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EMISSION FACTOR ESTABLISHMENT FOR PALM OIL MILL BOILER

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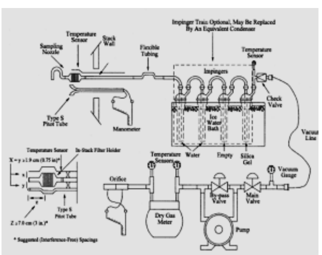
Graphical abstract



Abstract

A study to establish the total particulate emission factor (EFs) from boiler of a palm oil mill plant equipped with a multi-cyclones particulate arrestor was performed and reported in this research. The mill employs a 500 kg steam/ h capacity of water-tube typed boiler and processes 60 tonnes per hour of fresh fruit bunch (FFB). The samples of the dust were collected iso-kinetically using the USEPA method 17 sampling train through a sampling port located after a multidust cyclone unit. Results showed that the total dust generated from the boiler is 62.15 g/s and the calculated total dust emission factor based on the boiler capacity is 7.46 g/kg. Poor combustion process is among the main factor that leads to the high particulate emission. EFs data allows for early prediction of pollutants emission, which subsequently will assist in determining the degree of control and the air pollution control system needed, besides evaluating the effectiveness of the existing pollution control strategies. The establishment of EFs for palm oil mills will definitely bring benefits for a better management of health and safety risks in palm oil mills, now and in the future.

Keywords: Emission factors; Air pollution; palm oil mill; boiler; risk assessment

Abstrak

Satu kajian untuk mewujudkan jumlah faktor pelepasan zarah (EFs) dari dandang loji kilang minyak sawit dilengkapi dengan penangkap zarah berbilang siklon telah dilakukan dan dilaporkan dalam kertas kerja ini. Kilang ini menggunakan kapasiti 500 kg stim / h kapasiti dandang jenis air-tiub untuk memproses 60 tan buah tandan segar (FFB) setiap sejam. Sampel tanah yang telah dikumpulkan secara iso-kinetik menggunakan kaedah persampelan USEPA 17 melalui tempat persampelan terletak selepas unit multi-habuk siklon. Keputusan menunjukkan bahawa jumlah debu yang dihasilkan dari dandang adalah 62,145 g / s dan jumlah faktor pelepasan debu yang dikira berdasarkan kapasiti dandang adalah 7,457 g / kg. Proses pembakaran tidak lengkap adalah antara faktor utama yang membawa kepada pelepasan zarah yang tinggi. Data EFs membolehkan ramalan awal pelepasan bahan pencemar, yang seterusnya akan membantu dalam menentukan tahap kawalan dan sistem kawalan pencemaran udara yang diperlukan, di samping menilai keberkesanan strategi kawalan pencemaran yang sedia ada. Mewujudkan EFs untuk kilang minyak sawit pasti akan membawa manfaat untuk pengurusan yang lebih baik terhadap risiko kesihatan dan keselamatan di kilang minyak sawit, sekarang dan pada masa akan datang.

Kata kunci: Faktor pelepasan; pencemaran udara; kilang kelapa sawit; dandang; penilaian risiko

1.0 INTRODUCTION

Malaysia has enjoyed one of the least polluted urban environments in Asia. The goal of achieving industrial country status by the year 2020 and the associated rapid economic growth have started to costs in terms of industrial pollution and degradation of urban environment, which become more serious in recent years. Air pollution is among the major issues, affecting human health, agricultural crops, forest species, and ecosystems. Malaysia's palm oil industry is one of the main economic players, in which the country is the second largest producer of palm oil in the world; after Indonesia since year 2006 [1]. In October 2015, there were 442 palm oil mills in Malaysia with total capacities of 107 million tons fresh fruit bunch (FFB) and average 90.53% of capacity utilization rate [2]. Generally, palm oil mills in Malaysia use fiber and shell wastes as fuel source in boiler to produce steam and electricity for palm oil and kernel oil production processes. The fiber and shell generated by the mill alone can supply more than enough electricity to meet the energy demand of a palm oil mill [3]. One ton of FFB leaves 14-15 % fiber and 6-7 % shell; sufficient for a palm oil mill to self-generate energy for their internal use. However, the emission of pollutants released from the boiler poses quite a significant health and environmental impact. The use of biomass material from palm oil byproducts, i.e. fiber and shell as fuel is identified as the main culprit for pollutants generation. Economically, the usage of palm waste material as fuel is seen as productive since the material will not be wasted. However, combustion process in the furnace of the boiler releases emissions such as particulate matters (PM), carbon monoxide (CO), nitrogen oxide (NOx) and sulphur dioxide (SO2). Besides environment, these emissions also impose negative impact on human health since fine particulates are easily deposited in human's respiratory tract.

The study on emission factors of pollutants due to dust emissions and pollution gaseous from palm oil mills in Malaysia is still very much lacking so far. The establishment of the emission factors is critical and does offer significant benefit, to serve as guidelines as well as important input data for estimating pollutions emissions from palm oil mills. Eventually the impact of such emissions can be estimated much earlier, even before the development of new plant or expansion of existing plant with the aid of emission factors (EFs). Early emissions estimation however needs data on pollutants emission factors. Emission factors are usually expressed as the weight of pollutant emitted divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., pounds of particulate matter emitted per ton of coal burned). Therefore, more emphasis should be given in developing emission factors for pollutants from palm oil mills. This paper presents an attempt towards the establishment of total particulate emission factor from a boiler of a palm oil mill plant that is capable of processing 60 tonnes per hour of (FFB).

2.0 METHODOLOGY

2.1 Description of the Studied Palm Oil Mill

In Malaysia, more than 2.8 million hectares of land are used for oil palm cultivation. Malaysia's palm oil industry has grown to become a very important biomass-based industry. Basically, palm oil industry is divided into two 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 a palm oil mill. Whereas, palm oil refinery is to convert the crude oil into quality edible oil by removing offensive impurities to most efficient oil. This study focuses on palm oil mill as it is more significant in causing environmental air pollution by emitting dark smoke emission with carry-over of soot and partially carbonised fibrous particulates from palm oil mill boiler. Generally, in palm oil mills, fresh fruit bunch (FFB) of palm will go through several processes such as sterilization, stripping, oil extraction, clarification, nut-fiber separation and kernel extraction and drying to produce palm oil as shown in Figure 1. The processing wastes (fibre and shell) are used as an alternative boiler fuel for steam and electricity generation for palm oil and kernel production processes. However, there are some associated problems due to incomplete combustion of fuel such as the emissions of smoke and the carryover of particulate matters [4].

The palm oil mill plant that is selected for the study is located in the state of Johor. The 13,600 kg steam/hr capacity of water-tube typed boiler used in palm oil mill plant processes800 million tonnes per day of fresh fruit bunch (FFB). The fiber and shell are fed into the boiler with the ratio of 85 % to 15 %. The studied mill is equipped with two boilers and multi-dust cyclone as Air Pollution Control (APC). Table 1 presents the details of the two boilers operating conditions. The stack diameter is 2.4 m for both boilers and the average stack gas velocity is almost the same within each boiler, which are 15.97 and 15.94 m/s respectively. The main difference between these two boilers are in terms of average stack gas temperature which are 290 °C for boiler 1 and 224°C for boiler 2, while the average stack gas pressure for both boilers are 11.4 and 12.8 mmH2O accordingly.

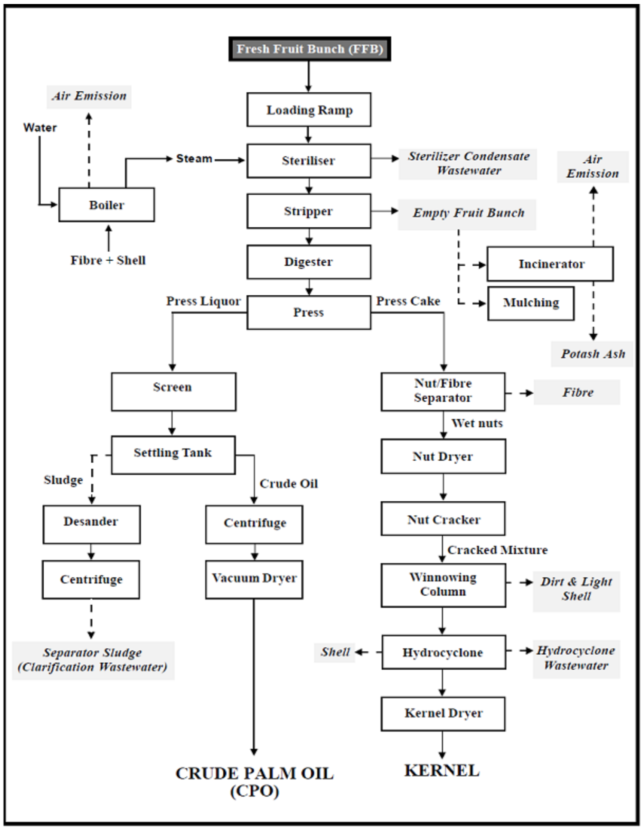


Figure 1 Conventional palm oil extraction process and sources of waste generation [5]

Table 1 The tested palm oil mill boilers conditions.

Boiler	Boiler 1	Boiler 2
Date of sampling	3rd October	2nd October
Stack ID	1	2
Fresh Fruit Bunch (FFB) processed per day (mt)	800	800
Fiber& shell ratio	85:15	85:15
Stack diameter at sampling plane (m)	2.4	2.4
Average stack gas temperature (°C)	290.0	224.0
Average stack ΔP (mmH_2O)	11.4	12.8
Average stack gas velocity (m/s)	15.97	15.94

2.2 Sampling Process

The stack emission samples were obtained from a mixed fibre and shell fired fuel palm oil mill with the capacity of processing 60 tonnes per hour. The particulate emission sampling was performed at the sampling port located after the multi-cyclones unit.

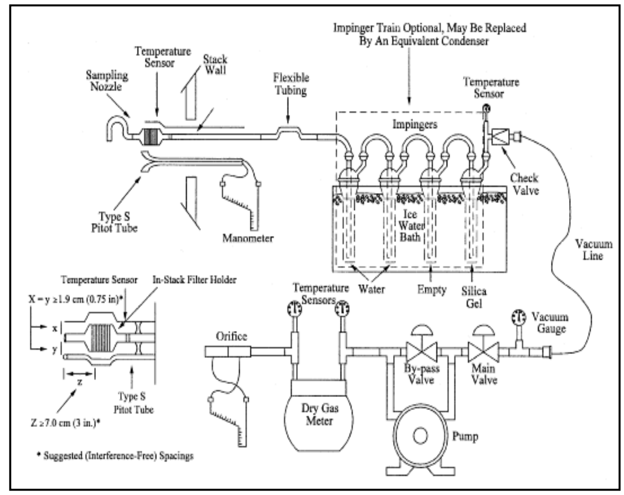


Figure 2 Particulate sampling train with in-stack filter [6]

The sampling procedures were made following the USEPA Method 17 - "Determination of in-stack particulate emissions from stationary sources". A schematic of the sampling train used in this method is shown in Figure 2. The required reagents for sample collection are filters, silica gel, water, crushed ice, and stopcock grease. Thimble filter placed in a canister is used to collect the particulates. Particulate matter is withdrawn isokinetically from the source and collected on a glass fibre filter maintained at stack temperature. Silica gels are used to determine the amount of moisture leaving the condenser. It is recommended that silica gel to still be used between the condenser system and pump to avoid the need to make corrections for moisture in the metered volume. During the test run, the crushed ice was added into the impinger ice bath to maintain a temperature of less than 20° C (68° F) at the condenser outlet that will prevent excessive moisture losses. The data (weight) was collected by using four thimbles for each boiler during, before, and after sampling and the data was collected more than once, specifically three times, for each thimble. Flue gas moisture content and volumetric flow rate were also 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 pitottube)",respectively.

2.3 Data Analysis

The analysis procedures of the samples collected were performed using gravimetric analysis. Glass fibre filters paper (Whatman GF) were used as the collection medium in the sampling. 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 hours and weighed by analytical balance. The average value of the collected weights from three filter papers has been computed to obtain the average concentration of each gaseous component and particulate matter in order to increase the reliability of the data. The difference in before and after weight represents the amount of particulate collected on filter media.

2.3 Data Calculation

The final weight of the particulate collected on filter media was used to obtain the total particulate emission concentrations at normal and dry conditions, Cpartn (g/Nm^3) using equation (1).

$$C_{partN} = \frac{Wtp}{Vmn} \quad (1)$$

Where,

C_{partN} = total particulate emission concentrations at normal and dry conditions, (g/Nm^3)

W_{tp} = Weight of Particulate Collected, (g)

V_{mn} = Dry gas volume sampled corrected to Normal Conditions (Nm^3)

Next, the flowrates of stack gas at normal and dry conditions, QsN,dry (Nm^3/s) were calculated using equation (2) as below :

$$QsN_{,dry} = Q_s \times \left(\frac{273K}{T_s}\right) \times (1-B_{ws}) \quad (2)$$

Where,

$QsN_{,dry}$ = Flowrates of stack gas at normal and dry conditions, (Nm3/s)

Q_s = Flowrates of Stack Gas, (m^3/s)

T_s = Temperature of Stack Gas, (KB_{ws} = Moisture content, (%)

Then, the total particulate emitted at normal and dry condition, $Mn_{,dry}$ (g/s) was obtained by multiply the particulate emission concentrations at normal and dry conditions, Cpartn (g/Nm3) and flowrates of stack gas at normal and dry conditions, QsN,dry (Nm3/s) as equation (3).

$$M_{N,dry} = C_{part,N} \times QsN_{dry} \quad (3)$$

Where,

$Mn_{,dry}$ = Total particulate emitted at normal and dry condition, (g/s)

C_{partN} = Particulate Emission Concentrations at Normal and Dry Conditions, (g/Nm

$QsN_{,dry}$ = Flowrates of Stack Gas at Normal and Dry Conditions, (Nm^3/s)

Thus, pollutant emissions from palm oil mill boiler can be expressed in term of emission factor which will be discussed in more details in the next subtopic.

2.5 Calculation of Emission Factor for Particulate Matters

Emission factors can be defined as emissions that are emitted by a particular source type based on specific of pollutants, process, age, size, control technology and other pertinent factors affecting the emissions [7]. Emission factors can also be defined as the mass of pollutants emitted per unit mass of dry stubble burned. Based on the later definition, the amount of pollutants including particulate emission can be estimated early based on certain characteristics of the industry or process [8]. Early prediction of pollutants emission will subsequently assist in determining the degree of control and the air pollution control system needed, besides evaluating the effectiveness of the existing pollution control strategies[8].

The total particulate emission factor based on the actual boiler capacity (EFBC), (g/kg)was calculated using equation (4). The boiler has the capacity of generating 500 kg steam/ h by processing 60 tonnes per hour of fresh fruit bunch (FFB).

The calculated particulate emission factor based on the boiler capacity [8]. :

$$EF_{BC} = \frac{Mn,dry\ (\frac{g}{s})}{BC\ (\frac{kg}{s})} \quad (4)$$

Where,

EF_{BC} = Total particulate emission factor based on the actual boiler capacity, (g/kg)

$Mn_{,dry}$ =Total particulate emitted at normal and dry condition, (g/s)

BC = Boiler capacity, (kg/s)

3.0 RESULTS AND DISCUSSION

As shown in Table 2, the total dust generated from the boiler ranges from 12.91 to 59.89 g/s. The generated total dust is greatly influenced by the capacity of feedstock which is Fiber and Shell (F&S) burned as well as the operating conditions of the boiler at the time of the sampling. The calculated total dust emission factor of boiler 1 based on the boiler capacity, BC, is 11.094±3.569 g/kg, whereas for boiler 2 it is 4.533±0.761 g/kg. As comparison, the total particulate emission factor for wheat straw, rice straw, corn straw and cotton stalk burning is 8.75±4.18, 6.28±1.59, 5.31±1.79 and 4.53±0.95g/kg, respectively as shown in Table 3 [9]. While, for vegetation fires like forest, savanna and grass, the particulate emission factor was 9.6±4.6, 6.3±3.0 and 4.7±2.1g/kg, respectively [10]. It is noted that the value of total particulate emission factor of boiler capacity in a palm oil mill boiler (i.e., 19.9±14.2g/kg) as found in previous study, is much higher than those biomasses process mentioned above. The emission factor of the particulate matters from palm oil mill boiler is higher because properties of the biomass feedstock (which are fibre and shell from FFB) e.g. moisture content is higher compared to the other types of biomasses. Such biomass property can greatly affect the amount of emissions produced. The material moisture content also varies with geographical location, season, and weather. However, high moisture, a tendency to form tars, and an ash chemistry that leads to the formation of low melting point solids when heated presents challenges to some conversion methods [11].

Table 2 Emission factor for total particulates, particulate matter 10 micrometers or less in diameter (PM_{10}) and particulate matter 2.5 micrometers or less in diameter ($PM_{2.5}$).

	Emission Factor Total Particulates (g/kg)	Emission Factor PM_{10} (g/kg)	Emission Factor $PM_{2.5}$ (g/kg)
Palm oil mill (studied)	7.91±4.245	1.28±0.427	0.22±0.073
Palm oil mill	19.9±14.2 [7]	NA	NA
Wheat Straw	8.75±4.18 [9]	NA	7.6±4.1 [12]
Rice straw	6.28±1.59 [9]	9.4±3.5 [13]	8.3±2.7 [13]
Corn Stover	5.31±1.79 [9]	NA	11.7±1.0 [12]
Cotton Stalk	4.53±0.95 [9]	NA	NA
Kentucky Bluegrass	NA	NA	12.1±1.4 [8]
Florida Sugarcane	NA	NA	2.49±0.66 [14]
Cereal waste	13.0±7.0 [15]	NA	NA

Note:
*Emission factor is based on 13600 kg/h boiler capacity.
*NA – Not available

Emission factor establishment also depends on the capacity of feedstocks. The resulting emissions of biomass burning are directly proportional with the feedstock inlet/feeding rate because the more biomass feedstock used, the more air pollution emission will be produced.This study also establishes emission factors for dust emission of various particle sizes ($PM_{2.5}$ and PM_{10}) from a boiler of a palm oil mill plant. PM_{10} is particulate matter 10 micrometers or less in diameter, whereas $PM_{2.5}$ is particulate matter 2.5 micrometers or less in diameter. $PM_{2.5}$ is generally described as fine particles and also known for triggering respiratory health complications [16]. As shown in Table 2, the PM_{10} emission factor from boiler 1 ranges from 1.06 to 2.17 g/kg (1.52±0.63 g/kg) while, for boiler 2, the emission factor ranges from 0.78 to 1.16 g/kg (1.034±0.173 g/kg). As comparison with other biomasses, the PM10 emission factor for wheat straw, rice straw, and corn straw is 5.74, 3.46 and 6.21g/kg respectively [17]. The emission factor of PM_{10} from corn straw burning is found to be much higher than the other biomasses including that from the palm oil mill boiler studied in this paper. This is due to the different elemental composition of different type of biomasses. Sillapapiromsuk et al. (2013) revealed that all types of biomass burning emitted five major ions including K^+, NH_4^+, Cl^-, NO_3^- and SO_4^{2-} where K^+ and Cl^- were the major ions emitted from agricultural waste burning which was probably related to the use of fertilizers and herbicides [18].

Table 3 The published particulate emission factors for other type of biomasses

	Thimble no.	Dust emitted (g/s)	Emission Factor Total Particulates (g/kg)	Emission Factor PM_{10} (g/kg)	Emission Factor $PM_{2.5}$ (g/kg)
Boiler 1	6	59.81	15.85	2.17	0.37
	7	44.15	11.69	1.60	0.27
	8	34.33	9.09	1.24	0.21
	9	29.27	7.75	1.06	0.18
	(Mean±SD)	41.91 ± 13.49	11.09 ± 3.57	1.52 ± 0.63	0.26 ± 0.08
Boiler 2	2	12.91	3.42	0.78	0.13
	3	19.21	5.09	1.16	0.19
	4	17.76	4.70	1.07	0.18
	5	18.63	4.93	1.12	0.19
	(Mean±SD)	17.13 ± 2.88	4.53 ± 0.76	1.03 ± 0.17	0.17 ± 0.03

As shown in Table 3, the emission factor of $PM_{2.5}$ for boiler 1 ranges from 0.18 to 0.37 g/kg (0.26 ± 0.09 g/kg), wheares boiler 2's ranges from 0.130 to 0.194 g/kg (0.17 ± 0.03 g/kg). With regard to emission factor of PM2.5, there has been no report from the closed system in the previous study. However, in this study, the emission factor of $PM_{2.5}$ for boiler 1 was much higher than boiler 2. The differences between these two boilers are found in specific stack gas conditions (temperature, pressure, volumetric flow rate, etc.). The smaller particles are likely to be responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract. $PM_{2.5}$ and PM_{10} are very important to be evaluated in this study because there are very significant health impacts for dust emission from palm oil mill boiler. Small airborne particles have large diffusion coefficients, thus they pose high probability ended to be deposited in alveoli. Basically, 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 [19]. The effect on the human organism is also influenced by the chemical composition of the particles, duration of exposure, and individual susceptibility. While all particles smaller than 10 microns in diameter can reach human lungs, the retention rate is the largest for finer particles. The elderly, children, and people with chronic lung disease, influenza, or asthma, are especially sensitive to the effects of particulate matter. The health impacts of concern due to PM_{10} exposure include effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death [20]. Therefore exposure to such substances should be so much reduced, if not totally avoided, and this is especially important for workers who need to be in this nature of process daily throughout their working lifetime.

Emission of particulate can be prevented by proper feeding and ensuring optimum combustion process. Overloading of fuel (i.e. fibre and shell) could cause higher rate of particulate emission. In order to reduce the generation of carbon particles due to incomplete combustion and fly ash due to excessive carryover of bottom ash that contribute to high particulate emission, it is recommended to improve combustion process such as follows:

i. Control air fuel ratio
Insufficient air supply leads to poor combustion that results in black smoke. Too much air supply may result in excessive carryover of bottom ash and unburned fibre. The higher volume of combustion air reduce the flue gas temperature thus reducing efficiency of steam production. This in turn requires more fuel which consequently resulting in higher emission level.

ii. Sufficient mixing of combustion air
Mixing in combustion chamber can be increased by proper distribution of overfire air and improvement in geometry design of the combustion chamber.

iii. Sufficient time for combustion process to complete
There are three Ts for good combustion process i.e. temperature, turbulence and time. Although if there were enough temperature and turbulence for proper mixing, combustion process cannot be completed if there was not enough time for the combustion reaction to take place.

iv. Control fuel feeding rate
Optimum fuel feeding rate to boiler capacity (F/B) should be determined for each boiler and maintained during operation. Higher F/B ratio results in higher black smoke and particulate emission.

v. Proper distribution of underfire/overfire air
High rate of underfire air results in black smoke and excessive carryover of bottom ash. Usually, underfire air is about 30% of the combustion air requirement.

In addition, particulate collection system (i.e. multicyclone) of suitable design with sufficient capacity with reference to the particulate emission level and exhaust gas volume should be installed to control particulate emission. High particulate emission from multicyclone system will occur in the event of failure of the multicyclone system. Therefore, measures shall be undertaken to ensure the multicyclone system is working properly, as follows:

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

ii. Conducting performance monitoring on the multicyclone system as recommended by 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). These include daily, weekly, monthly, quarterly and annual monitoring procedures for the multicyclone system. Therefore, exposure to such substances should be so much reduced, if not totally avoided, and this is especially important for workers who need to be in this nature of process daily throughout their working lifetime.

4.0 CONCLUSION

Emission factors have been experimentally determined for various sizes of particulate matters released from palm oil mill boiler stack (total particulate, PM10 andPM2.5). For water-tube typed boiler with capacity of 13,600 kg steam/h, the emission factor for particulate is 11.09±3.57 g/kg for boiler 1 and 4.53±0.76g/kg for boiler 2.It was found that the value is much higher than that from other types of biomass burning. Noted that the main difference between boilers 1 and 2 in the process is the operating conditions. The average stack gas temperatures are 290 °C and 224 °C while the average stack gas pressure are 11.4 mmH2O and 12.8 mmH2O for boiler 1 and 2, respectively. For particular particle size, the emission factors for PM10 from boiler 1 and boiler 2 are 1.52 ± 0.63 g/kg and 1.03 ± 0.17 g/kg respectively. Meanwhile, the values for PM2.5 for boiler 1 and boiler 2 are 0.26 ± 0.08 g/kg and 0.17 ±0.03 g/kg. As there is a very limited understanding concerning emissions from palm oil mill, this study has improved local knowledge on the scenarios regarding particle matters emissions from palm oil mill boiler in Malaysia. Also the study has paved the way for a more accurate estimation of airborne emissions from palm oil mill which definitely have been impacting the air quality and climatic conditions in Malaysia so far as well as in the future if the issue is not being properly looked into.

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