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Pollutant dispersion modelling (Dust, CO, NOx, and SOx) from palm oil mill stack

(*Case Study of PT. Mustika Agung Sawit Sejahtera*)

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Abstract: Pollutant dispersion modeling study of a stack is one of the efforts in addressing the problems that emissions of the palm oil industry can match the capacity of the environment, so it will not impact on the environment and society. Screeen view SCREEN3 software, based of Gaussian dispersion method for dust, CO, NOx, and SOx pollutant, was used for pollutant dispersion modeling. The input parameters in the simulation were the rate of emission of pollutants emitted from the stack, the air velocity around the source of emissions, atmospheric stability factor, and the topography of the site. While the expected output was a visualization of distribution of pollutants concentration in the form of 2-dimensional plane-shaped contour that came with concentration values of the distance from the source of emission. Modeling in this study was conducted with several scenarios that the average meteorological conditions at the time of measurement and the worst conditions. The results showed that the dominant wind direction was to the south with an average speed of 5.87 m/s. The resulting emission rate was 36.4 g/s. As for the pollutants, CO was 13.84 g/ s, SOx was 0.213 g/s and NOx 24.49 g/ s. Emission maximum distance was 1340 m from the stack with dust concentration at 133.9 ug/m$^{3.}$ The concentrations of CO, NOx, and SOx were 50.90 ug/m$^{3;}$ 90.06 ug/m^3; 0.7833 ug/m^3 respectively.

Keywords: environment, pollutant dispersion modeling, stack, palm oil mill, Gaussian dispersion method, Screen view Screen3

Introduction

Indonesia is the largest palm oil exporting country in the world with Riau area as the largest palm oil producer in Indonesia. Oil palm plantations in Riau Province based on the data of 2010 has reached 2,103,175 ha and the production of fresh fruit bunches (FFB) was as much as 36,809,252 tons per year. While the amount of palm oil processing plant in Riau were 146 pieces with production capacity of 6,254 tons per hour [1]. It is estimated that by 2015, biomass form of oil palm empty fruit bunch (PEFB), fiber, and shells from palm oil processing by products will be produced sequentially 23,940,361; 16,416,248 and 7,318,910 tons [2].

Based on existing data, Riau region still lack the palm oil mill for the future because the potential of the land area is still growing and there is still immature plants as well. Therefore we need an increase in palm oil mill processing capacity or the addition of palm oil mill. Seeing the development of the palm oil industry, it is required 41 units palm oil mill needs [1].

Currently, oil palm empty fruit bunch (EFB), fiber, and shells were used as boiler fuel in palm oil mills. According to Raharjo [2], shell, fiber, and oil palm bunches have a high carbon content, more than 44%, which can be easily transformed into dust during combustion. It also produces biomass combustion gases such as CO, SOx, and NOx.

Dust is a form of solid or liquid suspended in the atmosphere under normal conditions. The resulting dust is inhaled and is very easy to get into the lungs, and it will interfere with the upper respiratory system as well as the bottom (alveoli). In the alveoli, accumulation of tiny particles can damage tissue or lung tissue system. Whilst dust, which is smaller than 10 μm, will cause eye irritation and obstruct the view of the eye [3].

Similarly, particulates and gases emitted also have a harmful impact on society and the environment. CO can be a dangerous poison because it can form a strong bond with the blood pigment, haemoglobin, that if CO is inhaled it can lead to death. Sulfur dioxide causes respiratory disorders, gastrointestinal, headache, chest pain, and nerve. Moreover, at above the threshold, it can cause death. Nitrogen oxide itself causes lung damage, while SO and NO are gases that make acid rain [4].

Though the increase in number and capacity of palm oil mill resulted in the burning shell, fiber, and oil palm bunches, it will increase pollutant emissions from palm oil mill [5]. This increase will have an impact on public health due to the increasing number of emissions produced. However, at the present time there has been no research on the concentration of pollutants generated by the palm oil mill in a particular region. This decision making of an area development plan, primarily an industrial arca, docs not considcr thc capacity of the region to the increase in emissions that will be generated.

One effort in addressing the existing problems that the development of industrial estates, especially the palm oil industry, can match the capacity of the environment to give no impact on the environment and society is to conduct a modeling study of pollutant dispersion from a stack into the environment. Modeling study is to predict the distribution of the emission of pollutants in ambient air. Predicted distribution of pollutant emissions needs to be studied in the environmental management efforts to anticipate the negative impacts of industrial activity.

This study aimed to calculate emissions of pollutants generated by the palm oil mill stack, make modeling of the spread of pollutants from the stack to the environment, and to estimate the extent of the area affected by the emission of pollutants from oil palm mills.

Materials and methods

This research was carried out on 15-19 May 2014 in the palm oil industry PT Mustika Agung Sawit Sejahtera (PT. MASS), in the District of Pinggir, Bengkalis Regency, Riau Province. This research was conducted through three stages. The first stage was a preliminary study including the study of literature and preliminary surveys. The second stage was the implementation of the final phase of a research and the last was analysis of measurement data and the formulation of conclusions that have been made.

Primary data collection and processing

The data obtained from the measurements to be performed at the time of the study were as follows:

Measurement of wind speed and direction.

The wind speed was measured at a height of 10 m using a device called an anemometer. Measurement points were in the stack and at a distance of 1200 m, 1500 m, and 2000 m from the stack with the duration of each measurement was 1 hour.

Measurements of topography around the site.

Topography measurements was carried out on the basis of the stack and every 40 m distance as far as 400 m from the stack for each directions are to north, east, south, and west. There was also measured at a distance of 1200 m, 1500 m and 2000 m from the stack.

Measurement of temperature.

Temperature measured in this study was the ambient air temperature surrounding the location. Temperature measurement was done by means of an anemometer. Measurement points were in the stack at a distance of 1200 m, 1500 m, and 2000 m from the stack with the duration of each measurement was 1 hour.

Calculation of emitted pollutant concentrations.

In general, the calculation of emissions from the stack following equation:

$$\text{Emission} = \text{Emission Factor} \times \text{Fuel Feed Rate} \quad \text{(eq. 1)}$$

Note:
Emission = Total emissions of pollutants emitted
Emission Factor = Mass per activity unit

Emission factors used in this study were made by the emission factor from Kun and Abdullah [6] for dust pollutants. Whilst the gaseous pollutants CO, NOX, and SOx emission factors followed Subramaniam and Choo [7]. The emission factor depends on the amount of biomass (shell and fiber) were burned. The rate of fuel use was calculated with the equation as follows:

$$\text{Fuel feed rate} = \frac{\text{Total FFB}}{\text{Mill operation hours}} \times [(\text{Fibre percentage} \times \text{Dry weight percentage}) + (\text{Shell percentage} \times \text{Dry weight percentage})] \quad \text{(eq. 2)}$$

Secondary data collection and processing

The secondary data that had been collected and processed in this study were as follows:

Meteorological data from BMKG SSQ.
This data was needed to determine the predominant wind direction in a certain period of time so that it can be determined that the dominant areas affected by pollution.

Stack data and data sources of emissions.
Stack emissions data was obtained from PT. MASS. The condition data comprised data stack flue diameter and height of the stack. Data source stack emissions consisted of the data processing capacity of the plant, the rate of emission from the stack, the flow rate/velocity gas flowing from the stack, as well as the temperature of the gas emissions that came out of the stack. These were the main data to estimate the dispersion of emissions produced.

Data of spacing and height of buildings

This data was needed to determine the effects of traction building (building downwash) that occurred in the dispersion of pollution generated by PT. MASS.

Pollutant dispersion modelling

Dispersion modeling of pollutants emitted by PT. MASS was conducted using Screen View SCREEN3 software. This software ran on the basis of Gaussian dispersion equation. The modeling was stepped in 3 scenarios, namely:

1. Scenario A, conducted to determine the condition of the spread of pollutants to the environment yearly average. The data used was the average of the environmental conditions during the last 5 years and the average fuel consumption.
2. Scenario B, modeling the spread of pollutants carried to the actual conditions at the time of measurement.
3. Scenario C, carried out modeling the spread of pollutants to describe the worst condition using a class of highly unstable stability, ie the stability of B (unstable).

Validation of pollutant modelling results

Scenario B was validated with direct measurement of 3 stack points; at a distance of 1200 m, 1500 m, and 2000 m from the stack with the duration of each measurement was an hour. The dust measurements used dust sampler with gravimetric analysis method obtained in the Laboratory of Aquatic Ecology and Environmental Management Faculty of Fisheries and Marine Sciences Universitas Riau.

Mapping of pollutant dispersion

Pollutant concentrations were measured at all measurement points in PT. MASS with a concentration based mapping of points that have been set previously. Each point sampling would provide information of pollutant concentrations in the region based on the color levels of the predetermined concentration range. This area mapping was carried out with Surfer10 software.

Results and discussion

Pollutants emitted by oil palm mill

Emissions of pollutants generated by the palm oil mill stack of PT. MASS were calculated using equation 1 with the emission factors created by Kun and Abdullah [6], while for gaseous pollutants CO, SOx, and NOx emission factors followed Subramaniam and Choo [7]. The dust emission rate generated by PT. MASS was 36.4 g/s. The gaseous pollutants CO emission rate obtained at 13.84 g/s, SOx was 0.213 g/s and NOx was 24.49 g/s.

Pollutant dispersion modelling

1. Scenario A (*Annual Case*) modelling
The average wind speed was 5.87 m/sec from the last 5 years and the stability of the atmospheric stability belonged to class D, which was the neutral atmospheric stability. The dominant wind direction was to the south. The maximum concentration of dust emission to the south was at 1340 m from the stack with concentration of dust was 133.9 ug/m^3. The parameters of CO, NOx, and SOx emissions of CO was found that the maximum concentration was

also at a distance of 1340 m from the stack with successive concentrations were 50.90 ug/m^3; 90.06 ug/m^3; and 0.7833 ug/m^3. More detail can be seen in **Fig 1**.

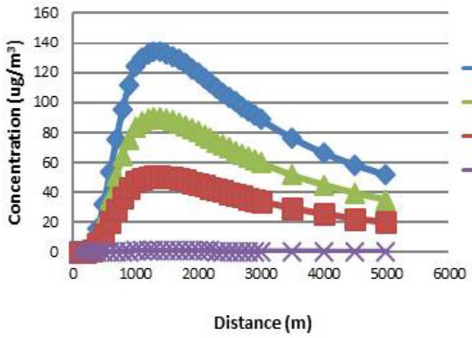

Fig 1. Emissions concentration in the south direction at neutral stability

Dispersion of pollutant emissions in the north showed that the concentration of dust and gas were at a distance of up to 1401 m. It was obtained that the maximum concentration of dust, CO, NOx, and SOx were 130,7 ug/m^3; 49.71 ug/m^3; 87.97 ug/m^3; and 0.7651 ug/m^3 respectively. More detail can be seen in **Fig 2**.

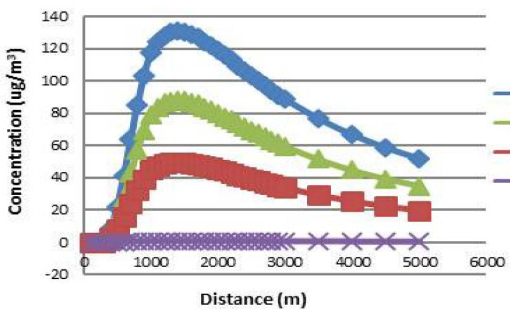

Fig 2. Emissions concentration in the north direction at neutral stability

The distribution on the west and east with maximum pollutant concentration was found at a distance of 1403 m from the stack. The maximum concentration of dust, CO, NOx, and SOx were 130,6 ug/m^3; 49.67 ug/m^3; 87.89 ug/m^3; 0.7644 ug/m^3. More detail can be seen in **Fig 3**.

2. Scenario B (*Actual Case*) modelling

The data at the time of measurement stated that the wind speed was 2.9 m/s, temperature was 36.4°C, the wind blew towards the south and the stability of the atmosphere belonged to class B which was un-stable. The result can be seen in **Fig 4**.

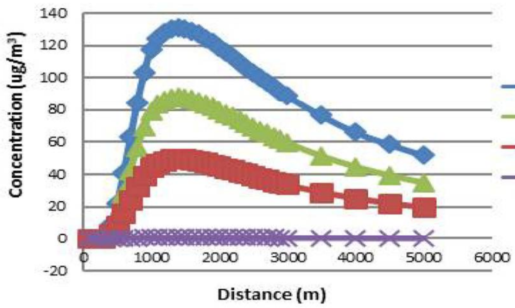

Fig 3. Emissions concentration in the east and west direction at neutral stability

This modeling showed that maximum concentration of the pollutant was at a distance of 715 m. The maximum concentration of dust, CO, NOx, and SOx were 158.4 ug/m^3; 60.22 ug/m3; 196.6 ug/m^3; 0.9268 ug/m^3.

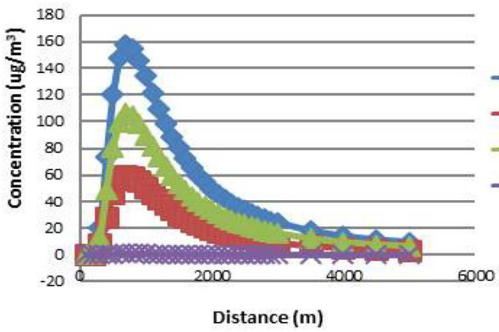

Fig 4. Emissions concentration on current measurement

3. Scenario C (*The Worst Case*) modeling

Along 5 years of meteorological data represented the worst conditions ie wind speed was 4 m/s and atmospheric stability conditions belonged to class B which is unstable. This modeling showed that the maximum concentration of dust emission to the south was at a distance of 649 m from the stack with a concentration of 164.3 ug/m3. CO, NOx, and SOx emissions of also at a distance of 649 m from the stack with successive concentrations were 62.48 ug/m^3; 110.6 ug/m^3; 0.9616 ug/m^3. More detail can be seen in **Fig 5**.

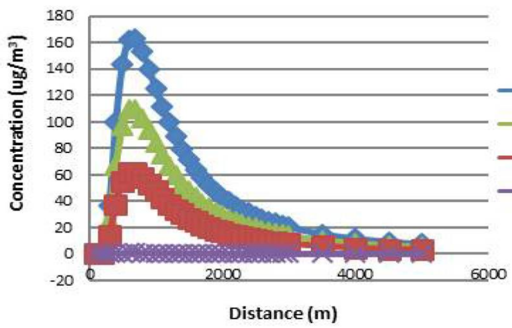

Fig 5. Emissions concentration in the south direction at the unstable stability

Dispersion of pollutant emissions in the north showed that the concentration of dust and gas that were at a distance of maximum 654 m. The maximum concentration of dust, CO, NOx, and SOx were 163,6 ug/m^3; 62.21 ug/m^3; 110.1 ug/m^3; 0.9574 ug/m^3. More detail can be seen in **Fig 6.**

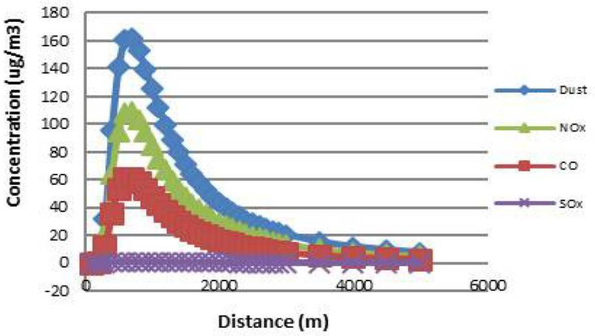

Fig 6. Emissions concentration in the north direction at unstable stability

In other directions, the distribution on the west and east of the maximum concentrations of pollutants were at a distance of 654 m from the stack. The maximum concentration of dust, CO, NOx, and SOx were 163,6 ug/m^3; 62.20 ug/m^3; 110.1 ug/m^3; 0.9573 ug/m^3 as shown in **Fig 7.**

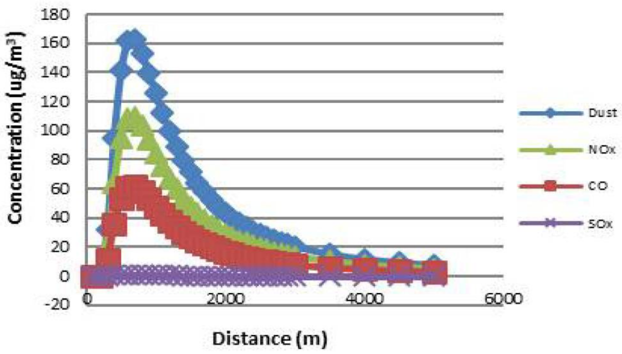

Fig 7. Emissions concentration in the west and east direction at unstable stability

Validation of pollutant modelling results

Validation was performed on the parameters of the dust with 3 different points. The measurement results were similar to the results of the calculations that have been made before. The value of difference between the emission load calculation results and the burden of emission measurement results can be seen in **Table 1**.

There were difference percentages of dust concentration between both dust emission measurement and the calculation. The results of these calculations had a smaller distance difference from the measurement results. All values were in negative number (-), the mean value of dust emission concentration measurement were below the value of the concentration of dust emission calculation. The difference was less than 19%.

Table 1. Comparison concentration dust emissions measurement results with results calculation

Parameter	Dust concentration (ug/m^3)		
	1250 m	1500 m	2000 m
Measurement	109.3	79.98	49.9
Calculate	95.091	67.983	40.419
% Difference	-13 %	-15 %	-19 %

Mapping of pollutant modelling results

Values obtained from the modeling that were used in mapping areas had the same concentration. The area of the region described was 10 x 10 km^2 and this mapping for the dust dispersion modeling used scenario A. The dust concentrations measured at all sample points were mapped in a mapping based on the concentration of the points that have been set previously (**Fig 8**).

The area of the flue dust dispersion palm of PT. MASS was divided into 6 general colors: red brick (110 ppm-140 ppm), orange (95 ppm-110 ppm), yellow (75 ppm-95 ppm), green (45 ppm-75 ppm), blue (10 ppm-45 ppm), and purple (-5 ppm-10 ppm). In this dust emission, it had a sampling point or a high concentration of red brick that was at a distance of 1,000 to 2,500 m from the stack. Each concentration at that point was 117.7; 124; 128; 130.1; 130.7; 130.2; 128.9; 126.9; 124.5; 121.7; 118.8; 115.7; and 112.5 ppm.

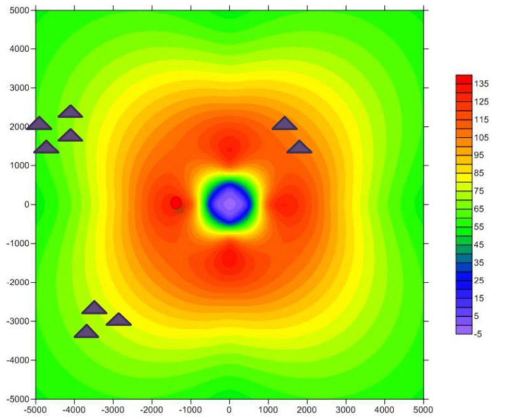

Fig 8. Mapping concentration of dust emissions PT. MASS

● = Stack of PT. MASS

▲ = Settlement

The dominant wind direction in this region was to the south, therefore, the south area region of PT. MASS would be affected so that the concentration of emissions that spread to the south should always be monitored. However, these concentrations remained at the threshold set by the government through the Indonesian Government Regulation No. 41 of 1999 which stated the air pollution control for airborne dust levels allowed was 230 ug/m3.

Recommendations for new palm oil mill capacity and location

Simulation of the increasing emissions can be seen in **Table 2.** Increasing emissions capacity from 30 tons of FFB per hour to 45 tons of FFB per hour are still below the quality standards established by the Indonesian Government Regu-lation No. 41 of 1999 on Air Pollution Control. However, on increasing the capacity to 60 and 75 tons of FFB per hour will lead the dust emis-sions exceed the quality standard specified. Therefore, the increase in capacity that is still allowed is 45 tons of FFB per hour.

Table 2. Maximum concentration of emissions mills in a series of capacities

Parameter		Capacity (ton FFB/hour)			
		30	45	60	75
Emission rate (g/s)	Dust	36.41	54.61	72.82	91.02
	CO	13.84	20.76	27.68	34.59
	NOx	24.49	36.73	48.97	61.21
	SOx	0.21	0.3194	0.4256	0.5323
Maximum Concentration (ug/m^3)	Dust	133.9	204.2	272.2	340,3
	CO	50.90	77.61	103.5	129.3
	NOx	90.06	137.3	183.1	228.8
	SOx	0.7833	1.194	1.591	1.990

In order to determine the location of the construction of a new palm oil mill; the certain distances and processing capacity have to be calculated. The calculation was carried out using consideration of pollutant concentration of dust to the south and to the north. The calculation of the emission concentration of palm oil mill construc-tion site can be seen in Table 3.

The establishment of palm oil mill with a capacity of 30 tons of FFB per hour could be done at any distance so whatever distance the new palm oil mill was established, the resulting emissions wouldl still meet the standards set. The establishment of palm oil mill with a capacity of 30 tons of FFB per hour could be done at a distance of 2000 m from PT. MASS while the establishment of palm oil mill with a capacity of 45 tons of FFB per hour could be done at a distance of 2500 m. However, the establishment of palm oil mill with a capacity of 60 and 75 tons of FFB per hour in the surrounding area of PT. MASS was not recommended because the concentration of dust emissions would result exceeding the quality standard set.

Table 3. Maximum concentration of emissions on mill siting and capacity

Distance (m)	Maximum concentration (ug/m^3) for each capacity (tons of FFB/hour)			
	30	45	60	75
700	258.20	324.50	390.80	457.10
1000	249.20	315.10	381.40	447.70
1500	233.00	299.10	365.40	431.70
2000	218.31	262.60	348.01	412.81
2500	176.38	200.70	301.08	363.38
3000	133.80	200.70	267.60	334.50

Conclusions

From the above explanation it could be concluded that the dust emission rate generated by the palm oil mill stack of PT. Mustika Agung Sawit Sejahtera was at 36.4 g/s. As for the gaseous pollutants; CO emission rate obtained at 13.84 g/s, NOx was 24.49 g/s, and SOx was 0.213 g/s. The dominant direction of pollutants spread was to the south with the maximum concentration of dust, CO, NOx, and SOx were 133,9 ug/m^3; 50.90 ug/m^3; 90.06 ug/m^3; 0.7833 ug/m^3 respectively. The affected area mapped was 10 x 10 km^2 where the lowest concentration was obtained at a distance of less than 200 m from the stack while the highest concentration was obtained in the area that lied between 1000 and 2000 m from the stack. It was found that the establishment of a new plant could be performed for a capacity of 30 and 45 tons of FFB per hour, where the distance allowed is 2000 m for a capacity of 30 tons of FFB per hour and 2500 m for the establishment of palm oil mill with a capacity of 45 tons of FFB per hours.

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