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SO2 Pollutant Distribution Model Using Gaussian Method for Multiple Point Sources (Case Study in PLTMG Duri)

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Abstract — Duri Machine and Gas Power Plant (PLTMG) is a company, built by the State Electricity Company (PT PLN) in Riau Province. This PLTMG deploys High Speed Diesel (HSD) and Liquefied Natural Gas (LNG) fuel. In this research, a SO2 pollutant distribution model from 4 active chimneys in PLTMG Duri has been made by using Gaussian dispersion. The results of the model show that SO2 Emission from HSD fuels have higher concentrations than in HSD fuels. The highest concentration at 2m receptor height occurs at a distance of 250 m from the chimney. The concentration of SO2 emissions in the air produced by PLMTG Duri is still below the quality standard (PP No. 41 of 1999).

Keywords—Gaussian, SO_2, Multiple Point Sources, Model

I. INTRODUCTION

Sulfur dioxide SO2 is a pollutant from industrial sources that acts as a precursor of sulfuric acid H2SO4, a colorless gas causing flavor when the concentration is 0.3 ppm and produces a strong odor at a concentration level which is greater than 0.5 ppm, a component of aerosol particles that affects acid deposition, global climate, and the global ozone layer. The main sources of SO2 are coal-fired power plants, burning fossil fuels, volcanoes and other industrial sector resulting in additional emissions in the air [1]

The Machine and Gas Power Plant (PLTMG) is one of the companies built by the State Electricity Company (PT.PLN) which is tasked with supplying and managing electricity power, much needed to support human life. This fossil fuel uses High Speed Diesel (HSD) and Liquefied Natural Gas (LNG) is a fossil fuel which can produce exhaust gases such as sulfur dioxide (SO2), nitrogen dioxide (NO2), methane and carbon dioside (CO2).

Gauss Dispersion Model is one of the calculation models that is widely used to simulate the effect of emissions. This can be included in the calculation of physical variables and contribute more detailed information about the source of contamination. This was reflected under the study of [2] modeling the distribution of pollutants in gaussian method conducted by Fazrol Rozi, (2016) about the Pattern of Chimney Emission Distribution Case Study of PT. Semen Padang Indarung West Sumatra Indonesia. The study used Gaussian Multiple Point Sources method with SO2 emissions [3]. Ardi Rahmadani, (2017), modelled such Multiple Point Sources Air Pollution in the Cement Industry in Tuban, East Java, by using Gaussian method with particulate (dust) emissions [4].

PLTMG in Duri is one of Power Plants in Riau Province. Several studies on emissions produced by such PLTMG include Yulia and Sri (2014) found that the CO2 Direction and Concentration in the Chimney of the PLTMG apparently adopted Gaussian method [5]. In 2016, Yulia and Sri continued their research by simulating the direction of distribution and calculating CO, NO2, SO2 and Particulate emission levels from Single Point Sources chimneys [6]. In this study SO2 pollutant modeling was developed by using Gaussian method of all Duri PLTMG chimneys (Multiple Point Sources).

II. THEORETICAL BACKGROUND

A. Emission Rate

To determine the rate of exhaust emissions, it is by multiplying the Emission Factor (FE) with the amount of fuel used by an activity (A). Emission factor shows the estimated amount of pollutants to be emitted by each unit component of the activity from an emission source.

$$Q = FE \times A \quad \text{………………………………………………(2.1)}$$

Q = Pollutant emission rate
FE = Emission factor
A = the amount of fuel used in an activity

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B. Wind Direction and Speed

Wind speed is normally measured at standard height, which is 10 meters. For modeling data, wind speed data at the emission release height is needed. To get wind speed at removable height, the following formula is used:

$$u = u_{10}\left(\frac{Z_e}{10}\right)^{p} \qquad (2.2)$$

u is the wind speed at the height of the chimney, *u10* is the wind speed at an altitude of 10 meters, *ze* is the height of the chimney, and p is the land surface roughness constant in accordance with the land use conditions of an area at an altitude of 10 meters (for rural areas constant 0, 07 is used in classes A and B, 0.10 for class C, 0.15 for class D, and 0.35 for classes E and F), and *Ze* is the height of the chimney at ground level.

C. *Atmospheric Stability*

Atmospheric stability is a method used to classify the atmosphere's ability to thin and digest air. Atmospheric stability shows the degree of air turbulence in the vertical direction. The air condition becomes unstable when there is vertical mixing. This happens when solar radiation is strong (daytime) and wind speeds are low. Absorption of solar radiation causes the earth's surface to heat up so that it warms the layers of air near the earth's surface. This warm air will increase and cause vertical mixing. Stable conditions occur when the surface of the earth is cooler than the air above it (such as on a clear night) [7].

Atmospheric stability according to Pasquill Gifort is classified into six classes, class A to class F. Class A is intended for the most unstable air conditions, class B is unstable, class C is slightly unstable, class D is neutral, class E is somewhat stable and class F is stable. The class of atmospheric stability during the day is more determined by wind speed and the level of sunlight radiation (in-solation). Whilst, the class of atmospheric stability at night is more determined by wind speed and cloud cover.

D. *Koefisien Dispersi*

Horizontal (σy) and vertical (σz) dispersion coefficients are pollutant dispersion parameters, which are the coefficient of distance function from pollutant sources in the dominant wind direction towards various classes of atmospheric stability. For the calculation of horizontal and vertical dispersion, it should be adjusted to the conditions in the field, which should be adjusted to the wind speed and the stability of the atmosphere. According to Fasquill-Gifford, the horizontal constant is expressed as

$$\sigma_y = a x^{0.894} \qquad (2.3)$$

and the vertical dispersion constant is expressed as

$$\sigma_z = c x^{d} + f \qquad (2.4)$$

Values a, c, d, and f depend on the stability of the atmosphere whose numbers are in accordance with Table 2.2. To determine the class of atmospheric stability A, B, C, D, E and F, the calculation depends on the surface wind speed, sunlight and the degree of clouds.

E. *Plume Height*

Plume height is a vertical and horizontal plume movement from the source. To determine the height of a puff of smoke is by using Equation 2.5, which is the height of the puff will decrease with an increase in wind speed, in other words the height of the puff (Δh) is inversely proportional to the speed of the wind.

$$\Delta h = \frac{Vs.d}{u}\left(1{,}5 + 2{,}68.10^{-3}.P\left(\frac{Ts-To}{Ts}\right)d\right) \qquad (2.5)$$

Where the velocity of the gas exits the chimney (vs) in m/sec, the top diameter of the chimney (d) in meters, the wind speed in the chimney (u) in m / sec, Atmospheric pressure (P) in mb (1 atm = 1,103 mb), temperature flue gas exits (Ts) in 0K, atmospheric air temperature (T0) in 0K.

The effective height of the chimney (H) as in Figure 2.1 is the sum of the height of the puff smoke (Δh) with the actual height of the chimney (h).

$$H = \Delta h + h \qquad (2.6)$$

F. *Gaussian Method on Multiple Point Sources*

Multiple Point Sources modeling is an accumulation of several sources that are considered as sources of emissions. If the distance of each chimney is more than 100 m point stated as area sources, and if the distance of each chimney point is less than 100 m and emissions are less than 20%, then it can be called a multiple point source [8]. Calculation of multiple point source models can be calculated by using a single point source model calculation after which accumulated emissions from several sources in a receiver.

$$C(x,y,z;H) = \frac{Q}{2\pi\,\sigma_y\,\sigma_z\,u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \qquad (2.7)$$

Where C expresses the concentration of air quality parameters in units of mass per cubic meter, Q represents the pollutant emission rate expressed in units

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of micrograms per second. σy is the dispersion coefficient horizontally with respect to the x axis and σz for the dispersion coefficient vertically with respect to the x axis, both of which are expressed in meters (m), u is the velocity of the chimney in meters per second, while H is the effective height of the chimney, and z is the height of the receptor (impact receptor) above ground level.

The assumptions used in this model include:

1. Pollutant emission rates are considered relatively constant.
2. The average wind speed and direction are constant.
3. The chemical properties of the compounds released are stable and unchanged in the air.
4. The area around the source of pollutants is flat and open.

III. METHODOLOGY

A. *Determination of Variables*

This data was taken from January to February in 2019. To make a gaussian method, equation 2.7 is used, the data needed is industrial source data (PLTMG) and meteorological data (BMKG Sultan Syarif Kasim II Pekanbaru). This requires chimney data from industrial sources which can calculate the SO2 emission rate, the effective height of the chimney, and smoke height and average wind speed. It determines the level of atmospheric stability in accordance with meteorological conditions and calculates the values coefficient of vertical dispersion (σz) and horizontal (σy).

B. *Data Collection*

In collecting the data, it requires industrial data and meteorological data. The data used in this study are PLTMG data derived from data on the amount of LNG and HSD fuel, chimney diameter, chimney tower height, release temperature and velocity.

Calculating SO2 Concentration Value includes determining the concentration of pollutants at several points and making a map of pollutant distribution. Concentration calculations at several receiving points are based on the level of emissions produced by each stack, thus the concentration values at the same receiving point are accumulated. Following are the steps to Calculate SO2 Concentration Value Accumulation, such as:

a. Calculation of emission rates originating from chimneys of known diameter width, and emission discharge rates.
b. Calculate the effect of meteorology on the process of pollutant dispersion in the atmosphere. The dispersion process is influenced by the state of vulnerability, wind direction and speed, and ambient temperature.
c. Determination of atmospheric stability is based on the stability class criteria table according to Pasquill-Gifford. Determination of criteria is based on wind speed and sunlight radiation or cloud cover.
d. Model SO2 emissions with Gaussian dispersions

IV. RESULT AND DISCUSSION

A. SO_2 Emission Rate

There are 7 chimneys found in PLTMG Duri, but there are only 4 active chimney; chimney 1, chimney 2, chimney 4 and chimney 6. There are 3 nonactive chimneys such as chimney 3, chimney 5 and chimney 7, as it is caused by the damage to the engine and there has been no repair or maintenance actions. Emission fuels used throughout the chimney are Liquefied Natural Gas (LNG) and High Speed Diesel (HSD), where the required data is emission factor (FE) data and the amount of fuel emissions. The data collection was carried out in January and February 2019, because it was caused by the system that occurred in the PLTMG using the latest data annually.

How to calculate the SO2 emission rate is by using equation 2.1. The results of the calculation of SO2 emission rates can be seen in Table 4.1, based on the fuel used, the total SO2 emission rate of 4 chimneys of LNG fuel is 30,208,333 and HSD is 21,534,753. The rate of emission of LNG fuel is greater than HSD fuel, because the emission factor (FE) of LNG fuel is greater than HSD.

B. *Atmospheric Stability Classes*

Classes of atmospheric stability according to Pasquill Giford are divided into six classes, namely class A to class F. Class A is indicated for the most unstable air conditions, class B is unstable, class C is slightly unstable, class D is neutral, class E is somewhat stable and class F is stable which is affected by wind speed and solar intensity. The intensity of the sun is determined based on the number of sunny days. If the number of sunny days > 60%, categorized as strong sun intensity, 30% - 60% is categorized as moderate sun intensity and < 30% is categorized as weak sun intensity.

In January and February 2019, wind speeds were 3.9 m/s and 3.87 m/s, respectively. The number of sunny days is above 60%, both in January and February. So that the atmosphere's stability is in class B (unstable) and the sun's intensity is categorized as strong.

C. *Calculation of SO2 Concentration Gaussian Dispersion Model*

Gaussian dispersion model uses equation 2.7. In this study, this concentration was calculated from a distance of 0m to 3000m at 500m intervals. The SO2 concentration threshold used is the national ambient air quality standard according to government regulation No. 41 of 1999 [9]. The parameter used is SO2, where the SO2 quality standard has 24 hours with 365 quality

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standards, the calculation is 365 multiplied by 31 days (in one month) with 11,315 results.

BMKG analysis results in January found that the wind moved from northeast to southwest with an average wind speed of 3.90 m/s and an ambient temperature of 32.5 C, so that the receiving point of the emission distribution is in the west. In February, it was found that the wind moved from the southwest to the northeast with an average wind speed of 3.78 m/s and an environmental temperature of 31.8 C, so that the receiving point of the emission distribution was in the northeast of the industrial area.

For LNG fuels with a range of (x) 50 to 3000 m, the highest SO2 concentration values were found in Chimney 1 in January with a distance of 250 ie 189.2706519 µg / m3 and the lowest was in chimney 2 which was 140.7483918 µg / m3 (Figure 4.1). This LNG fuel used 70% of natural gas, namely coal, since it burns faster and the biggest combustion occurs at a distance of 250 m. This resulted in the evaporation of smoke and the spread of smoke accompanied by wind direction which is not necessarily all stable depending on the difference in chimney temperature with ambient temperature and wind conditions at such time. If the air in the surrounding environment is cold, the smoke coming out of the chimney can decrease instead of going up.

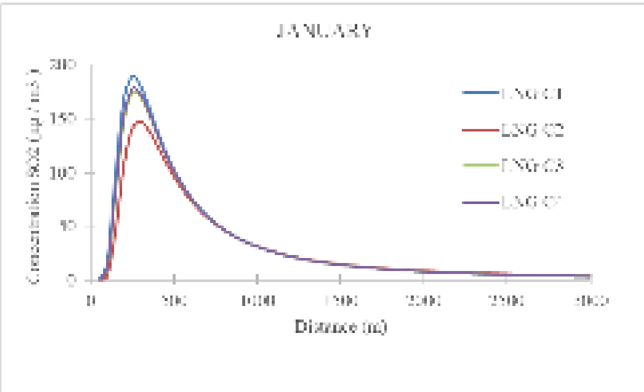

Figure 4.1. Concentration of SO_2 with LNG fuel in January

LNG fuel with the highest SO2 concentration value was found in February at chimney 1 with a distance of 250 m; 186.7541995 µg / m3 and the lowest was found in chimney 3; 160.7371886 µg / m3 (Figure 4.2). In February SO2 concentrations had almost the same concentration value.

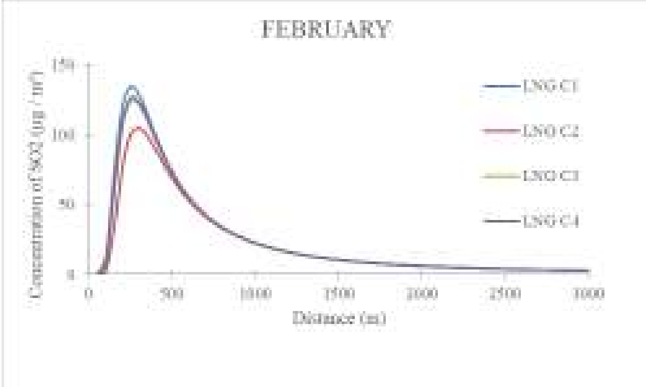

Figure 4.2. Concentration of SO_2 with LNG fuel in February

Gaussian SO2 dispersion with LNG and HSD fuels can be seen in Figure 4.3. In January, LBG fuel obtained with the lowest SO2 concentration was found at a distance of 50 m with a value of 0.028255366 µg / m³ and the highest was at a distance of 250 m with a value of 681.4055409 µg / m³. While at a distance of 300 m, there was an exponential decrease and SO2 concentrations began to stabilize at a distance of 2050 m with a value of 31.75000568 µg / m³ to a distance of 3000 m with a value of 15.01369571 µg/m³.

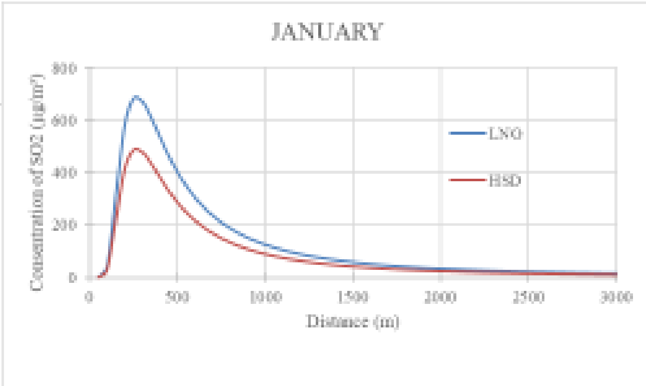

Figure 4.3. Concentration of SO_2 with HSD and LNG Fuels

The same thing happened with HSD fuel in January, but the highest value of SO2 emission concentration was lower than LNG fuel. The lowest concentration was at a distance of (x) 50 m with a value of 0.020142532 µg / m³ and the highest was at a distance of 250 m with a value of 485.7566891 µg / m³, and an decreasing SO2 concentration occured at a distance of 300 m.

In February, the highest concentration of SO2 emissions from LNG fuel was found at a distance of 250 m with a value of 699,3619097 µg / m³. While the SO2 concentration of HSD fuel is lower at 498.557328 µg / m³.

SO2 emissions generated from chimney 4 by using gaussian dispersion indicated that the value of SO2 emissions from LNG fuels was higher than HSD fuels.

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And the value of SO2 emissions from the PLTMG was still below the quality standard, both in January and February.

V. CONCLUSION

1. SO2 Emission Concentrations from HSD fuels have higher concentrations than HSD fuels
2. The highest concentration at 2m receptor height occurs at a distance of 250 m from the chimney
3. SO2 emissions concentrations in the air are still below the quality standard (PP No. 41 of 1999)

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