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# TOTAL PARTICULATE MATTER, PM10, PM2.5 EMISSIONS FROM PALM OIL MILL BOILER

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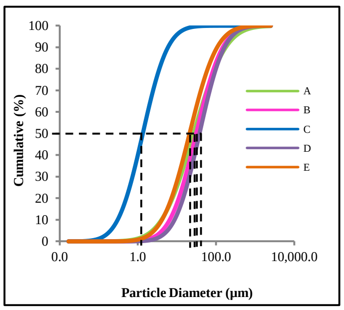
## Graphical abstract




## Abstract

Utilization of fiber and shell as boiler fuel in palm oil mill industry generates particulate emission that need to be controlled before emitting to the environment. This study investigates the particulate mass size distribution of particulate matter sampled from palm oil mills having different boiler capacities. The particulate emission was performed at the stack following US EPA Method 17 and while the particulate size distribution was determined using particle size analyzer. Results showed that the total particulate mass concentration varied between 0.42 and 3.77 g/Nm$^3$ (corrected at 7% $O_2$). The emitted particulate was mainly found in the coarse particles, with 50% cumulative size distribution ranged from 21 to 38 µm. The particulate mass concentration of PM2.5 and PM10 of the total particulate emission was varied from 0.03 to 0.30 g/Nm$^3$ and 0.37 to 0.73 g/Nm$^3$, respectively. This contributes 0.8 to 71% and 13 to 95% of the total particulate mass concentration, respectively.

*Keywords*: Palm oil mill, particulate emission, PM10, PM2.5, biomass



## 1.0 INTRODUCTION

Combustion of biomass fuels leads to relatively high emissions of particulate matter (PM). The fine PM fractions particularly smaller than 2.5 µm or PM2.5 are harmful to human health especially in relation to respiratory and cardiovascular disease [1]. Since, the size of PM are major concern for human health, the fraction of particulates is the main interest to study due to most of the biomass burning aerosols are smaller than 10 µm (PM10) or even smaller than 1µm (PM1) [2].

Studies of particulate emission from different types of biomass fuel revealed that uni-modal mass size distribution and the particle size range less than 10 µm [3-5]. Tissari *et al.,* [6] reported that fine particulate emission from agricultural fuels showed a bi-modal mass size distribution with the fine particle was around 0.15 µm and second mode significantly in the size range of 2 to 8 µm. Obernberger *et al.,* [7] identified more than 90% and 75% of total dust emissions are in size range of less than 10 µm in pellet furnace and wood chip furnace, respectively. Boman *et al.,* [8] found that particulate with PM1 accounts 89.5% of total PM with diameter size of 0.20 to 0.38 µm emitted from wood pellet boiler.

Syahirah *et al.,* [9] reported that particulate mass concentration of PM2.5 and PM10 emitted from a 13,600 kg/hr a palm oil mill boiler steam capacity was 2.33% and 13.7% of the total particulate, respectively. The authors also reported that the 50% cumulative particle size distribution removed by the dust arrestor was 40 µm, which is considerably large. Recently, Norelyza *et al.,* [10] developed a multi-cyclone unit known as MR-deDuster, which is capable to capture particulate of 2.4 µm at 50% collection efficiency and manages to achieve more than 95% total collection efficiency with low pressure drop. This paper presents the particulate size distribution of fly ash emission from palm oil mills with different boiler capacities. The total particulate mass concentration, PM10 and PM2.5 were determined in the study.

# 2.0 METHODOLOGY

## 2.1 Data Collection

A total of five palm oil mills equipped with water tube type boiler were selected in this study. The steam capacity of the boilers ranged between 18,000 and 45,000 kg/hr. Table 1 presents the characteristics of the biomass fired boiler and its operating conditions where fiber and shell are used as fuel to generate steam to run the mill. The fiber and shell utilized as fuel varied between 6,000 and 12,000 kg/hr. All the boilers were equipped with multi-cyclones dust collector unit.

The particulate fly ash sample was collected from the stack gas and the sampling was performed at the stack downstream of a multi-cyclones particulate arrestor. Particulate matter was sampled iso-kinetically following the USEPA Method 17: 'Determination of in-stack particulate emissions from stationary sources'. A microfiber thimble filter was used to collect the particulate. The flue gas velocity, gases component and moisture content were also measured at the stack gas follow the standard USEPA Method 2: 'Determination of stack gas velocity and volumetric flow rate (Type S-pitot tube)', USEPA Method 3: 'Determination of dry molecular weight', and USEPA Method 4: 'Determination of moisture content in stack gas' respectively.

## 2.2 Particle Size Analysis

The particulate size distribution of the collected sample was determined by using a Laser Diffraction Particle Size Analyzer (SHIMADZU, SALD-2201) where the analyzer is able to measure the particulate size from 0.03 to 1000 µm. Particulate size distributions is calculated from the light intensity distribution pattern of the diffracted light emitted from particle group.

Initially, the particulates were disengaged from the thimble by ultra-sonification technique. Then, dispersant solution which is water and NaHMP (act as dispersing agent) were added into a very small amount of particulates sample before the analysis. The sample was placed in the flow cell with sonification mode for better dispersion before the measurement of the particulate size distribution.

# 3.0 RESULTS AND DISCUSSION

Table 2 presents the stack parameters obtained in the study which includes stack gas temperature, volumetric flow rate, velocity, moisture content, oxygen and carbon dioxide concentration, as well as particulate concentration and emission rate. The total particulate mass concentration varied between 0.42 and 3.77 g/Nm$^3$ (corrected at 7% $O_2$) with high coefficient of variation of 82% illustrating the large variation of emission between the mills.

**Table 1** Characteristics of the boiler and its operating conditions

| Palm oil mill plant | A | B | C | D | E |
|---|---|---|---|---|---|
| Boiler manufactured year | 2004 | 2002 | 1983 | 2009 | 2009 |
| Boiler rated steam capacity(kg/hr) | 25,000 | 45,000 | 18,000 | 45,000 | 40,000 |
| Boiler running steam capacity (kg/hr) | 24,000 | 26,000 | 17,000 | 35,000 | 30,000 |
| Boiler steam outlet temperature (°C) | 247 | 247 | 215 | 215 | 215 |
| Boiler pressure (psi) | 300 | 310 | 300 | 312 | 300 |
| FFB processed per boiler per hour (kg/hr) | 30,000 | 54,000 | 30,000 | 45,000 | 40,000 |
| Fibre & shell feeding (kg/hr) | 8,000 | 9,000 | 6,000 | 12,000 | 10,000 |
| Ratio of fibre/shell | 80:20 | 70:30 | 80:20 | 80:20 | 80:20 |

**Table 2** Parameter of stack data obtained in the study

| Parameter | Mill | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| Stack gas temperature (°C) | 268 | 286 | 264 | 248 | 252 |
| Stack gas volumetric flow rate (Nm$^3$/s) | 14.2 | 10.0 | 13.7 | 13.5 | 12.9 |
| Stack gas velocity (m/s) | 16.2 | 17.2 | 15.6 | 15.4 | 15.8 |
| Moisture content (%v/v) | 4.27 | 7.02 | 4.99 | 5.37 | 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$^3$)@ 7%$O_2$ | 2.36 ± 0.96 | 1.97 ± 0.02 | 0.42 ± 0.09 | 3.77 ± 0.69 | 2.52 ± 0.23 |
| Particulate emission rate (g/s) | 7.46 ± 3.03 | 13.8 ± 0.13 | 4.20 ± 0.90 | 53.6 ± 9.84 | 23.9 ± 2.21 |

Note: number of sample: 3; Nm$^3$ means dry gas volume corrected at T=0°C and P=101.325 kP

Figure 1 presents the cumulative particulate size distribution of the stack fly ash of different boiler capacities which showed that the particulate was dominated by coarse particles with 50% cumulative at 21 to 38 µm for mill A, B, D and E with the exception of mill C which was at 1.3 µm. The 50% cumulative particulate size distribution indicates particle size collected at 50% collection efficiency (or cut-diameter) by dust collector. Thus, in this case most of the mills (with the exception of mill C) were expected to have lower particulate collection efficiency dust collector. This finding is in agreement with Syahirah *et al.*, [9] who reported that the 50% cumulative particulate distribution of 13,600 kg/hr of boiler capacity was 40 µm in size. There are several factors contributing to the low collection efficiency of the dust collector such as deterioration of dust collection system with time, poor maintenance or even poor design of dust collection systems [11].

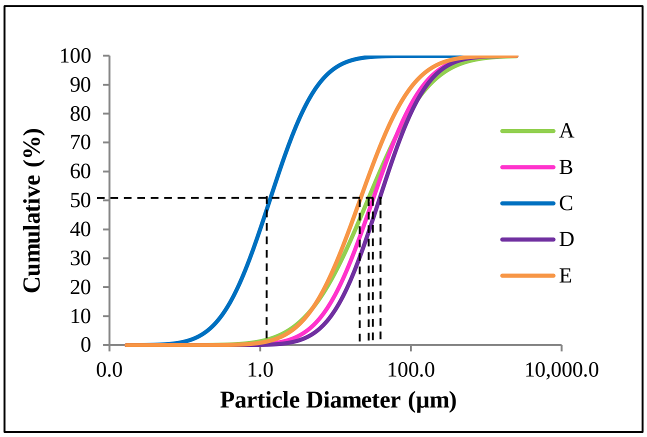



**Figure 1** Cumulative particulate size distribution of fly ash from different mill

Table 3 presents the concentration PM2.5 and PM10 of the total particulate emission from each of the boiler which showed that the former varied from 0.03 to 0.30 g/Nm$^3$ while the latter from 0.37 to 0.73 g/Nm$^3$. Accordingly, PM2.5 and PM10 contributes 0.8 to 71% and 13 to 95% of the total particulate emission concentration, respectively. Boiler from mill C generates fine particles compare to the other mills with 71% and 95% contributed by PM2.5 and PM10, respectively. Reason for this finding is not known which requires further investigation. Generally, it is noteworthy that the PM10 particulate emission concentration of all mills exceeded the new Clean Air Regulation 2014 limits of 0.15 g/Nm$^3$ where any new proposal of dust emission control system should take into this consideration. The size-segregated particulate emission of PM2.5 and PM10 are partly influenced by the combustion conditions such as poor mixing and short burning residence time of fiber and shell in the boiler as well as combustion temperature. In many cases, these are not easily controlled during operation.

**Table 3** Particulate emission concentration of PM2.5 and PM10

| Particulate Matter (g/Nm$^3$) | Mill | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| PM2.5 | 0.13 ± 0.05 (5.5%) | 0.04 ± 0.0004 (2.0%) | 0.30 ± 0.06 (71%) | 0.03 ± 0.006 (0.8%) | 0.12 ± 0.01 (4.8%) |
| PM10 | 0.62 ± 0.25 (26%) | 0.37 ± 0.003 (19%) | 0.40 ± 0.09 (95%) | 0.50 ± 0.09 (13%) | 0.73 ± 0.07 (29%) |
| Total Particulate | 2.36 ± 0.96 | 1.97 ± 0.02 | 0.42 ± 0.09 | 3.77 ± 0.69 | 2.52 ± 0.23 |

Note: (%) percentage of the total particulate concentration

## 4.0 CONCLUSION

A study to determine the total particulate emission concentration as well as its particulate size distribution in terms of PM2.5 and PM10 collected from palm oil mills with different boiler capacities concludes that the former contributes 0.8 to 71% and the latter 13 to 95% of the total particulate mass concentration. It was found that most of the boilers generate coarse particulates with 50% cumulative particulate size distribution ranging from 21 to 38 µm with the particulate emission concentration of PM10 and PM2.5 ranging from 0.37 to 0.73 g/Nm$^3$ and 0.03 to 0.30 g/Nm$^3$, respectively. The study found that PM10particulate emission concentration exceeded the new Clean Air Regulation 2014 and suggested that any new proposal of dust emission control system to be installed should take into this consideration.

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