Dispersion analysis of SO$_2$ pollutants caused by sugar industry of PT. Makassar Tene

R A Putra$^1$, A H Assegaf$^{2,4}$ and S Suryani$^3$

$^1$Department of Environmental Management, Faculty of Graduate School, Hasanuddin University, Makassar, Indonesia
$^2$Department of Geophysics, Faculty of Mathematics and Natural Science, Hasanuddin University, Makassar, Indonesia
$^3$Department of Physics, Faculty of Mathematics and Natural Science, Hasanuddin University, Makassar, Indonesia
$^4$Center for Environmental studies, Hasanuddin University, Indonesia

E-mail: ridhaanugerahputra@pasca.unhas.ac.id

Abstract. National sugar production only reached 2.756 million tons in 2014. This number has not been able to meet total consumption of 5.396 million tons. The steam boiler stack generated from coal combustion process in sugar production produces sulfur dioxide gas waste. This research purpose was used as simulation tool to determine the concentration of emissions produced at distance, time, the dispersion of emissions direction, and the type of distribution patterns. The research method was the American Meteorological Society - Environmental Protection Agency Regulations Model (AERMOD). The data input of the AERMOD model consisted of meteorology data, stack emissions, and topography for past 5 years. Meteorological data processed by AERMET was taken from the Hasanuddin station (ID WMO 971800 / WAAA). The topographic data was obtained from the AERMAP model which was downloaded and processed using SRTM3 coordinate data. The result of the AERMOD model was the isopleth map which showed the dispersion pattern of pollutants with different concentrations. The SO$_2$ concentration value of 6.91348 μg/m$^3$ was the highest value that occurred at 1 hour measurement since the pollutant was emitted from the stack located 293 meters from the emission source (UTM 774635.04 m and 9435968.83 m).

1. Introduction

National sugar production only reached 2.756 million tons in 2014. This number has not been able to meet (direct and industrial) total consumption of 5.396 million tons. This condition put the country at a disadvantage if it is seen from the aspect of national food security [1]. Indonesia must produce more sugar to meet domestic sugar needs.

Makassar city, there is a sugar industry with coal fuel. An industry that uses coal fuel has the potential to cause air pollution. The steam boiler stack generated from the coal combustion process in producing sugar produces sulfur dioxide gas waste (SO$_2$) [2].

Dispersion is the process of transferring and transporting pollutants that have been emitted to the ambient air. Several studies related to air pollutant dispersion indicated that there are differences in air concentrations around sources of emissions that are at risk of exposure to contaminants [3, 4]. Wind direction and speed can be used as a reference to find where the direction of emissions is distributed and by knowing the wind speed we can know the range of receptors (impact recipients).
Figure 1. Forms of smoke puffs (a) fanning type, (b) fumigation type, (c) looping type, (d) conning type and (e) lofting type [5].

Table 1. Conversion of MO length into PG stability criteria [6].

| Stability Class       | MO Length (m) |
|-----------------------|---------------|
| A: very unstable      | -40 ≤ L < -12 |
| B: unstable           | -200 ≤ L < -40 |
| C: weakly unstable    | -1000 ≤ L < -200 |
| D: Neutral            | L > 1000     |
| E: weakly stable      | 200 < L ≤ 1000 |
| F: stable             | 100 < L ≤ 200 |
| G: moderately stable  | 40 < L ≤ 100  |
| H: very stable        | 10 < L ≤ 40   |

The form of emission from the stack can be determined based on atmospheric stability. Atmospheric stability can be known based on Monin-Obukhov length. There are five forms of smoke puffs based on atmospheric stability conditions, (a) fanning type under stable conditions, (b) fumigation type which is associated with radiative inversion which generally disappears at noon, (c) looping type in unstable atmospheric conditions, (d) conning type in neutral conditions and (e) lofting type which does not occur downward, but spreads towards the top [5].

Good air quality needs to be maintained for the survival of living things. One attempt at maintaining air quality around the sugar industry is by using the pollutant disperse prediction model. The model used to predict pollutant disperse is AERMOD (American Meteorological Society - Environmental Protection Agency Regulatory Model). AERMOD is a model of the distribution of emissions in horizontal and vertical directions using a Gaussian concentration distribution. By predicting the pattern of emissions distribution, the concentration of pollutants from emission sources can be described up to a radius of several kilometers from the source of these emissions [7].

The AERMOD model can be a reference in determining air quality sampling points and screening areas. The advantages of the AERMOD model are the higher results of calculations with a higher level of accuracy than other models. This model was used as a simulation to determine the concentration of emissions produced at a distance, time, the dispersion of emissions direction and the type of distribution patterns.

2. Methodology and data
PT. Makassar Tene is a sugar industry located in Makassar Industrial Area at coordinates of (5° 5’47.58”S, 119°28’29.31”E). The sugar industry using coal-fired boilers produces SO2 gas emissions [8]. The AERMOD model was used to simulate SO2 gas emissions emitted by the sugar industry located in Makassar (Figure 2).
2.2 Data

2.2.1 Meteorological data

The meteorological data were obtained from the results of recording from the station of sultan Hasanuddin international airport, Ujung Pandang, Indonesia (WMO station code: 971800) at the coordinates of (5.080553S, 119.551243E). The data were recorded in the period of January 1, 2014 - May 15, 2019, there were 94132 recordings from the meteorology station. The upper air data were taken every hour. This data consisted of humidity (%), temperature (°C), air pressure (mbar), wind speed (m/s) and wind direction (degrees).

![Figure 2. Location of study.](image)

2.2.2 Topographic data

Topographic data were also used as one of the factors that affect the dispersion of pollutants. DEM data were downloaded from the AERMAP model. The topographic condition was considered elevated.

2.2.3 Stack emission data

Stack emissions monitoring showed that SO$_2$ concentrations were below the Quality Standards of 900 mg/m$^3$ [9] (Table 1.). The debit value was obtained from the multiplication of the exhaust gas velocity (m/s) and the stack area (m$^2$). The debit value would be automatically calculated on the AERMOD model. The emission rate (g/s) was obtained from the multiplication of the emission concentration (μ/m$^3$) and the debit value (m$^3$/s) then the
product of the multiplication was divided by 1000.

| Data Type               | Result                        |
|-------------------------|-------------------------------|
| Type of fuel            | coal                          |
| Cooker height (m)       | 60                            |
| Stack diameter (m)      | 5                             |
| Gas temperature (°K)    | 366                           |
| Gas exit speed (m/s)    | 5.67                          |
| Emission release (m³/s) | 111.3302                      |
| Stack X (UTM) coordinates | 774341.18 m East             |
| Stack Y (UTM) coordinates | 9435968.75 m South           |
| Gas concentration (mg/m³) | 24.84                         |
| Emission rate (g/s)    | 2.765442168                   |

2.2.4. Receptor data
Receptor data was set in the form of a uniform mesh (may not be uniform) that showed the coordinates position (UTM). Stack positions plotted as emission centers.

2.3. Method
The research method was the AERMOD Model. The AERMOD model is a model used for atmospheric impact analysis [1]. The AERMOD model is an air quality disperse modeling system created by the US Environmental Protection Agency (EPA). The AERMOD system consists of AERMOD (air disperse model), AERMAP (Terrain Preprocessor) and AERMET (Meteorological Preprocessor). AERMOD uses the Gaussian and bi-Gaussian approaches in its dispersion model, which results in concentrations of ambient air pollutants in daily, monthly and annual periods. AERMOD can be used for urban and rural areas, flat or elevated earth surfaces, emissions from a low or high surface, and emissions from many sources (including source points, area or volume) [2].

3. Results and discussions
3.1 Windrose results
Windrose is a description of the wind direction and dominant speed in a place at a certain time.

![Windrose and wind distribution](image)

Based on Figure 4, it can be seen that the wind direction for the last 5 years was dominated by west to east south east with an average speed of 1.08 m/s. Where the highest frequency occurs at the wind speed of < 0.50 m/s (calms) was 45629 times with a percentage of 45.1%.
3.2. AERMOD model result
3.2.1. Hourly variation
Figure 5 is the result of an isopleth map of SO2 pollutant dispersion from the stack of PT. Makassar Tene. The direction of distribution of SO2 pollutants was in accordance with the direction of windrose dominant wind which was to the southeast. The maximum value of SO2 concentration varies every hour.
Figure 5 Isopleth map of SO$_2$ pollutant dispersion in PT. Makassar Tene was based on measurement time of (a) 1 hour, (b) 2 hours, (c) 3 hours, (d) 4 hours, (e) 6 hours, (f) 8 hours, (g) 12 hours and (h) 24 hours.

Figure 5 (a) shows the maximum value for 1 hour which was 6.91 μg/ m$^3$ located at a distance of 293 meters from the emission source (UTM 774635.04 m and 9435669.83 m), Figure 5 (b) was at 2 hours which was 6.53 μg/ m$^3$ located at a distance of 423 meters from the emission source (UTM 774335.58 m and 9435669.90 m), Figure 5 (c) was at 3 hours which was 6.31 μg/ m$^3$ located at a distance of 298 meters from the emission source (UTM 774635.04 m and 9435669.90 m), Figure 5 (d) was at 4 hours which was 5.49 μg/ m$^3$ located at a distance of 427 meters from the emission source (UTM 774036.12 m and 9435669.90 m), Figure 5 (e) was at 6 hours which was 4.12 μg/ m$^3$ located at a distance of 664 meters from the emission source (UTM 774934.50 m and 9435669.90 m), Figure 5 (f) was at 8 hours which was 4.50 μg/ m$^3$ located at a distance of 419 meters from the emission source (UTM 774635.04 m and 9435669.90 m), Figure 5 (g) was at 12 hours which was 3.74 μg/ m$^3$ located at a distance of 419 meters from the emission source (UTM 774635.04 m and 9435669.90 m), Figure 5 (h) was at 24 hours which was 2.31 μg/ m$^3$ located at a distance of 419 meters from the emission source (UTM 774635.04 m and 9435669.90 m). Although the maximum concentration of each hour varied, the location of the maximum concentration per hour tended to be the same, which was located at (UTM 774635.04 m and 9435669.90 m), meaning that the maximum concentration occurred at a distance of 419 meters to the southeast from the emission source, where it was the warehousing location.
3.2.2. Month and annual variation

Figure 5 (a) shows the distribution pattern of SO$_2$ pollutants which was to the west from the source of emissions. This means that the monthly wind direction is inversely proportional to the hourly wind direction. Based on Figure 3 the dominant wind direction went to the west with an average wind speed of 3.60-5.70 m/s. The maximum value of monthly SO$_2$ concentration was 0.22 μg/ m$^3$ which was located at a distance of 904 meters from the emission source (UTM 773437.20 m and 9435968.83 m).

The maximum concentrated area was a residential area. However, the optimum value was still far below the quality standard so it did not have a significant impact on the environment. The same pattern was shown in Figure 6 (b). The difference was only in the lower concentration value than the monthly measurement time pattern (Figure 6 (a)). The maximum value of SO$_2$ concentration at the annual measurement time was 0.13 μg/ m$^3$ which was located at a distance of 3014 meters from the emission source (UTM 771340.98 m and 9435669.90 m). Even though the area was a residential location but the impact did not have a significant effect on the environment.

Figure 7 The graph of the relationship between distance to SO$_2$ concentration (1 hour, 2 hours, 3 hours, 4 hours, 6 hours, 8 hours, 12 hours, and 24 hours).
Figure 7 is a graph of the relationship between distance to SO₂ concentration (1 hour, 2 hours, 3 hours, 4 hours, 6 hours, 8 hours, 12 hours, and 24 hours). Graph 1 hour shows that the emissions coming out of the stack were directly dispersed into the ambient air so the SO₂ concentration decreased before continued to increase until it reached a maximum concentration of 11.2 μg/ m³ at a distance of 262.5 m. After that, the SO₂ concentration continued to decrease by an average of 0.1 μg/ m³ to a distance of 1000 m. Furthermore, on the 2 hours chart, the patterns was the same, there was no significant difference from the overall charts. All patterns showed that the maximum concentration value did not exceed the determined ambient air quality standard of 900 μg/N m³ [9].

3.3 Results of Monin-Obukhov length
Monin-Obukhov (MO) length determines the class of atmospheric stability. When the MO length (Figure 7) was negative it indicates an unstable condition, the value was not limited to neutral conditions and a positive value is in a stable condition.

![Figure 8 Annual mean value of Monin-Obukhov length.](image)

Atmospheric unstability arises in the morning and increases because more heat accumulates during the day. The value of MO length can reach the maximum in the afternoon just before the time transition. The MO length was converted to the Pasquill-Gilford (PG) atmosphere stability class (Table 1). The annual mean value of the MO length was 28.6641 m, which means that the atmospheric conditions were very stable (H). Stable atmospheric conditions indicate that the pattern of SO₂ emission dispersed into ambient air was categorized as the fanning type.

3.4. Discussion
The form isopleth pattern had no significant difference. The most important factor in the formation of isopleth patterns of pollutants was the direction and speed of the wind indicated by windrose (Figure 5). It can be seen for all simulation results of the dispersion of the SO₂ emissions that the movement of pollutants lead towards the southeast and northwest. There was almost no movement towards the north from the emissions source. High-speed winds would carry pollutants in wide disperse (Figure 6), while winds at low speeds (calm wind) made the pollutants concentrated high and at certain locations (Figure 5). The distribution of concentration horizontally was affected by wind direction and speed. In addition, the atmospheric stability in the fanning type was at a stable atmospheric condition (Figure 1). This condition has a negative impact on ambient air which is more concentrated in certain places because there is no dilution of the pollutants.

4. Conclusion
The results and discussion shows that the emission distribution pattern is fanning type. The distribution of pollutants that occur at 1-hour measurement shows that the dominant wind direction is to the southeast with a maximum concentration of 6.91 μg/ m³ located at a distance of 298 m from the source of emissions. Where it is in the warehousing area, but the maximum concentration is still far below the ambient air quality standard. The difference in the pattern occurs when the annual measurement shows that the dominant wind direction was to the northwest with a maximum concentration of 0.13262 μg/ m³ located at a distance of 886.88 m from the source of emissions. Where it is in a residential area, but the maximum concentration has a very small value that closes to zero so it does not exceed the ambient air quality standard.
Acknowledgments
We thank Hasanuddin University for supporting this research. Thank you also for my friends has helped a lot.

References
[1] López-Cima M F, García-Pérez J, Pérez-Gómez B, Aragonés N, López-Abente G, Tardón A and Pollán M 2011 Int. J. Health Geogr. 10 10
[2] Minister Environment Regulation of Number 07 2007 Ambient Air Quality Standards and Emissions from Stationary Sources for Steam Boilers
[3] Ranzi A, Fano V, Erspamer L, Lauriola P, Perucci C A and Forastiere F 2011 Environ. Health 10 22
[4] Baccarelli A, Barretta F, Dou C, Zhang X, McCracken J P, Díaz A, Bertazzi P A, Schwartz J, Wang S and Hou L 2011 Environ. Health 10 108
[5] Ahrens C D 2009 Meteorology Today: An Introduction to Weather, Climate, and the Environment Ninth Edition (Canada: Brooks/Cole Cengage Learning) chapter 18 p 518
[6] Pelliccioni A, Monti P, Gariazzo C and Leuzzi G 2012 12 405
[7] Cimorelli A J, Perry S G, Venkatram A, Weil J C, Paine R J, Wilson R B, Lee R F, Peters W D and Brode R W 2005 J. Appl. Meteorol. Climatol. 44 682
[8] East java governor regulations of number 10 2009 East Java in Ambient Air Quality Standards and Emissions from Stationary Sources
[9] Republic of Indonesia Government Regulations of Number 41 1999 Air Pollution Control