Emission dispersion modelling of Gresik power plant using Gaussian analysis to evaluate environmental impacts in receptor point

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Abstract. Air pollution is one of the impacts that must be concerned by Gresik Power Plant. The presence or absence of pollution can be seen in the ambient air quality around the plant location which is routinely monitored every six months. However, the monitoring data is not representative because there is no daily data conducted. Therefore, emission dispersion modeling can be carried out to obtain ambient air conditions around the plant site. In this research, the modeling is carried out using Gaussian Analysis for the HRSG chimney 3.1 and it can be seen that the area around the power plant and Pulopancikan village are significantly affected. This is indicated by the presence of a red zone in the results of the modeling and the concentration of NO\textsubscript{2} pollutants can reach 892.65 µg/m\textsuperscript{3} exceeding the government standard (150 µg/m\textsuperscript{3}). However, the validation of the model shows significant gap due to some circumstances such as meteorology condition, vehicles pollution, and human activities. In consequence, such a modeling can be developed further. For instance, the study needs to forecast emission dispersion of all active chimneys on the site in order to capture environmental condition and more concern to meteorology condition and other pollution sources.

Keywords: air pollution, dispersion modelling, NO\textsubscript{2} pollutant.

1. Introduction
Air pollution is the presence of harmful pollutant in air, in quantities large enough to produce dangerous impacts. Pollutants enter the atmosphere from sources currently beyond human control. However, in the most densely inhabited parts of the globe, particularly in the industrialized countries, the principal sources of these pollutants are human activities [1]. PJB Gresik power plant in its activities produce air emissions resulting from the combustion of gas. Referring to the Minister of Environment Regulation No. 15 of 2019, the pollutant parameters that must be considered are the SO\textsubscript{2}, NO\textsubscript{2}, and particulates. Even though gas-fired power plants are environmentally friendly, all of these pollutants still need to be monitored to ensure that the plants do not produce excessive emissions considering the Gresik plant does not have pollutant control devices. The environment team in Gresik power plant has routinely monitored ambient air and air emissions. Emission air monitoring is carried out in each chimney while ambient air is carried out in the community surrounding the plant site in accordance with environmental documents (AMDAL). However, this manual monitoring is only done every semester which does not give an overall picture.
of the distribution of pollutants in the power plant area, especially for ambient air. In contrast to air emissions monitoring, each chimney is equipped with a continuous emission monitoring system (CEMS) that can measure pollutant levels every day.

Ambient air monitoring is a crucial activity to determine whether there is pollution in the community around the plant site. Ambient air monitoring every semester is not strong enough to determine the presence of pollution because at the time of monitoring, the condition of the plant may not be operating optimally so that the results obtained also do not fully reflect environmental conditions. However, the company is not possible to do manual monitoring every day because it requires large costs and limitations of external laboratories availability. Besides that, in the environmental document (AMDAL) of the Gresik plant, there was also no pollutant dispersion study found so that it could not be known the location with the potential for heavy or light pollution.

Limitations for conducting daily ambient air monitoring can be overcome by environmental modeling, namely the Gaussian plume model. Gaussian model is an analysis of the distribution of air pollutants from a pollutant source so that it can be estimated the impact that might occur. This model is a mathematical model that is used to present the process of disperse pollutants in the air especially from point sources, in this case the chimney. In this model the behavior of pollutants follows the normal distribution or the Gauss distribution. The Gauss model is widely used to estimate the effects of nonreactive pollutants from point or line sources.

Based on the above matters, an analysis and depiction of the disperse pattern were conducted by using Gaussian model (in this case HRSG 3.1 chimney). Through this model, it can be estimated the concentration of pollutants at various points based on meteorological conditions in the area around the plant. Furthermore, a pollutant distribution contour can be made through mapping using a surfer device. Besides, the results of this study together with ambient air laboratory data can be used as a reference whether air emission control needed.

2. Theory Approach

2.1. The use of dispersion modelling

An atmospheric-diffusion model is a mathematical calculation regarding the emission of pollutants into the atmosphere to the downwind ambient concentration of the material. The main target is to predict the concentration of a contaminant at a certain receptor point by calculating from some basic information about the source of the pollutant and the meteorological conditions. For the present, the stochastically based Gaussian-type model is the most useful in modelling for regulatory control of pollutants.

Essentially the models are used to forecast the atmospheric concentration field in the absence of monitored data. In this case, the model can be a part of an alert system serving to signal when air pollution potential is high. The models can provide to locate areas of predicted high concentration for correlation with health effects [2]. The models also can be implemented for

- Stack-design researches
- Combustion-source permit applications
- Regulatory variance assessment
- Monitoring-network design
- Control strategy evaluation for state implementation plans
- Fuel conversion research
- Control-technology assessment
- New-source assessment

2.2. Dispersion of the pollutants

There are substantial parameters that influence the pollutant dispersion [1].
a. Atmospheric stability. It depends on wind direction, ambient temperature, and wind velocity. The stable of atmosphere makes the value of wind velocity and temperature becoming low, therefore there is no dilution process of contaminant in the air and pollutant concentration in the area will be high [1].

b. Topographical effect. It affects the local wind patterns, an example is the onshore and offshore wind, and another example is the heat island over large urban areas. Another manmade effect is the generation of mechanical turbulence caused by the non-uniform height of buildings in a city [1].

c. Atmosphere temperature. Temperature change with altitude has huge effect on the motion of air pollutants. For instance, inversion conditions produce only limited vertical mixing. The amount of turbulence available to diffuse pollutants is also a purpose of the temperature profile [2].

3. Method

3.1. Wind Velocity and Direction

Pollutants dispersion depend on the mean wind and atmospheric turbulence [2]. Analysis of wind velocity and direction using WR-Plot software to determine atmosphere class condition.

Table 1. Wind direction and velocity in July to September 2019 [3].

| Year | Date | July | August | September |
|------|------|------|--------|-----------|
|      |      | Wind Direction (°) | Wind Velocity (m/s) | Wind Direction (°) | Wind Velocity (m/s) | Wind Direction (°) | Wind Velocity (m/s) |
| 2019 | 1    | 130  | 5      | 130       | 9        | 100       | 6        |
| 2019 | 2    | 110  | 5      | 110       | 7        | 130       | 7        |
| 2019 | 3    | 130  | 6      | 120       | 6        | 110       | 6        |
| 2019 | 4    | 130  | 7      | 120       | 5        | 110       | 6        |
| 2019 | 5    | 100  | 8      | 140       | 5        | 110       | 5        |
| 2019 | 6    | 100  | 6      | 120       | 4        | 100       | 6        |
| 2019 | 7    | 100  | 8      | 110       | 4        | 110       | 6        |
| 2019 | 8    | 110  | 6      | 90        | 4        | 130       | 6        |
| 2019 | 9    | 140  | 6      | 110       | 6        | 130       | 6        |
| 2019 | 10   | 110  | 6      | 110       | 7        | 110       | 8        |
| 2019 | 11   | 110  | 6      | 110       | 6        | 100       | 6        |
| 2019 | 12   | 110  | 6      | 100       | 8        | 130       | 6        |
| 2019 | 13   | 90   | 5      | 110       | 8        | 130       | 6        |
| 2019 | 14   | 130  | 7      | 110       | 7        | 130       | 6        |
| 2019 | 15   | 130  | 6      | 110       | 6        | 110       | 6        |
| 2019 | 16   | 110  | 5      | 110       | 6        | 100       | 7        |
| 2019 | 17   | 130  | 6      | 130       | 6        | 110       | 7        |
| 2019 | 18   | 110  | 7      | 130       | 6        | 110       | 7        |
| 2019 | 19   | 110  | 7      | 150       | 4        | 140       | 6        |
| 2019 | 20   | 110  | 7      | 100       | 5        | 110       | 6        |
| 2019 | 21   | 130  | 6      | 120       | 7        | 120       | 5        |
| 2019 | 22   | 130  | 6      | 110       | 6        | 110       | 6        |
| 2019 | 23   | 120  | 6      | 110       | 6        | 100       | 9        |
| 2019 | 24   | 90   | 6      | 140       | 6        | 110       | 8        |
3.2. Gaussian Analysis

Most diffusion models take the Gaussian plume framework, which also is a substance balance model. In it, one considers a point source i.e. a factory smokestack and attempts to compute the downwind amount resulting from this point source [1].

\[
c = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp - 0.5 \left( \frac{y}{\sigma_y} \right)^2 \left[ \exp - 0.5 \left( \frac{z-H}{\sigma_z} \right)^2 \right] + \exp - 0.5 \left( \frac{z+H}{\sigma_z} \right)^2 \right] \tag{1}
\]

- \(c\): Pollutant concentration \((x, y, z)\) (µg/m\(^3\))
- \(Q\): Emission rate (g/s)
- \(\sigma_y\): Horizontal spreading coefficient (m)
- \(\sigma_z\): Vertical spreading coefficient (m)
- \(u\): wind velocity (m/s)
- \(H\): stack height (m)
- \(\Delta h\): Plume rise (m)

Calculation of plume rise using Holland’s formula to estimate the value of \(\Delta h\) [2].

\[
\Delta h = \frac{V_s D}{u} x (1.5 + 2.68 \times 10^{-3} x P x D x \frac{T_s - T_a}{T_s}) \tag{2}
\]

- \(\Delta h\): Plume rise (m)
- \(V_s\): Stack exit velocity (m/s)
D : Stack diameter (m)
U : Wind speed (m/s)
P : Pressure (mbar)
Ts : Stack gas temperature (K)
Ta : Atmospheric temperature (K)

Table 2. Key to stability categories [1].

| Surface wind speed at 10 m (m/s) | Day | Night |
|----------------------------------|-----|-------|
|                                  | Strong | Moderate | Slight | Thinly overcast | Clear |
| 0-2                              | 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     |

Calculation of horizontal spreading coefficient (σy) and vertical spreading coefficient (σz) in urban area [4].

Table 3. Spreading coefficient in urban area.

| Stability class | Σy           | σz           |
|-----------------|--------------|--------------|
| A               | 0.32X(1+0.0004X)⁻¹/² | 0.24X(1+0.0001X)⁻¹/² | (3) |
| B               | 0.32X(1+0.0004X)⁻¹/² | 0.24X(1+0.0001X)⁻¹/² | (4) |
| C               | 0.22X(1+0.0004X)⁻¹/² | 0.2X          | (5) |
| D               | 0.16X(1+0.0004X)⁻¹/² | 0.14X(1+0.0003X)⁻¹/² | (6) |
| E               | 0.11X(1+0.0004X)⁻¹/² | 0.08X(1+0.0015X)⁻¹/² | (7) |
| F               | 0.11X(1+0.0004X)⁻¹/² | 0.08X(1+0.0015X)⁻¹/² | (8) |

4. Result and Discussion

4.1. Atmosphere Class Condition
Atmosphere class condition depends on wind velocity and wind direction, from figure 2, we can conclude that from July to September 2019 the wind blew from south-east and stability class in July, August, and September 2019 (a) according to table 2 is C because average wind velocity 6.13 m/s, 6.0 m/s, and 6.4 m/s (between 5.70 and 8.80 m/s) about >44 percent of the time.

Figure 2. Wind rose July 2020

Figure 3. Wind rose August 2020
4.2. Dispersion Result and Environmental Damage Analysis

From Gaussian analysis, the distance of dispersion is 2.6 km x 2 km from emission source point with 100 m for level of accuracy.

Table 4. Detail of emission source condition.

| Parameter                  | July | August | September | Unit |
|----------------------------|------|--------|-----------|------|
| Stack diameter             | 4    | 4      | 4         | m    |
| Stack height               | 65   | 65     | 65        | m    |
| Service Hour               | 24   | 24     | 24        | Hour |
| Flow rate                  | 337.7| 319.9  | 193.6     | m$^3$/s|
| NO$_2$ Emission            | 238  | 273    | 345.3     | mg/m$^3$|
| Stack gas temperature      | 112.1| 109.2  | 77        | $^0$C|
| Atmospheric temperature    | 25   | 25     | 25        | $^0$C|
| Wind velocity              | 6.13 | 6.00   | 6.40      | m/s  |
| Atmospheric pressure       | 1013.25 | 1013.25 | 1013.25 | mbar |
From figure 3, there are some crucial points that should be discussed. Those four villages that must be monitored according to Environmental and Social Impact Analysis (AMDAI) as shown in figure 5 [5]. A red zone means high level pollution from source point. Emission from HRSG 3.1 spreads in power plant area and Pulopancikan village. According to this model, Kramat Inggil and Sidokumpul villages are not in the red zone thus these villages should be less concerned. The highest pollutant of NO\(_2\) from Gaussian calculation in September is 892.65 µg/m\(^3\) in power plant area. This exceeds maximum level Indonesian's regulation (150 µg/m\(^3\)) [6]. If it occurs continuously, the area is unhealthy for employee, local community, and biodiversity. Yet, surrounding of power plant area is relatively safe for living and actually there are many parameters that influence dispersion, not only meteorology condition such as the height of surrounding buildings and mixing height.

Furthermore, the modelling can estimate the atmospheric concentration field as many as possible. The company then can have many data alongside manual data taken by external laboratory. These forecasted data from the model is needed due to the fact that ambient monitoring routine of NO\(_2\) is usually conducted once in six months and only one hour. The data cannot represent the real condition as the model shows some area are in the red zones, whereas the laboratory results show clean ambient air. It is possible when the lab tests conducted, the power plant not in peak activities or in shutdown status.

Besides, by using this model, the company can further evaluate its environmental policy in decreasing environmental impacts in surrounding of power plant. For instance, management can install a wet scrubber or electrostatic precipitator to control flue gas and operation controlling in burning process to prevent gas pollution released in the atmosphere. Moreover, in case there is a suspect of pollution caused by power plant from local society, the company can use this model to provide adequate data rather than showing only manual data.

However, this dispersion modelling must be compared with ambient monitoring routine from laboratory’s third party. The laboratory results is important to prove the modelling forecasts correctly in the same time.
Table 5. Comparison between Gaussian calculation and laboratory result

| Location           | Gaussian Calculation (µg/m³) | Laboratory Result (µg/m³) | Value difference (µg/m³) | Percent of Error (%) |
|--------------------|-----------------------------|---------------------------|--------------------------|----------------------|
| Pulopancikan village | 1.715                      | 5.267                     | 3.552                    | 67.44                |
| Sidokumpul village  | 0.830                      | 5.9                       | 5.07                     | 85.93                |
| Sidorukun village   | 0.0423                     | 7.833                     | 7.79                     | 99.46                |
| Kramat Inggil village | 25.824                    | 39.5                      | 13.676                   | 34.62                |

In this case, there are significant gap between calculation and ambient measurement data because there are some parameters affecting the measurement such as flue gas from transportation and another pollution from public services or human activities. The value of Gaussian calculation is smaller than laboratory result because the calculation only considers meteorology condition. In fact, when taking laboratory data, there are many pollution sources possibly counted such as vehicle emission, road particulates, and any other fugitive emission [7].

Another parameter significantly influencing emission dispersion is manmade effect. It is the generation of mechanical turbulence caused by the non-uniform height of buildings in a city. Moreover, the model results may be slightly affected by meteorological condition such as green area and building area since these can influence the mixing area. In addition, wind measurement equipment must be installed in power plant area to measure meteorology on site to increase the accuracy of the modelling because climatology station of government agency usually installs far from power plant area.

5. Conclusion
In this study one case was taken in the HRSG 3.1 chimney where the results of the modeling showed that the area around the chimney and Pulopancikan village were contaminated by high concentrations of NO2 pollutants. In the power plant area, the modeling shows a number high enough to exceed the quality standards set by the government. In contrast, the laboratory results always show well data. This needs to be examined deeply whether the laboratory tests that have been carried out have shown representative condition. Consequently, using only lab test as a reference in determining the presence or absence of pollution is not adequate. Therefore, implementing Gaussian model can be an alternative to support lab data. The model in this research also needs to be developed to obtain better results so that it can be a perfect tool in evaluating environmental impacts in Gresik power plant. For example, modelling another chimneys, evaluating meteorological condition, and taking into account another pollution sources.

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