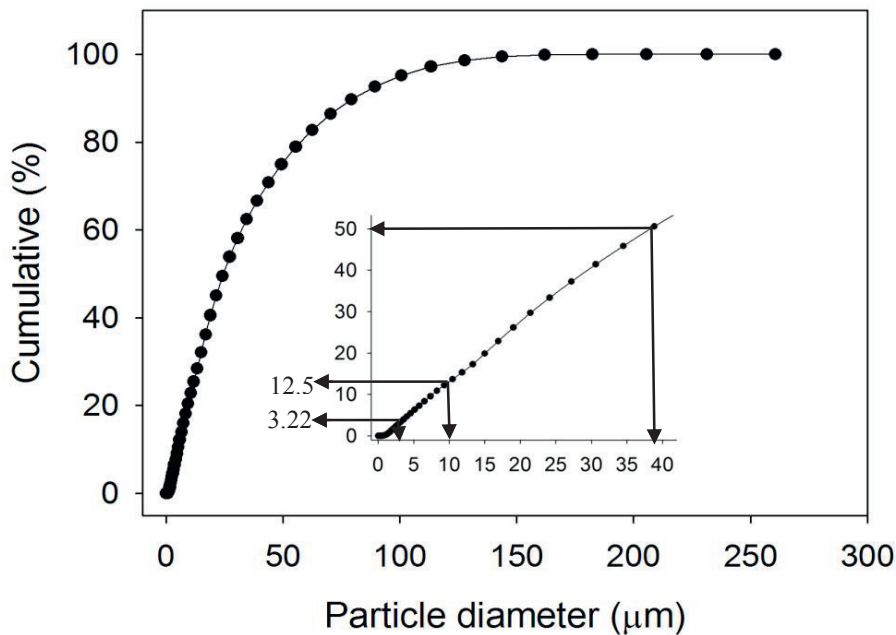


Fig. 1. Particulate size distribution of the palm oil mill boiler fly ash.

3.2 Stack particulate emission factor

An emission factor is the average emission rate of a given pollutant from a given source relative to the intensity of a specific activity of industry and process. Emission intensities are used to derive estimates of air pollutant based on the amount of fuel combusted or similar activity data. This in turns will assist in determining the degree of control of an air pollution control system. Data from source-specific stack tests or continuous emission monitoring systems are usually chosen to estimate a source's emissions because those data provide the best representation of the tested source's emissions.

Table 3 presents the summary of the stack particulate emission concentration and estimated emission factor based on the boiler steam capacity of 13,600 kg steam/h which showed that the estimated particulate emission factors with dust control unit for TP, PM10 and PM2.5 was 11.6, 1.46 and 0.37 kg particulate per kg BC, respectively. It is

expected that particulate emission factor increases with boiler capacity. However, on the contrary, Rashid et al. (2013) reported that particulate emission factor was 19.9 ± 14.2 g particulate/kg BC for a smaller boiler size of 8,000 kg steam/h. The discrepancies may be due to the types, operational conditions of the boiler and the efficiency of the particulate dust collector of the mills.

As illustrated in Table 3, particulate size distributions exiting the palm biomass fired boiler revealed a sizeable portion of the total particulate comprised of PM_{2.5} which is not easily captured by the existing particulate pollution control device. Thus, a special consideration has to be given to this fine particulate size fraction when proposing future air pollution system to be installed in the mill.

Table 3. Stack particulate emission concentration and emission factors estimated from the palm biomass fired boiler.

Parameter	Value
Boiler capacity, BC (kg/h)	13,600
FFB processed (kg/h)	40,000
Stack average temperature (°C)	290
Oxygen level	18%
Stack gas volumetric flow rates (Nm ³ /s)	35
Particulate emission concentration (g/Nm ³)	1.25±0.40
Particulate mass flow rate (g/s)	44
Particulate Emission Factor (g/kg) at STACK with multi-cyclone particulate control unit.	
i. EF _{TP-BC}	11.6
ii. EF _{PM10-BC}	1.46
iii. EF _{PM2.5-BC}	0.37

3.3 Particle morphology

The physical characteristics of the particulates generated are related to degree of exposure of the solid fuel in the combustion zone. SEM was used to investigate particle morphology. Fig. 2 presents SEM images of fly ash particle collected on the microfiber filters.

In regard to morphology in terms of particle size analysis, the SEM analyses allowed to identify different types of particle structures. Fig. 2(a) shows the size fractions above 10 µm mainly consist of isolated spherical and irregularly shaped large particles of unburned carbon material. In addition, the figure shows the presence of silica which is clearly presented by a sphere shaped particle structure. Fig. 2(b) depicts the particle size fraction between 2.5 µm and 10µm mostly incorporate micrometer sized particles but also some isolated spherical and irregularly shaped large particles are also observed. Finally, as shown in Fig. 2(c) the size fraction below 2.5 µm comprised essentially sub micrometer and ultrafine sized particles.

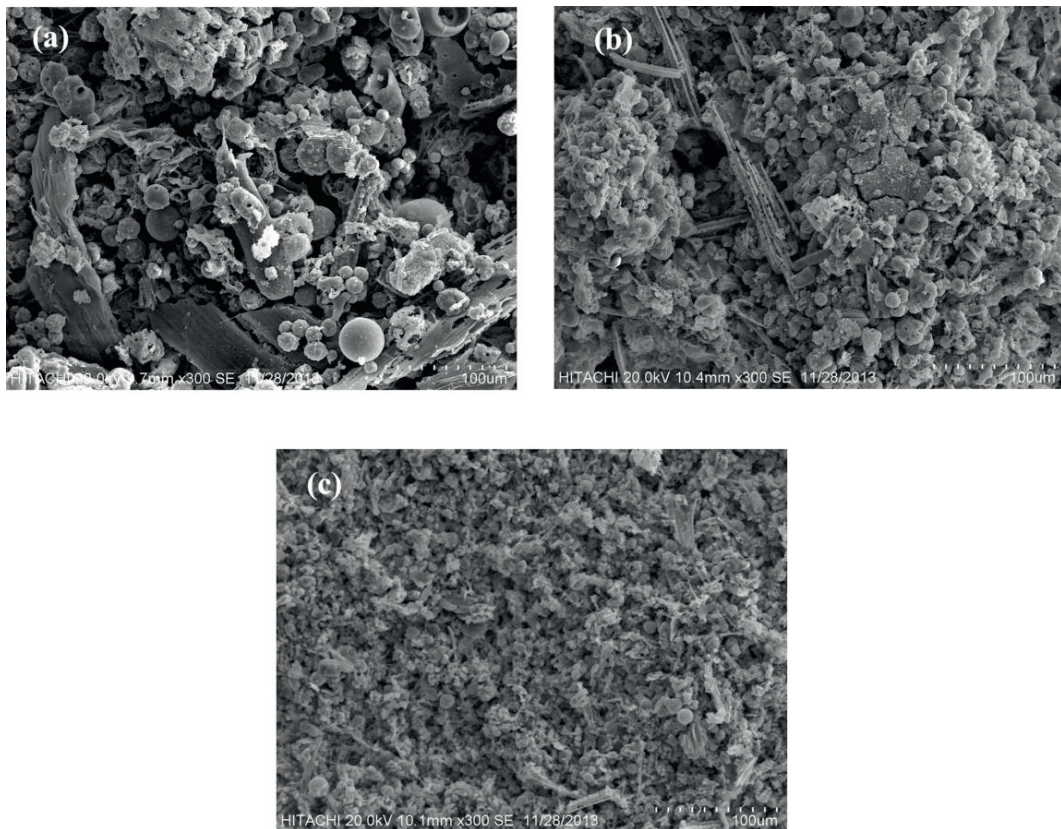


Fig. 2. SEM images of fly ash samples collected on the microfiber thimble, showing different type of structures of fly ash. (a) particle size above 10 μm ; (b) particle size between 2.5 μm and 10 μm ; (c) particle size below 2.5 μm .

4. Conclusions

The particulate emission characteristics of a palm biomass fired boiler with a capacity 13,600 kg steam/h and the particulate emission properties of stack sample have been examined. The study revealed that average total particulate emission concentration after the particulate arrestor unit multi-cyclone unit was $5.84 \pm 1.88 \text{ g/Nm}^3$ with PM_{2.5} and PM₁₀ accounts 3.22% (0.19 g/Nm^3) and 12.5% (0.73 g/Nm^3) of the total mass concentration, respectively. The PM_{2.5} represents 26% of the PM₁₀ particulate mass concentration, the finer particulate size fraction that is difficult to capture by the existing dust emission control unit. Based on the steam capacity of the boiler, the particulate emission factors for TP, PM₁₀ and PM_{2.5} was estimated to be 11.6, 1.46 and 0.37 g particulate per kg boiler steam capacity, respectively. While, the analysis of particle morphology shows that the isolate shape of submicron particle produced after combustion is characterized by various sizes including ultrafine particle sized fraction.

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Accepted for oral presentation in CAFEi2014 (December 1-3, 2014 – Kuala Lumpur, Malaysia) as paper 154.