Emission Dispersion Modelling using AERMOD on GT 1.3 PLTGU Muara Karang in Evaluate Combustor Upgrade Effect

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Abstract. Muara Karang power plant dominated by Gas Turbine Power Plant. One of those there is Gas Turbin 1.3 has been upgraded, thus make load output become increased. This study aims to see the emission dispersion generated from combustor before and after being upgraded. The emission data is obtained from combustion modelling on combustor GT 1.3 pre and post extendor using CFD methode. Then, the data will be used for emission dispersion modelling using AERMOD. The emission dispersion modelling uses two condition. First is the initial state based on environment assessment document in 2010 and second is in current environment state. The modelling shows that after the combustor upgraded, the NOx emission increase by 15%, CO emission decrease by 37%. Emission dispersion modelling result shows that there is a change in the area that has the highest concentration. In the initial environment state, area with highest concentration is on the west side of the power plant with NOx concentration is 35.46303 ug/m³, And CO concentration is 1.3362 ug/m³. In the current environment state, the area is on the east side of the power plant area with highest concentration is NOx concentration is 61.47481 ug/m³ And CO concentration is 2.3163 ug/m³.

1. Introduction

Currently, world has reached to a stage of environmental crisis that its size and intensity rise. This problem is the results of unstable development that have been created in the past and present in the field of energy production and consumption patterns, industry, transportation and lifestyle. Sustainable development depends on the earth protection, and the environment protection means care and rational use of natural resources [1]. Nowadays, power plant is required to have good efficiency and comply with regulation in order to avoid negative impact on the environment. Muara Karang power plant, as a peak load, must be able to anticipate the changing load production that affect fuel and air supply in combustion process and also emissions gas produced. Muara Karang Gas Turbine 1.3 has installed capacity of 107 MW and operated since 1992. In October 2016, combustor was upgraded into extendor, replacing the old one with the new one. This upgrade increase the overall gas turbine efficiency from 31.062% to 34.722% corrected to ISO condition [2].

Sustainable development gives effects to environment. This is also occurs in the environment around Muara Karang power plant. Apartment, increase of settlement, and reduction of green open space will give impact on the environment capacity along with electricity produced. Emission will be dispersed to the atmosphere which is affected by the dynamics of the atmosphere as wind speed and
direction, turbulence, air temperature, and stability of the atmosphere. One of alternative form of modelling air quality is Gaussian dispersion model. The prediction of the plume rise can be used by power plant to manage the right production time and capacity so that environment quality remains maintained. The aim of this study is to see the change in the distribution of emission and the concentration of the pollution which is produced after upgrade GT 1.3 and emission distribution according to changes in environment condition around Muara Karang power plant.

2. Methodology
The study is conducted for GT 1.3 Muara Karang power plant, located in North Jakarta with coordinates X = 697383.37, Y = 9324332.65. Simulation is done in two different conditions which are emission generated before and after upgrade with early environment condition as described in environmental assessment document, and emission generated before and after upgrade with current environment condition. Data used in the study consist of:
- Emission data from combustion modelling on combustor GT 1.3 pre and post extender. The modelling is using Computational Fluid Dynamics (CFD) method with solver software ANSYS
- Hourly meteorological data during one-year period that will be used in emission dispersion model using AERMOD Software

The data is used in this study can be seen on Table 1.

Table 1. Parameter Used In Study

| No | Parameter                  | Unit  |
|----|----------------------------|-------|
| 1  | Emission rate              | m³/s  |
| 2  | Coordinates the study areas| UTM   |
| 3  | Study areas                | m²    |
| 4  | Cloud cover                | Tenth |
| 5  | Temperature                | ºC    |
| 6  | Humidity                   | %     |
| 7  | Barometric                 | Mb    |
| 8  | Wind direction             | Degree|
| 9  | Wind speed                 | m/s   |
| 10 | Mixing height              | m     |
| 11 | Precipitation              | Mm    |
| 12 | Solar radiation            | Wh/m² |
3. Computational Fluid Dynamics (CFD)
This research uses Computational Fluid Dynamics (CFD). CDF is a useful tool for predicting flow and temperature field. In this case CFD was carried out by using ANSYS FLUENT [3]. The process of CFD simulation is divided into 4 phase: drawing geometric model, establishing mesh, configuring the model, and post-processing. The Geometry used for simulation as shown in the figure 1.

Figure 1. Geometry of Combustor

Mesh structure used is in the type of polyhedral. Referring to previous research [4], polyhedral mesh affects to accelerate convergence rate. The numbers of cells on fluid domain combustor are 4231562 nodes and 996162 elements after mesh independency was tested.

Numeric validation is intended to validate that simulation has been made appropriate with procedures of error reduction in numeric calculations [5]. Although the research is not validated through experiments, the result is still validated by performing criteria for validation. At least there are 4 (four) criteria for numeric validation [6]:
1. Mesh Independence Test;
2. Residual Convergence;
3. Value consistency;
4. Mass Flow Inlet-Outlet Difference

In this study, 2 (two) geometries gas turbine were carried out by modeling the non-mixed combustion system both pre and post upgraded of gas turbin 1.3. There are 4 (four) variables will be inputted consisting of air flow rate, fuel flow rate, inlet air temperature, inlet fuel temperature. Then all these variables are inputted for 2 (two) gas turbine combustion models with the same value. After the simulation, the temperature and emission values from the simulation results will be compared.

4. Emission Modelling Description
An air pollutant is transported by wind, and the process is affected by various other meteorological quantities. It also disperses through the atmosphere according to certain stability conditions [7]. In this study, simulated parameters are NOx, CO, and CO2. Emission dispersion model widely used is Gaussian Dispersion Model. The illustration of Gaussian dispersion model can be seen in Figure 2.

Figure 2. Gaussian Dispersion Model

The Gaussian plume equation can be written as follow [8]:
\[ C_{xyz} = \frac{Q}{2\pi u\sigma_y \sigma_z} \exp \left( -\frac{1}{2} \frac{y^2}{\sigma_y^2} \right) \left\{ \exp \left( -\frac{1}{2} \frac{(Z-H)}{\sigma_z^2} \right) + \exp \left( -\frac{1}{2} \frac{(Z+H)}{\sigma_z^2} \right) \right\} \]  

This model uses AERMOD software that can be run after secondary data has been collected such as:
- NOx and CO maximum emission rate
- Coordinates, boundaries, and the grid of study area
- Meteorological data that has been treated in AERMET with .PFC and .SFC format
- Elevation data generated from AERMAP software with .dem format

All treated data and information are put into AERMOD so the software can run the simulation and the isopleths image of the emission dispersion on the study area can be obtained.

4.1 Emission Data Source
The emission concentration which is used in this research is resulted from combustion simulation in GTG 1.3 combustor post extendor that has already been modified with maximum load. In order of the emission concentration could be inputted into AERMOD software, the unit value should be converted into grams per second (g/s). Calculations which used are multiplication between emission concentration and emission rate in the chimney. An emission inventory was compiled which consisted or air pollution sources and types, pollutant types, and emission rate [9].

4.2 Meteorological Data
AERMET used to develop the meteorological inputs for AERMOD by inputting several data [10]. Meteorological data which is required in this study by inputting several data consist of cloud cover, ambient air temperature, humidity, air pressure, wind direction, wind velocity, mixing height, rainfall, and solar radiation. All of this data is an hourly data series in a year. Thus meteorological data then processed into worksheets before it can be accepted by the AERMET software which is one part that can be used for the AERMOD program. Furthermore, meteorological data station shall be inputted where the meteorological data is taken and in this study data was taken from soekarno hatta airport station. Information needed includes the name of the station. Station ID, coordinates (latitude and longitude), elevation base of meteorological station above sea level, elevation of anemometer equipment, and ambient air temperature monitoring unit elevation.

5. Result and Discussion

5.1 Data Emission
In this study, the emission concentration is used for dispersion modeling which is from results of combustion simulation of Gas Turbine 1.3 with maximum load. It can be seen in Table 2 and Table 3 which are the simulation results using Computational Fluid Dynamics (CFD) shows the emission values of the two models pre and post upgrade of Gas Turbine 1.3 is almost perfect because there is no reactant gas at the outlet, all the gasses are burned completely either at pre and post upgrade gas turbine GT 1.3.

In addition, the CO\textsubscript{2} emission after the GT 1.3 upgrade was higher which is 3.29% if compared to before the upgrade, which was 3.23%. The pre-upgrade GT 1.3 gas turbine does not produce gas CO at all, while after upgrade it produces CO gas with amunt of 0.0005%. The content of H\textsubscript{2}O from the combustion process in the post-upgrade GT 1.3 higher at 6.25% compared with the pre-upgrade, which was 6.12%. The combustion process still leaves 14.10% of the remaining air in the GT 1.3 pre-upgrade and 13.95% in the GT 1.3 post-upgrade.

| Species (Major Emission) | Mole Fraction Pre-Upgrade (%) | Mole Fraction Post-Upgrade (%) |
|--------------------------|------------------------------|-------------------------------|

Table 2. Emission at the Outlet of Pre and Post-Upgrade Combustor
Table 3. Minor Emission at the Outlet of Pre and Post-Upgrade Combustor

| Species (Major Emission) | Minor Emission Pre-Upgrade (ppm) | Minor Emission Post-Upgrade (ppm) |
|--------------------------|----------------------------------|-----------------------------------|
| NO\textsubscript{x}       | 4.7                              | 5.5                               |

Emission concentrations obtained from the simulation process then converted to g/s unit so that it can be processed for simulations on AERMOD with the following calculation results can be seen in Table 4.

Table 4. Concentration and Emission Flowrate

| Year | Gas Turbin Power Plant | Pollutant | Concentration (mg/Nm\textsuperscript{3}) | Debit (m\textsuperscript{3}/s) | Emission Flowrate (g/s) |
|------|-----------------------|-----------|------------------------------------------|-------------------------------|-------------------------|
|      |                       |           | Pre (Extendor)                           | Post (extender)               | Pre (extendor)          | Post (extender)        |
| 2017 | GTG 1.3               | NO\textsubscript{x} | 123,80                                  | 144,87                       | 593,55                  | 73,48                  | 85,99                  |
|      |                       | CO        | 8,66                                    | 5,45                         | 51,4                    | 3,24                   |

5.2. Windrose

Windrose is a distribution diagram showing the direction and speed of wind in an area study within a certain period thus the frequency of direction and dominant speed can be known. This study used 8 (eight) wind directions. Windrose is made by using WRPLOT which is one of the software needed to support AERMOD.

Based on meteorological data from Soekarno Hatta Airport observation station, windrose diagram as shown in Figure 3. It is known that the average wind speed is 5.14 m/s with maximum wind speeds reaching 11.80 m/s and minimum wind speeds lower than 1.54 m/s. The frequency of occurrence of calm wind or wind speed below 1.54 m/s reaches 0.4% (350 times). The highest frequency of wind speed shows the wind speed in the range of 5.14 m/s  at 35.8% (3,136 times).
5.3. Emission Dispersion Modelling

The simulation modeling conducted with AERMOD software by used maximum emission rate according to result of combustion simulation. This simulation used is the average time of measurement of 1 (one) hour according to specified quality standards. The result of dispersion simulation is a map of isopleths of concentration where each concentration range is shown with different colors. This simulation also showed the effect of buildings and high-rise buildings that was built or planned to or to be built around the area of study towards the pattern of distribution of emissions produced compared with the initial state when the environmental permit was issued in 2010.

The simulation of emission consist of CO and NOx which these 2 kind of pollutants are the parameters that should be monitored continuously according to environmental permit issued by government. The result of the emission dispersion patterns is as follows.

4.3.1 CO Parameters

In initial environment state, CO emission dispersion modelling in combustor pre extendor GT 1.3 has the highest concentration by 2.11978 ug/m$^3$ and the lowest concentration by 0.37332 ug/m$^3$, located in Pantai Indah Kapuk. CO emission dispersion modelling in combustor post extendor GT 1.3 has the highest concentration by 1.3362 ug/m$^3$ and the lowest concentration by 0.23532 ug/m$^3$. The CO dispersion is showed in Figure 4.

In current environment condition, CO emission dispersion modelling in combustor pre extendor GT 1.3 has the highest concentration by 3.67462 ug/m$^3$ and the lowest concentration by 0.37332 ug/m$^3$, located in Muara Baru and Waduk Pluit. CO emission dispersion modelling in combustor post extendor GT 1.3 has the highest concentration by 2.3163 ug/m$^3$ and the lowest concentration by 0.23532 ug/m$^3$. The CO dispersion is showed in Figure 5.
5.3.1 NOx Parameter

In initial environment state, NOx emission dispersion modelling in combustor pre extendor GT 1.3 has the highest concentration by 5.33694 ug/m$^3$ and the lowest concentration by 0.3038 ug/m$^3$, located in Pantai Indah Kapuk. NOx emission dispersion modelling in combustor post extendor GT 1.3 has the highest concentration by 35.46303 ug/m$^3$ and the lowest concentration by 6.24555 ug/m$^3$. The NOx dispersion is showed in Figure 6 as follow.

In current environment state, NOx emission dispersion modelling in combustor pre extendor GT 1.3 has the highest concentration by 52.53133 ug/m$^3$ and the lowest concentration by 5.33694 ug/m$^3$, located in Muara Baru dan Waduk Pluit. NOx emission dispersion modelling in combustor post extendor GT 1.3 has the highest concentration by 61.47481ug/m$^3$ and the lowest concentration by 6.24555 ug/m$^3$, located in the east side of the power plant area. The NOx dispersion is showed in Figure 7.

**Conclusion**

GTG 1.3 extendor combustor upgrade produces lower CO emissions if compared before upgrading and showed the results perfect burning process. NOx emissions which is generated after upgrading is
increased to 14.5% with a value of 5.5 ppm if compared before upgrading which is 4.5 ppm. This is because the average temperature at the extendor combustion post is higher with value is 1252°C if compared before extendor which is 1157°C. Environmental baseline is changed around the study area affect to pattern and distribution of emission concentrations. It is result in changes of location points that have the highest pollutant concentrations. Initial environmental baseline, the highest pollutant concentration fell in the Pantai Indah Kapuk area (west side of the generating unit), however the current conditions, the highest pollutant concentration fell in the Muara Baru area (east side of the generating unit).

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