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Dispersion Modeling of Power Plant Emissions on Air Quality

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Abstract—Air pollution caused by emission is one of the serious environmental problems in the world. Emissions resulted from industrial, transportation, and energy sectors. The latter two mentioned as the major contributor in decreasing ambient air quality due to the outcome of fossil fuels combustion containing the toxic gaseous of sulfur dioxides (SO_2), nitrogen oxides (NOx), and particulate matter ($PM_{2,5}$) that have an impact to the human health and environment. To prevent the ambient air quality getting worse, strict environmental regulations worldwide has been established and one of them is in Indonesia. The Ministry of Environment of Indonesia has formed a regulation of ambient air quality limitation that must be complied by the whole industries, including energy sector. This study is going to present the prediction concentrations of emission dispersion of power plant at ground level in an urban area of Indonesia based on the principle of Gaussian plume dispersion modeling. The result of the prediction model showed that gaseous emission dispersion of SO_2, NOx, and $PM_{2,5}$ were below the Indonesia ambient air quality standard.

Index Terms—ambient air quality, dispersion Modeling, emission, gaussian plume model, nitrogen oxides, particulate matter, power plant, sulfur dioxides

1 Introduction

RAPID economic and population growth which lead to the high industrial activities, energy consumption and number of vehicles not only offer great advantages for world income but also cause severe impact for human due to the main sources of air pollution that could decrease ambient air quality [1], [2]. Emissions of air pollution from transportation and energy sector are the result of fossil fuels combustion, such as coal, natural gas and oil. The fossil fuels combustion of energy sector depends on the composition and grade of the fossil fuels, the type and size of the plant, and the firing and loading practices used [4]. Coal is the major fuel of energy sector and also the main contributor to air pollution [2], [3].

The fossil fuels combustion has been a disputable issue debated around the world, specifically coal combustion due to the most gaseous emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon oxide (CO), carbon dioxides (CO_2), and particulate matter (PM) emitted from power plants that could adverse effect to the human health, economic, and environment in the large country of developing world [5]. For instance, in China 1995, the health and economic cost caused by this emissions were estimated nearly 8 percent of GDP [4]. A study conducted in Istanbul that the 0-2 age group investigated had respiratory system disease due to being exposure SO_2 and PM for 5 years [6]. Another research revealed that hospital in Ontario, Canada had admission in 168 acute cares of cardiac and respiratory problems due to increasing of PM [7]. According to WHO, NOx emissions from vehicle increased due to the growth in number of vehicles and the effect to human health can be in short-term and long-term, include lower respiratory illness, bronchitis, chronic cough, and increasing infant mortality [8], [9].

The population and economic have been grown significantly in Indonesia, particularly in the urban areas. Nowadays, to fulfill the demand of energy consumption, one of the developments conducted by the government of Indonesia is energy sector through the construction of 35.000 Megawatt of power plants whereas the most fossil fuels used in this program is coal and it can threat to the ambient air quality. For investigating the decreasing ambient air quality caused by power generation, it can be known from the dispersion. The dispersion of emissions can be estimated by simulating air quality dispersion models based on Gaussian distribution model. Gaussian distribution model used to estimate the concentrations downwind of a pollutant source are affected by several factors like emission rate, terrain, and wind speed and wind direction [10], [11]. Hence, the aim of this study is to forecast the concentrations of the dispersion emissions of power plant at ground level in the urban areas of Indonesia, especially in the region of Jakarta and the surrounding areas.

2 Material and Method

2.1 Sampling Location

The region of Jakarta and the surrounding areas is the urban areas of Indonesia where the economic and also the population growing fast. It is contain with various industrial activities and transportation. Supporting those, some power plants constructed. Five power plants used as samples of point source were natural gas power plant (PLTGU) of Muara Karang, Tanjung Priok 3, and Muara Tawar, and coal fired power plant (PLTU) of Lontar 3 and Suralaya 8. PLTGU Muara Karang and PLTGU Tanjung Priok 3 located in Jakarta, PLTGU Muara Tawar located in Bekasi, while PLTU Lontar 3 located in Tangerang, and PLTU Suralaya 8 located in Cilegon.

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2.2 Meteorological Data

In this study, the meteorological data used was 20 years (1998–2018) and collected on three station, Jakarta, Tangerang, and Cilegon. Jakarta station was used for PLTGU Muara Karang, PLTGU Tanjung Priok 3, and PLTGU Muara Tawar. Meanwhile, Tangerang station and Cilegon station used for PLTU Lontar 3 and PLTU Suralaya 8, respectively. All the six stability classes of the wind speed that recorded on those stations calculated in the simulation.

The meteorological data used to determine where the direction of emissions plume mainly dispersed according to wind data is transformed into Wind Rose plot [12]. Wind rose is a wind speed distribution diagram that shows the wind blowing from each direction [13].

2.3 Dispersion Modeling

Air dispersion modeling can be solved with various methods. However, the well-known method is Gaussian distribution [12]. Gaussian dispersion model is the most widely used dispersion model and the computational basis model distributed by U.S. EPA [4]. It has an extremely fast response time due solving a single formula that can be written as follows [12]:

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

Where,
C = the concentration (µg/m^3)
Q = the emission rate of the pollutant from the source (g/s)
u = wind speed (m/s)
y = crosswind (m)
z = vertical direction (m)
H = effective stack height (m)
σy = standard deviation of plume concentration distribution in horizontal (m)
σz = standard deviation of plume concentration distribution in vertical (m)
The illustration of plume dispersion shown in Fig 1.

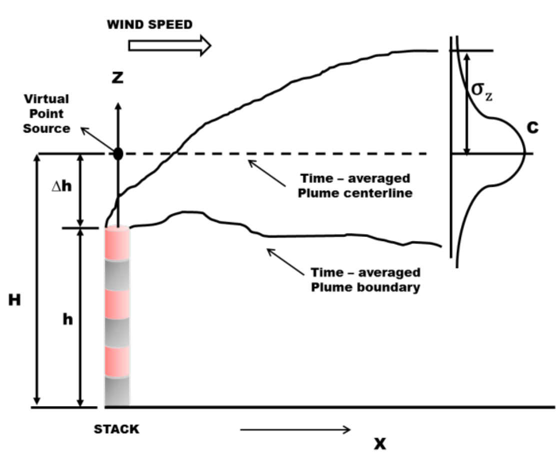

Fig 1. Plume Dispersion Ilustration

The emission rate (Q) is obtained from emission flow rate multiplied by the emission value of point source. The emission gases would be simulated in this research were sulfur dioxide (SO_2), nitrogen oxides (NOx), and particulate matter (PM).

Wind speed (u) divided into six atmospheric stability classes (A-F) with the most unstable conditions till the most stable conditions. Class A defines unstable condition, B refers to moderate unstable, C is slightly unstable, D is neutral condition, E is slightly stable, and class F is the most stable condition. For the detail, it can be seen in Table 1 [14], [15].

TABLE 1
ATMOSPHERIC STABILITY CLASSES

Surface Wind Speed (m/s)	Day-time insolation			Night-time cloud cover	
	Strong	Moderate	Slight	≥ 4/8	< 3/8
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

The determination of atmospheric stability will enable σy and σz which is a dispersion coefficients in the lateral and vertical direction to be quantified of the main equation [12], [14]. It was first discovered by Pasquil in 1961, then it developed by Gifford in that time. σy and σz can be written as follows:

$$\sigma y = a x^{0.894} \quad (2)$$
$$\sigma z = c x^{d} + f \quad (3)$$

The value of a, c, d, and f varies for each classification of atmospheric stability. Table 2 shows these values [15].

Assuming at ground level (z = 0), the equation can be simplified as follows:

$$C(x,y,0) = \frac{Q}{\pi u \sigma_y \sigma_z}\left[-\frac{y^2}{2\sigma_y^2} - \frac{H^2}{2\sigma_z^2}\right] \quad (4)$$

TABLE 2
DISPERSION COEFFICIENTS

Atm. Stability	a	$x \leq 1\ km$			$x \geq 1\ km$		
		c	d	f	c	d	f
A	213	440.8	1.941	9.27	459.7	2.094	-9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	-1.7	44.5	0.516	-13.0
E	50.5	22.8	0.678	-1.3	55.4	0.305	-34.0
F	34	14.35	0.740	-0.35	62.6	0.180	-48.6

U.S. EPA have been developed some modification Gaussian plume models to predict ambient air concentration of pollutant and one of them is widely used plume model, namely Industrial Complex Source (ICS) [5], [16]. ICS is a steady-state Gaussian model that requires input data on source characteristics, hourly meteorological data records, receptor location, and topography to define the conditions of plume rise, transport, deposition, and diffusion [16]. This model would be performed in the simulation to estimate the concentrations.

2.4 Ambient Air Quality Standard

Indonesia has own maximum ambient air quality limitation for each industries, including power plant business which has

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been regulated by Ministry of Environment and Forestry on Ministerial Regulation Number 41 of 1999 about maximum value of air pollution control [17] and shown in Table 3.

TABLE 3
MAXIMUM VALUE OF AMBIENT AIR QUALITY

Pollutant	Maximum Value (µg/Nm³)
Sulfur Dioxide (SO_2)	900 (1 hour) 365 (24 hours)
Nitrogen Dioxide (NO_2)	400 (1 hour) 150 (24 hours)
Particulate Matter ($PM_{2,5}$)	65 (24 hours) 15 (1 year)

The result then compared to the regulation whether the value was lower or even higher than the threshold. Hence, various appropriate ways of prevention of uncontrolled emissions can be considered and implemented if the concentration is higher than the limitation.

3 Result and Discussion

3.1 Wind Rose Plot

Fig 2a and 2b showed that the most dominant wind blowing of Jakarta and Tangerang station was in the east with the highest speed was 6 to 9 m/s. However, the frequency of 6 to 9 m/s of Tangerang station were less than Jakarta station. It could be inferred that the plume would be dispersed in reverse direction, was in the west. As shown in Fig 2c, Cilegon station had the most dominant wind blowing in the east-northeast whereas the pollutant would be spread out in the west-southwest direction at speed 6 to 9 m/s.

3.2 Predicted SO_2 Concentration

The SO_2 concentration output was an hourly, hence according to Table 3, the ambient standard used to compare was 900 µg/m³. The graph that illustrated on Fig 3 showed the difference levels of concentration in a range 15000 m.

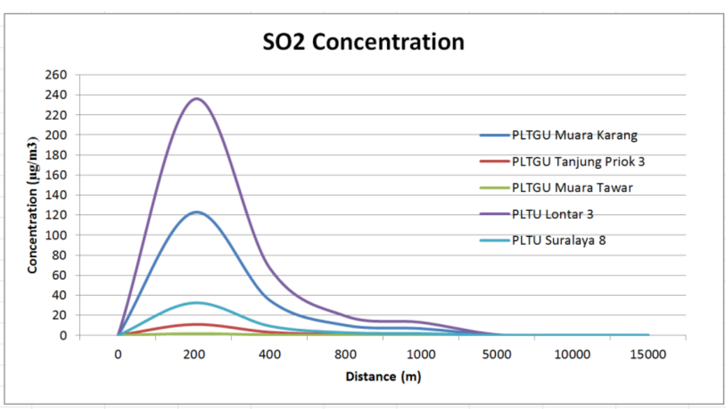

Fig 3. Predicted SO_2 Concentration

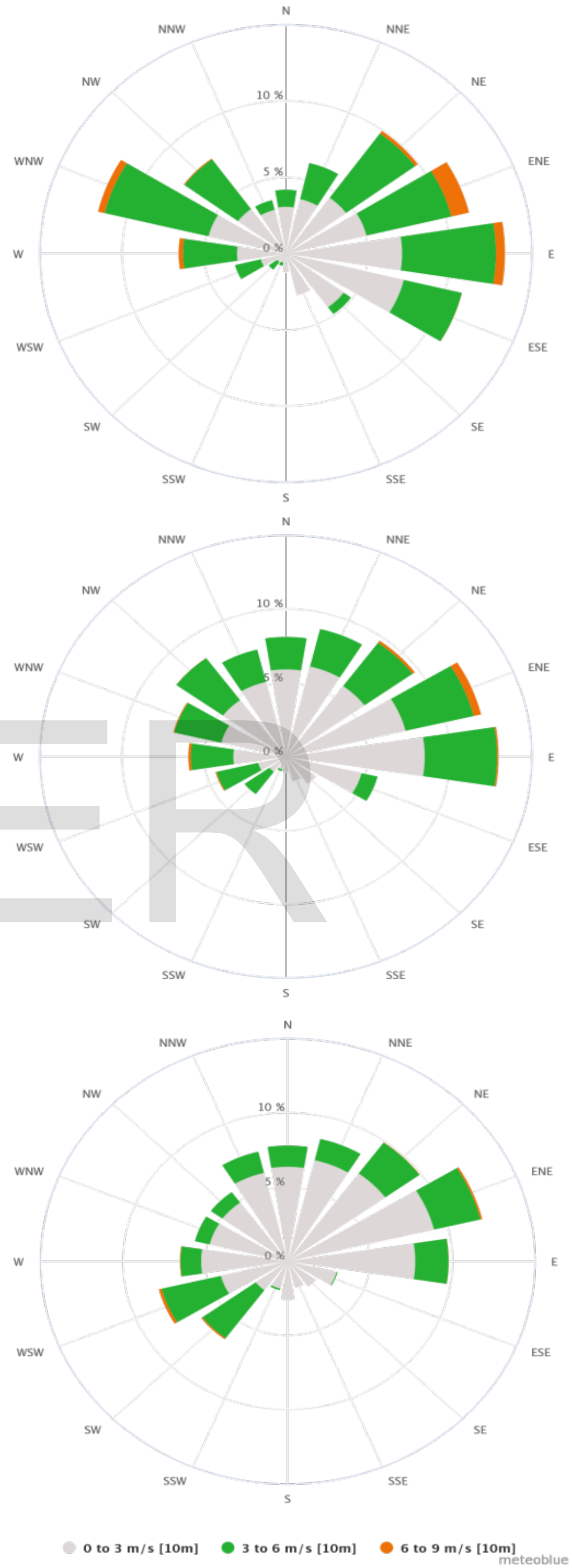

Fig 2. Wind Rose Plot: a) Jakarta Station, b) Tangerang Station, c) Cilegon Station

The highest value of SO_2 was PLTU Lontar 3 (approx. 235 μg/m^3) at 200 m distance. PLTU Lontar 3 was coal fired power plant whereas sulfur content is much higher than others fuels. Nevertheless, it still met the standard that has been established. The minimum concentrations for each power plant were nearly to zero at 15 km distance.

3.3 Predicted NOx Concentration

Similarly the predicted SO_2 concentration, the output decreased with an increasing distance whereas the minimum concentration was at 15000 m distance and the maximum concentration of ground level was at 200 m for each power generation. As shown in Fig 4 below, the highest predicted concentration of NOx founded in PLTGU Muara Tawar was about 170 μg/m^3, while the hourly ambient air quality standard is 400 μg/m^3, thus the concentration not exceed the NOx ambient standard.

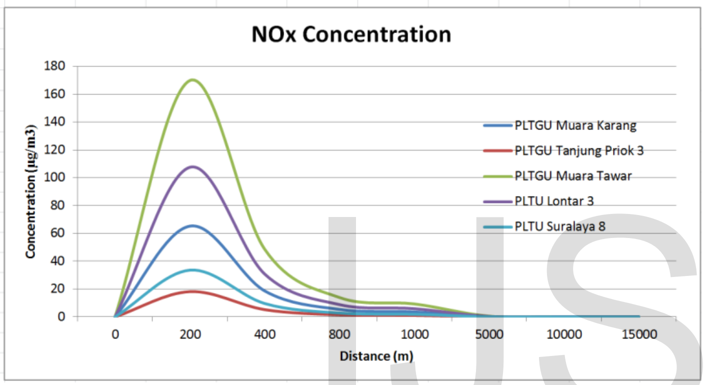

Fig 4. Predicted NOx Concentration

3.4 Predicted $PM_{2.5}$ Concentration

According to Fig 5, the highest hourly predicted concentration of $PM_{2,5}$ was appeared in PLTU Lontar 3 about 183 μg/m^3. It could not be compared to the ambient standard in Table 3 due to the hourly concentrations, while the ambient air quality standard was in 24-hour and annually. If the highest concentration divided into 24-hour, the concentration was less than 65 μg/m^3 which is the the ambient standard of $PM_{2,5}$. Hence, it could be implied that the predicted $PM_{2,5}$ concentrations were below the standard.

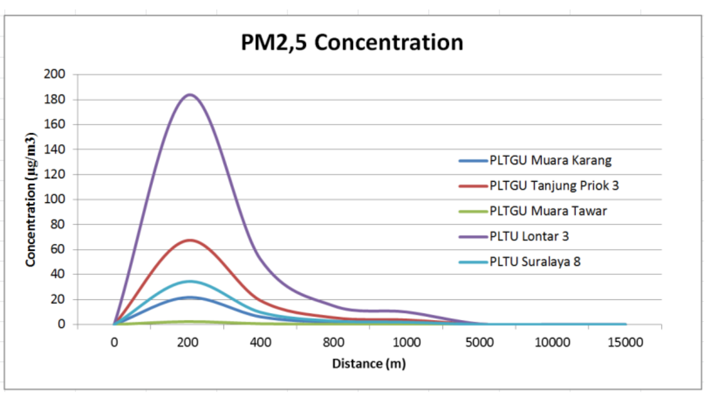

Fig 5. Predicted $PM_{2,5}$ Concentration

The graphs indicated that natural gas power plant had lower emission concentration than coal fired power plant due to the content of the fuel. The coal combustion released much more NOx, SO_2 and $PM_{2,5}$ per kWh than natural gas combustion in air pollution problems [18]. The findings not showed the greatest contribution of decreasing ambient air quality in the region of Jakarta and the surrounding areas because the concentrations not exceed the threshold of ambient standard. However, it could be from transportation as a study stated that vehicle in Jakarta resulted NOx emission was about 71%, 15% of SOx, and 70% of PM_{10} [19].

4 Conclusion

Emission is the result of fossil fuels combustion from transportation and energy sector that can be harmful for human health and environment due to some toxic gaseous. Coal as the major fuels used in energy sector, particularly in the urban areas such as the region of Jakarta and the surrounding areas mentioned as the biggest contributor in decreasing ambient air quality. For proving the statement, this study conducted by simulating emission dispersion released from 5 samples of power plants. The output of simulation showed that gaseous of SO_2, NOx, and $PM_{2,5}$ were below the Indonesia ambient air quality standard and the greatest contributor of air pollution can be from other sources such as transportation and industrial activities.

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