Environmental Odor Analysis in West and East Java's Ambient Air and Odor Reduction Using Biofilter Model

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Abstract

The odor affects both one's health and quality of life. This study measures and analyzes odor concentration and odor sources in ambient air, the correlation between odor gas concentration and the hedonic scale, and the design of an odor-reduction instrument. The research commenced from February to May 2022 in the small industrial area (SIA) of Magetan Regency and compost bins of Bogor City. Data was collected through chemical analysis, and the hedonic scale was measured at four points divided into radii one and two. The concentration of odor parameters in Magetan and Bogor City is below the quality standard, while the correlation between ammonia gas concentration and the hedonic scale is low. Regarding the biofilter, its odor reduction efficiency is 35% for rotten fish, 70% for goat manure, 82% for compost waste, and 47% for chicken carcasses.

Keywords: biofilter, hedonic scale, odor concentration, reduction

1. Introduction

The odor is a sensation associated with one or multiple compounds. Measuring the impact of odors on society gradually takes importance because of the effects on health and quality of life. The odor evaluation is a significant topic in the field of indoor air quality which has a quality standard for maintaining the health and safety of the surrounding environment [1]. Disturbing odor risks disrupt public health and damage the environment [2]. Therefore, the odor disorder had a predetermined quality standard [3]. Two components comprised the theory of odor measurement analytical and sensory. Analytical measurements represent the physical and chemical characteristics of odor compounds, and the most used measurement is odor concentration, while sensory measurements were made with the human nose [4]. There were five odor parameters, namely ammonia (NH_3), methyl mercaptan (CH_3SH), hydrogen sulfide (H_2S), methyl sulfide (CH_3S), and styrene ($C_6H_5CH_2S$) [5]. Odor measurement can use the panel method [5], and it can be done by rating a hedonic scale from -4 to +4 with respective odor impressions in different values.

The small industrial area (SIA) in Magetan Regency was a leather industry processed into handicraft materials such as bags, shoes, jackets, and others. However, the leather industry produced a pungent odor due to leather drying and the discharged wastewater. In addition, the compost bins are often regarded as the cause of odor. One of the composting processes was carried out in Bogor City. Moreover, due to the degradation process of organic waste, the odor from the compost bins is unpleasant and disgusting. Even though the odor concentration didn't exceed the quality standards, the odor would still be annoying [6].

As a result, it has become a polemic. To examine the concentration of odorant compounds in the ambient air, the ambient air samples were taken and tested by measuring the concentration of odor gasses and the odor hedonic scale. Odor reduction with biofilters was used to reduce the community's disturbance by utilizing microorganisms' ability to break down odor gasses

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[7]. Meanwhile, biofilter was more environmentally friendly than chemical and physical methods [8]. Therefore, this study aims to analyze the concentration of odorant compounds in the ambient air and the correlation between odor gas concentration and hedonic scale. Furthermore, a biofilter model was designed to reduce odor gas concentration.

2. Methodology

2.1. Place and timing

The research started from February to May 2022, and it was conducted. near the SIA of leather in Magetan Regency, East Java, and compost bins in Bogor City, West Java. Odor measurements were carried out from morning to evening, and the measurements were taken with less humidity. The panelists participating in this research were local community members who needed continuous activity at the SIA of Magetan Regency and Bogor City compost bins. The panelists didn't have respiratory problems, and the panelists were nearly in the same state in odor measurements.

Afterward, at least eight panelists, which accounted for more than half of the test subjects, could detect the level of odor produced by the odorant mixture [5]. Specifically, the panelists who participated in each measurement point were eight in the SIA of Magetan, nine in the Bogor City compost bins, and eight for the biofilter experiment. In the meantime, odor reduction simulations using biofilters were carried out with several odor sources, such as goat manure, chicken carcasses, rotting fish, and compost waste.

The directly-measured odor level parameters include ammonia, methyl mercaptan, hydrogen sulfide, methyl sulfide, and styrene. Ammonia was analyzed by the indophenol method using a spectrophotometer [9]. Lodge [10] analyzed hydrogen sulfide by the methods of air sampling and analysis (MASA). Styrene was analyzed by National Institute for Occupational Safety and Health (NIOSH) method 1501 [11]. Methyl mercaptan was analyzed by NIOSH method 2542 [12]. Methyl sulfide was analyzed by gas chromatography-flame photometric detector (GC-FPD) [13].

2.2. Data collection methods

The data used primary data to directly measure gas concentrations of five odor parameters on the odor hedonic scale with the panel method [3]. The odor level parameters measured directly include ammonia, methyl mercaptan, hydrogen sulfide, methyl sulfide, and styrene. Odor gas concentrations were analyzed at the Environmental Laboratory of Unilab Perdana Jakarta and Surabaya Ltd. The panelists used the panel method to measure the parameters of the odor hedonic scale, namely the five odor compounds. Meanwhile, the hedonic scale for the impression of an odor is presented in Table 1. The hedonic scale had a scale ranging from +4 to -4, and the effect of the odor was marked as "Very good" to "Stink" with corresponding hedonic scale.

Table 1 Hedonic scale on the effect of odor [6]

Scale	Effects of odor	Scale	Effects of odor	Scale	Effects of odor
+4	Very good	+1	Moderate	-2	Not good enough
+3	Good	0	No odor	-3	Bad
+2	Good enough	-1	Rather bad	-4	Stink

The measurements were made with eight points, with four points in Radius 1 and 2 respectively. The measurement points in Radius 2 were farther than Radius 1 at the SIA of Magetan. The distance from the measurement location to the SIA of Magetan is presented in Table 2. The chosen measurement point was the closest point to the community. The measurement points in Radius 1 and 2 in Bogor City were 3 m and 6 m from the compost bins, as presented in Table 3. Location points were divided into Radius 1 and 2 to determine the effect of distance on the odor perceived by the panelists. The four points were measured according to the cardinal directions: North, South, West, and East. Odor measurement points at the SIA of Magetan, and Bogor compost bins City was presented in Fig. 1 and Fig. 2.

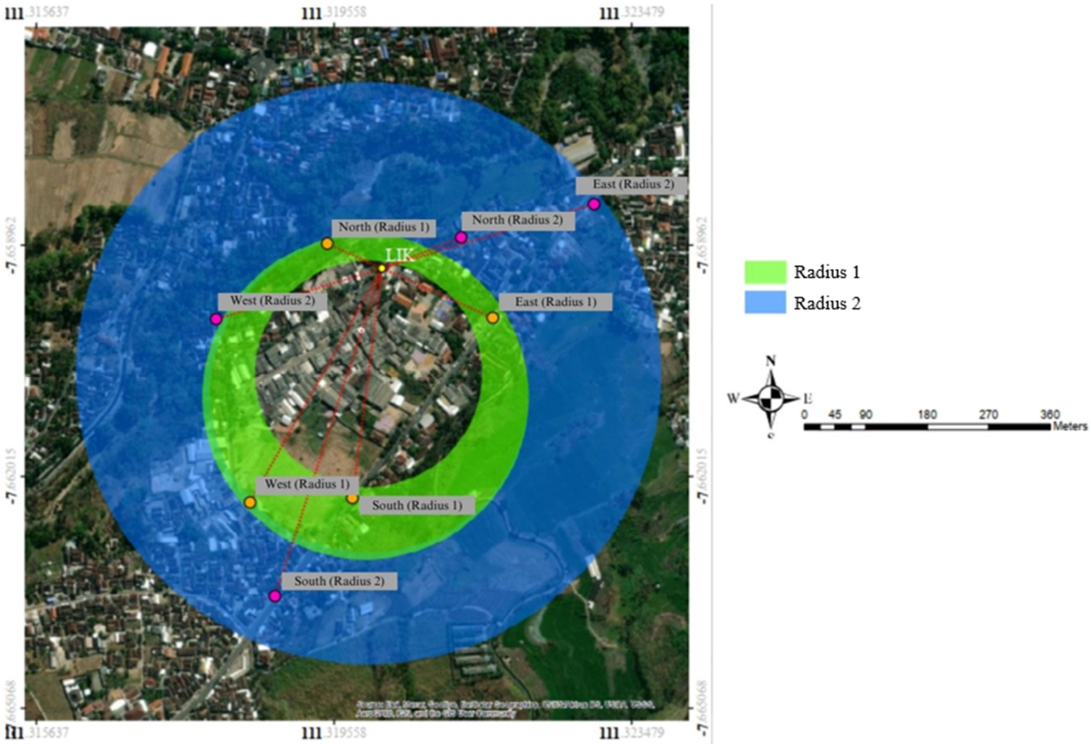

Fig. 1 Odor measurement point at the SIA of Magetan

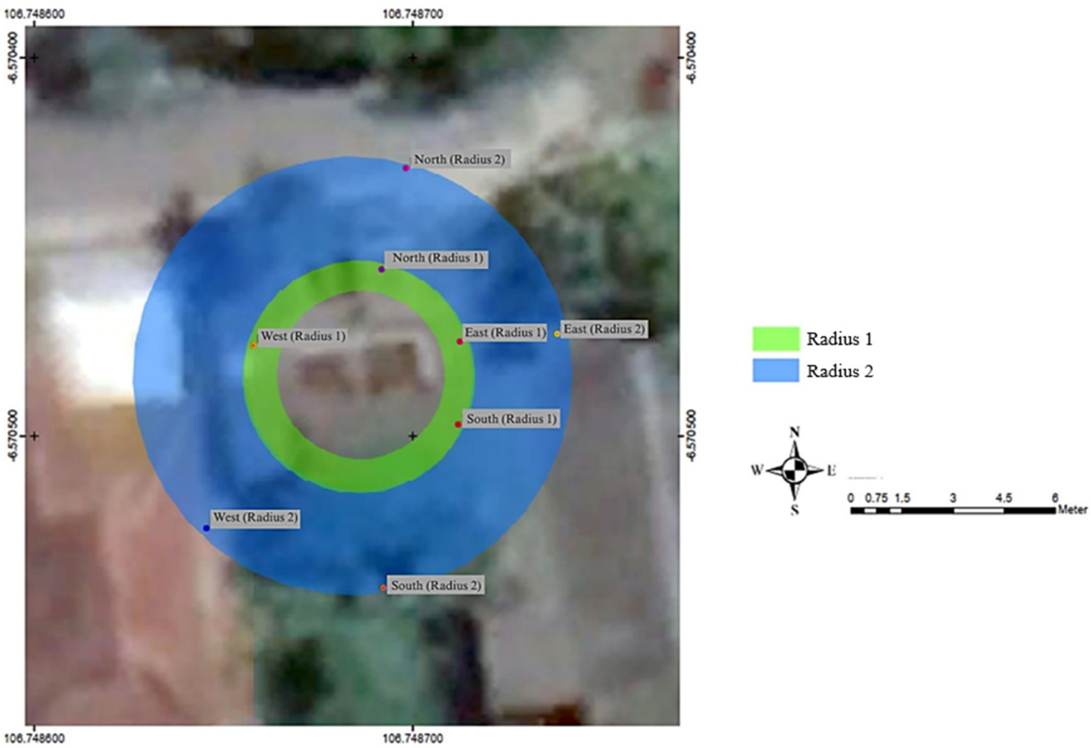

Fig. 2 Odor measurement point at the compost bins of Bogor City

Table 2 The distance from the measurement location point to the SIA of Magetan

Wind direction	Distance from measurement location to SIA of Magetan (m)	
	Radius 1	Radius 2
North	87.2	123.5
South	338.1	502.7
West	391.8	253.0
East	176.4	321.9

Table 3 The distance from the measurement location point to the compost bins of Bogor City

Wind direction	Distance from measurement location to compost bins of Bogor City (m)	
	Radius 1	Radius 2
North	3	6
South		
West		
East		

2.3. Making biofilters to reduce odor

The manufacture of biofilters was still only in the form of a biofilter model. Consequently, the goat manure, chicken carcasses, rotting fish, and compost waste were included in the used screw sources. The tools and materials were needed in the manufacture of biofilters which include two acrylic boxes, 4" and 5/8" acrylic pipes, a table, three pipe clamps, closed and perforated pipe caps, aquarium hoses, stop taps, sprinklers, pumice stone, netting, water, glue sealant, pneumatic hoses, a 3000 L/hour water pump, and a 45 L/minute air pump. The selection of pump type was adjusted to reactor volume and retention time. In addition, to keep the air moist, water was needed in distribute through a sprinkler. The tools were also needed when testing biofilters which include a thermometer to measure reactor temperature, an anemometer to measure air velocity, and an environment meter to measure relative humidity in the reactor. After the biofiltration was completed, the data was collected for odor reduction. The data was collected using the panel method with a hedonic scale as presented in Table 1.

Eight panelists carried out odor reduction simulations before and after passing through the biofilter. The panelist perceived the odor and gave a score from +4 to -4, and the effect of the odor was marked as “Very good” to “Stink” with a corresponding hedonic scale as presented in Table 1. The difference between the hedonic scale will be calculated to determine odor reduction efficiency, while the source of odor will be inserted alternately into the odor source container. Odor reduction simulations using biofilters were carried out with several odor sources, such as goat manure, chicken carcasses, rotting fish, and compost waste. Besides, to optimize the reactor in odor reduction, monitoring the biofilter reactor’s temperature and humidity was also carried out during the biofiltration process. The airflow from the pump must be adjusted with a valve to get the airflow according to the design.

3. Results and Discussion

3.1. The concentration of odor compounds in ambient air from several types of odor sources

The smallest average value of the hedonic odor scale at SIA of Magetan was found in the North direction at the Radius 1 of -1.8, as presented in Table 4. This value had the impression of quite an unpleasant odor and a standard deviation of ±0.2. It was also supported by the distance of 87.2 m from the closest location to the SIA of Magetan, as presented in Table 2. The closer the measurement location to the SIA of Magetan positioned, the stronger the odor was perceived. Odor gas concentration at SIA of Magetan with five odor parameters was still below the quality standard of odor [5]. The odor parameter quality standards are presented in Table 5.

Table 4 Hedonic scale result and measurements of odor gas concentrations in the SIA of Magetan

Wind direction	Radius	Hedonic scale (mean ± STD)	NH_3 (ppm)	H_2S (ppm)	$C_6H_5CHCH_2$ (ppm)	CH_3SH (ppm)	$(CH_3)2S$ (ppm)
North	1	(-1.8 ± 0.2)	0.5	0.003	< 0.02	< 0.002	< 0.01
	2	(-0.7 ± 0.1)	0.07	< 0.003	< 0.02	< 0.002	< 0.01
South	1	(0.1 ± 0.1)	0.1	< 0.003	< 0.02	< 0.002	< 0.01
	2	(0.1 ± 0.1)	0.08	< 0.003	< 0.02	< 0.002	< 0.01
West	1	(-1.4 ± 0.3)	0.02	< 0.003	< 0.02	< 0.002	< 0.01
	2	(-0.8 ± 0.4)	0.07	< 0.003	< 0.02	< 0.002	< 0.01
East	1	(-0.4 ± 0.1)	0.3	< 0.003	< 0.02	< 0.002	< 0.01
	2	(0.3 ± 0.1)	0.09	< 0.003	< 0.02	< 0.002	< 0.01

Notes: NH_3 = ammonia, H_2S = hydrogen sulfide, $C_6H_5CHCH_2$ = styrene, CH_3SH = methyl mercaptan, and CH_3S = methyl sulfide

The positive odor impression was in the South direction at Radius 1 and 2 with both the average hedonic scale of 0.1, and both standard deviations of ±0.1 in the distance to SIA of Magetan was 338.1 m and 502.7 m. In addition, the positive impression was also in the East direction at Radius 2, with an average hedonic scale of 0.3, a standard deviation of ±0.1, and a distance to SIA of Magetan of 321.92 m. This point was farther away than any other point. Therefore, the farther the measurement location point was from the SIA of Magetan, the less odor would be perceived. To reduce odor in industrial tanneries, biofilters can be applied with an odor reduction efficiency of > 99% [14] owing to the pungent odor of effluent and sludge in the tannery industry [15]. The odor concentration value would be influenced by climatic factors such as wind speed, temperature, relative humidity, dominant wind direction, and weather. However, the values were varied, as presented in Table 6. It was because measurements were taken at every two points simultaneously, and the odor source should be measured at each point simultaneously.

Table 5 Quality standards for odor [5]

Parameter	Quality standards (ppm)
Ammonia (NH_3)	2.0
Hydrogen sulfide (H_2S)	0.02
Styrene ($C_6H_5CHCH_2$)	0.1
Methyl mercaptan (CH_3SH)	0.002
Methyl sulfide (CH_3S)	0.01

Table 6 Climatic conditions when measuring odor in the SIA of Magetan

The direction of the measurement location	Radius	Wind speed (km/hour)	Temperature (°C)	Relative humidity (%)	Wind direction dominant	Weather
North	1	0.1	28-32	59-74	South	Cloudy
	2	0.6	33-34	41-43	North	Cloudy
South	1	0.5	32-33	64-67	East	Cloudy
	2	0.3	32-33	45-48	East	Cloudy
West	1	0.9	32-38	26-45	East	Sunny
	2	0.8	30-33	32-53	North	Cloudy
East	1	1.1	32-34	30-35	North	Sunny
	2	0.7	32-33	44-49	East	Cloudy

The minor average of the hedonic scale for the odor of compost bins was found in the South and West at Radius 1 of -1.0, as was presented in Table 7. This value has the impression of an unpleasant odor, with a standard deviation of ±0.2 and ±0.1 respectively. The concentration of odor gas in the compost bins with five odor parameters, namely ammonia, hydrogen sulfide, styrene, methyl mercaptan, and methyl sulfide, was still below the quality standard of odor. The standard quality standards for odor parameters are presented in Table 5. The odor stood at a negative impression and smaller hedonic scale value in Radius 1, with a distance closer to the compost bins of 3 m compared to Radius 2.

Table 7 Hedonic scale result and measurements in the compost bins of Bogor City

Wind direction	Radius	Hedonic scale (mean ± STD)	NH_3 (ppm)	H_2S (ppm)	$C_6H_5CHCH_2$ (ppm)	CH_3SH (ppm)	$(CH_3)2S$ (ppm)
North	1	(-0.3 ± 0.2)	0.04	< 0.003	< 0.02	< 0.002	< 0.01
	2	(-0.1 ± 0.1)	0.02	< 0.003	< 0.02	< 0.002	< 0.01
South	1	(-1.0 ± 0.2)	0.02	< 0.003	< 0.02	< 0.002	< 0.01
	2	(0.4 ± 0.1)	0.03	< 0.003	< 0.02	< 0.002	< 0.01
West	1	(-1.0 ± 0.1)	0.06	< 0.003	< 0.02	< 0.002	< 0.01
	2	(-0.3 ± 0.1)	0.04	< 0.003	< 0.02	< 0.002	< 0.01
East	1	(-0.2 ± 0.1)	0.06	< 0.003	< 0.02	< 0.002	< 0.01
	2	(-0.1 ± 0.1)	0.03	< 0.003	< 0.02	< 0.002	< 0.01

Notes: NH_3 = ammonia, H_2S = hydrogen sulfide, $C_6H_5CHCH_2$ = styrene, CH_3SH = methyl mercaptan, and CH_3S = methyl sulfide

The odor of ammonia from food waste bioconversion in composting came from products and the areas of biodegradation, and ammonia was the dominant odor parameter [16]. However, hydrogen sulfide was also one of the primary odors in composting [17]. The concentration value of odor would be influenced by climatic factors such as wind speed, temperature, relative humidity, dominant wind direction, and weather. However, the values varied, as presented in Table 8. It was because measurements were taken at every two points simultaneously, and the odor source should be measured at the same time at each point. Furthermore, fluctuations would influence the perception of an unpleasant odor in temperature, relative humidity, atmospheric pressure, and wind speed [18].

Table 8 Climatic conditions when measuring odor in the compost bins of Bogor City

Wind direction	Radius	Wind speed (km/hour)	Temperature (°C)	Relative humidity (%)	Wind direction dominant	Weather
North	1	0.9	30-31	67	West	Cloudy
	2	0.8	29	69	West	Cloudy
South	1	0.7	30-31	67	West	Cloudy
	2	1.4	29	75	West	Cloudy
West	1	0.8	30	67	West	Cloudy
	2	0.9	29	69	West	Cloudy
East	1	1.2	31	64	West	Cloudy
	2	0.4	29	69	West	Cloudy

3.2. The correlation between odor gas concentration and hedonic scale

The result of odor gas concentration measurements and the panelists' hedonic scale were subsequently analyzed by looking for a correlation. Based on the graphs in Fig. 3 and Fig. 4, the correlation between odor gas concentration and the hedonic scale on the ammonia parameter was weak in the SIA of Magetan and Bogor City compost bins. The R^2 values of 0.2189 and 0.0476 in Figs. 1 and 2 were taken into consideration. Such a result indicates that the gas concentration was low. This difference was controversial because the leather industry and compost bins would permeate unpleasant odor, whereas the concentration of odor gas was still below the quality standard of odor [5].

In other words, the public was disturbed by an unpleasant odor, while the detection of odor gas concentration did not exceed the quality standard. The panelist screening method for measuring odor was necessary for the effect of odor differences among individuals, and the odor could be assessed with efficiency and accuracy [19]. Respondents' gender and age wouldn't be counted in the sensory odor assessment. The longer the respondent stayed in the odor environment, the less harmful the odor became due to the tolerance to the odor [20]. The coefficient of determination could not be determined for the parameters hydrogen sulfide, styrene, methyl mercaptan, and methyl sulfide because the measurement results were presented as < 0.003 ppm, < 0.02 ppm, < 0.003 ppm, and < 0.01 ppm.

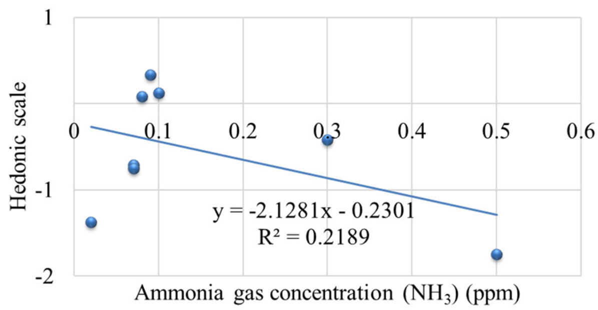

Fig. 3 The correlation between the hedonic scale and ammonia gas concentration in the SIA of Magetan

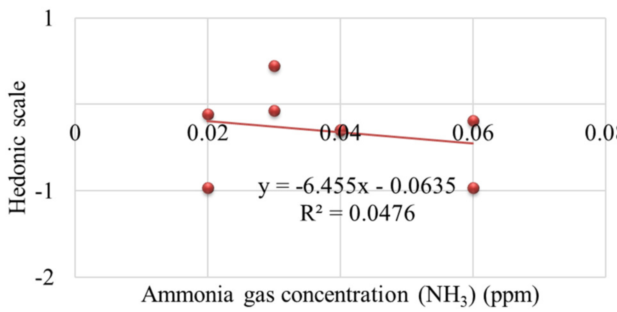

Fig. 4 The correlation between the hedonic scale and ammonia gas concentration in the compost bins of Bogor City

3.3. Design and build odor-reduction equipment

The air in the odor source container was transferred to the humidifier to maintain relative humidity, while the humidifier had a water sprinkler to moisten the air conditioner, and air would pass through the pumice stone as a filter media in a 4" diameter reactor. To enable the panelists to feel the odor after the biofiltration, several holes were drilled at the end of the reactor. The filter of used stone in odor reduction has been treated with compost for approximately two weeks. The filter media is placed for bacteria biofilms to reduce odor. The air circulated by using a pump with an output of 45 L/min, while the volumetric rate was 5 L/min. The air velocity from the pump was measured with an anemometer, and the result was 1.4 m/sec.

Hence, when the volumetric design rate was 5 L/min, the airspeed was 0.2 m/s and adjusted by the valve. The completed biofilter is shown in Fig. 5. The odor source will be tested alternately in the odor source container. The air in the container will be drawn by a pump with an airflow of 5 L/min and a retention time of 60 seconds. Afterward, the air will flow into the humidifier to maintain humidity around 95-100%. The bacteria in the biofilm attached to the filter media will degrade the odor, and the biodegradation could deodorize most odor substances [21]. The work scheme of the biofilter model is shown in Fig. 6.

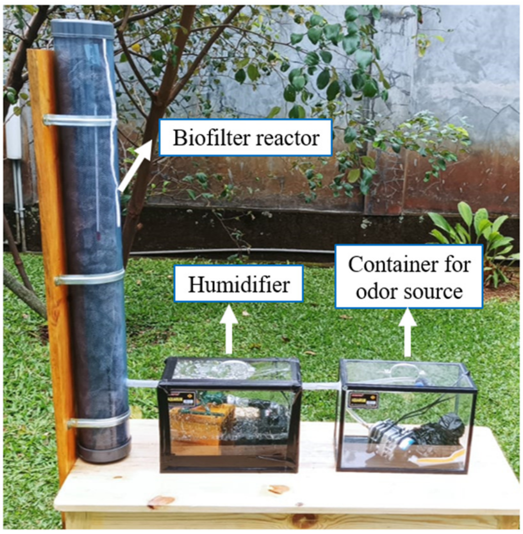

Fig. 5 Completed biofilter model

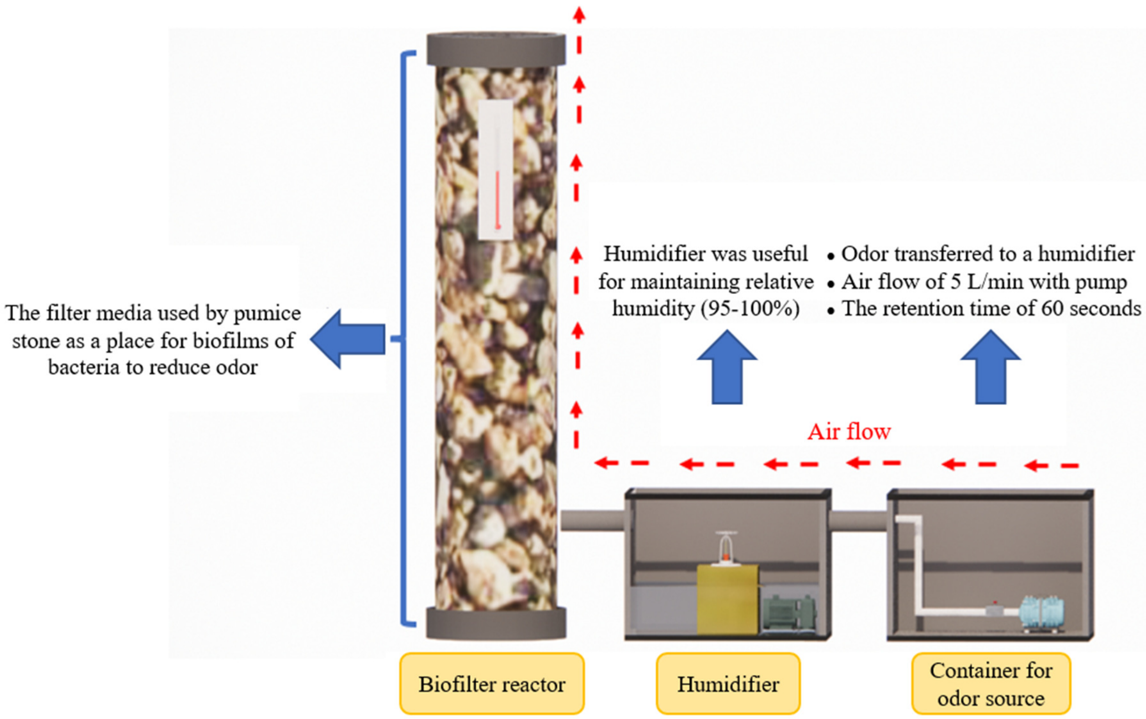

Fig. 6 Work scheme of biofilter model

Eight panelists carried out odor reduction simulations of the biofilter, and the average value of the hedonic odor scale increased after passing through the biofilter for the following odor source: rotting fish from -3.9 to -2.5; goat manure from -1.3 to -0.4; compost waste from -1.4 to -0.3; and chicken carcasses from -4 to -2.1, as presented in Fig. 7. The results showed that each type of odor had been reduced. The difference in the hedonic scale will be calculated to determine the odor reduction efficiency. The odor reduction was 35%, 70%, 82%, and 47% for the odor of rotting fish, goat manure, compost waste, and chicken carcasses, respectively, as presented in Fig. 7. During the biofiltration process, microorganisms would consume odor substances, and the products of biodegradation were CO_2, water steam, and heat [21]. The effectiveness of odor reduction (NH_3 and H_2S) depends on the used filter media material and the mixture between the filter media and compost [22]. For microbial growth, micro-nutrients are supported by compost [23].

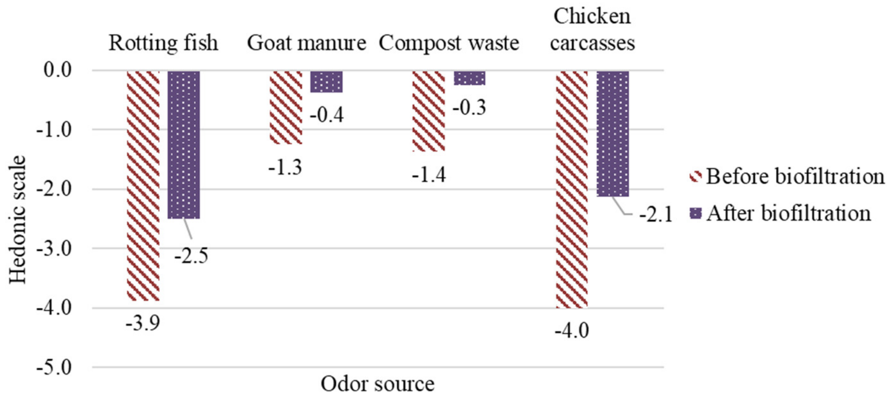

Fig. 7 The hedonic scale before and after passing the biofilter

The recommended temperature for the biofilter is ranged from 25 to 35 °C [24], while the temperature of the biofilter is ranged from 15 to 50 °C, with an optimum temperature of 30 °C [25]. The designed biofilter reactor had an average temperature of 31.7 °C, as presented in Table 9, and it was appropriate due to being in the range of 15 to 50 °C, and 25 to 35 °C. Moreover, it was near the optimum temperature of 30 °C. The relative humidity average was 81.7%, as presented in Table 9.

Table 9 Temperature and relative humidity of the biofilter reactor

Measurement	Temperature (°C)	Relative humidity (%)
1	31.0	95.2
2	32.0	95.4
3	32.0	96.3
Average	31.7	95.6

The biofiltration process must be moistened to reach a relative humidity of 95 to 100% [26]. To optimize the reactor in odor reduction, monitoring the biofilter reactor's temperature and humidity was also carried out during the biofiltration process. The retention time in the biofilter test was 60 seconds. When the H_2S removal efficiency was 99%, it retained for 60 seconds [27]. Hydrogen sulfide should be monitored to avoid smelly gas caused by the management activities and ensure the air condition both indoors and outdoors [28]. Due to the influence on the speed of chemical reactions and the metabolic rate of microorganisms, high temperature, and suitable humidity would increase biodegradation efficiency. Microbial metabolic reactions help remove H_2S and NH_3 [29]. In addition, the performance of the reactor in degrading odor is assisted by the bacteria in biological activity [27]. Therefore, to maintain bacterial growth, the biofilter reactor must be monitored.

4. Conclusions

This study investigates two odor measurements of odor gas concentrations and the employment of a panel for analyzing odor quality standards in Ministry of Environment Decree No. 50, 1996. Furthermore, the design of a biofilter model with a new filter media using pumice stone is deployed. The main conclusions are summarized as:

(1) The concentration of 5 odor gas parameters, namely ammonia, hydrogen sulfide, styrene, methyl mercaptan, and methyl sulfide, in the SIA of Magetan and compost bins of Bogor City were below the quality standard. Furthermore, the odor intensity is inversely proportional to the distance of measurement location to the odor source.

(2) The correlation between gas concentration and the hedonic scale on the ammonia parameter was weak in the SIA of Magetan and compost bins, which is evident in the R^2 values of 0.2189 (SIA of Magetan) and 0.0476 (compost bins of Bogor City). Such a result indicates that the gas concentration was low.

(3) The biofilter model has been able to reduce odor by using pumice stone filter media. Meanwhile, the odor reduction efficiency of the biofilter was 35%, 70%, 82%, and 47% for the odor of rotting fish, goat manure, compost waste, and chicken carcasses, respectively.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] V. Thiele, C. Monsé, F. Hoffmeyer, T. Brüning, J. Bünger, and K. Sucker, “Indoor Air Quality – An Overview of Methods for Measuring Odor Detection Thresholds of Single Substances,” Respiratory Physiology & Neurobiology, vol. 315, article no. 104108, September 2023.

[2] Y. Zhang, X. Ning, Y. Li, J. Wang, H. Cui, J. Meng, et al., “Impact Assessment of Odor Nuisance, Health Risk and Variation Originating from the Landfill Surface,” Waste Management, vol. 126, pp. 771-780, May 2021.

[3] Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup, Peraturan Pemerintah (PP) Nomor 22, 2021. (In Indonesia)

[4] P. Gostelow, S. A. Parsons, and R. M. Stuetz, “Odour Measurements for Sewage Treatment Works,” Water Research, vol. 35, no. 3, pp. 579-597, February 2001.

[5] Baku Tingkat Kebauan, Keputusan Menteri Negara Lingkungan Hidup No. 50, 1996. (In Indonesia)

[6] A. S. Yuwono, “Odour Quantification and Odour Pollution in Indonesia,” Jurnal Purifikasi, vol. 9, no. 2, pp. 175-186, December 2008. (Indonesia)

[7] P. Márquez, A. M. Herruzo-Ruiz, J. A. Siles, J. Alhama, C. Michán, and M. A. Martín, “Influence of Packing Material on the Biofiltration of Butyric Acid: A Comparative Study from a Physico-Chemical, Olfactometric and Microbiological Perspective,” Journal of Environmental Management, vol. 294, article no. 113044, September 2021.

[8] K. Barbusinski, K. Kalemba, D. Kasperczyk, K. Urbaniec, and V. Kozik, “Biological Methods for Odor Treatment – A Review,” Journal of Cleaner Production, vol. 152, pp. 223-241, May 2017.

[9] Ambient Atmospheres - Part 1: Test Methods of Ammonia (NH_3) Content by Indophenols Using Spectrophometers, SNI 19-7119.1-2005, 2005. (In Indonesia)

[10] J. P. Lodge, Methods of Air Sampling and Analysis, 3rd ed., Washington: Lewis Publishers INC, 1988.

[11] NIOSH Manual of Analytical Methods, 4th ed., Method 1501, March 2003.

[12] NIOSH Manual of Analytical Methods, 4th ed., Method 2542, August 1994.

[13] M. E. Elde, Dimethyl Sulfide, Method number: PV2210, July 1987.

[14] B. Gandu, S. Palanivel, S. Juntupally, V. Arelli, S. Begum, and G. R. Anupoju, “Removal of NH_3 and H_2S from Odor Causing Tannery Emissions Using Biological Filters: Impact of Operational Strategy on the Performance of a Pilot-Scale Bio-Filter,” Journal of Environmental Science and Health, Part A, vol. 56, no. 6, pp. 625-634, 2021.

[15] N. Shivasankaran, A. V. Balan, S. P. Sankar, S. Magibalan, and C. M. Dinesh, “Removal of Hydrogen Sulphide and Odour from Tannery & Textile Effluents,” Materials Today: Proceedings, vol. 21, part 1, pp. 777-781, 2020.

[16] Y. Wang, F. Lü, X. Kang, X. Xu, W. Chen, H. Chai, et al., “Odor Characteristics and Health Risks during Food Waste Bioconversion by Housefly (Musca domestica L.) Larvae,” Journal of Cleaner Production, vol. 376, article no. 134343, November 2022.

[17] C. A. Rincón, A. De Guardia, A. Couvert, S. Le Roux, I. Soutrel, M. Daumoin, et al., “Chemical and Odor Characterization of Gas Emissions Released during Composting of Solid Wastes and Digestates,” Journal of Environmental Management, vol. 233, pp. 39-53, March 2019.

[18] A. C. Carvalho, A. Carvalho, I. Gelpi, M. Barreiro, C. Borrego, A. I. Miranda, et al., “Influence of Topography and Land Use on Pollutants Dispersion in the Atlantic Coast of Iberian Peninsula,” Atmospheric Environment, vol. 40, no. 21, pp. 3969-3982, July 2006.

[19] Y. Xu, W. Liang, and Y. Hu, “Methodological Assessment of Screening Methods and Minimum Panel Member Requirements for Odor Assessments,” Building and Environment, vol. 237, article no. 110326, June 2023.

[20] M. Wojnarowska, G. Plichta, A. Sagan, J. Plichta, J. Stobiecka, and M. Sołtysik, “Odour Nuisance and Urban Residents’ Quality of Life: A Case Study in Kraków’s in Plaszow District,” Urban Climate, vol. 34, article no. 100704, December 2020.

[21] A. S. Yuwono, T. Hamacher, J. Nieß, P. Boeker, and P. S. Lammers, “Implementation of a Quartz Microbalance (QMB) Sensor Array-Based Instrument and Olfactometer for Monitoring the Performance of an Odour Biofilter,” 2nd IWA International Workshop & Conference on Odour & VOC’s, pp. 1-8, September 2003.

[22] A. Rolewicz-Kalińska, K. Lelicińska-Serafin, and P. Manczarski, “Volatile Organic Compounds, Ammonia and Hydrogen Sulphide Removal Using a Two-Stage Membrane Biofiltration Process,” Chemical Engineering Research and Design, vol. 165, pp. 69-80, January 2021.

[23] M. Kumar, B. S. Giri, K. H. Kim, R. P. Singh, E. R. Rene, M. E. López, et al., “Performance of a Biofilter with Compost and Activated Carbon Based Packing Material for Gas-Phase Toluene Removal under Extremely High Loading Rates,” Bioresource Technology, vol. 285, article no. 121317, August 2019.

[24] M. Galwa-Widera, A. Kwarciak-Kozłowska, and J. Bień, “Reduction of Odour Nuisance of Industrial Plants– Biofiltering in Composting Plants,” Journal of Ecological Engineering, vol. 19, no. 5, pp. 135-143, 2018.

[25] Y. C. Chung, C. Huang, and C. P. Tseng, “Operation Optimization of Thiobacillus Thioparus CH11 Biofilter for Hydrogen Sulfide Removal,” Journal of Biotechnology, vol. 52, no. 1, pp. 31-38, November 1996.

[26] R. Lebrero, R. Muñoz, S. Villaverde, and Y. T. Hung, “Air Biofiltration Applied to Odor Treatment”, Handbook of Environment and Waste Management: Air and Water Pollution Control, pp. 149-174, February 2012.

[27] I. Omri, F. Aouidi, H. Bouallagui, J. J. Godon, and M. Hamdi, “Performance Study of Biofilter Developed to Treat H_2S from Wastewater Odour,” Saudi Journal of Biological Sciences, vol. 20, no. 2, pp. 169-176, April 2013.

[28] M. I. Nunes, C. Kalinowski, A. F. L. Godoi, A. P. Gomes, and M. Cerqueira, “Hydrogen Sulfide Levels in the Ambient Air of Municipal Solid Waste Management Facilities: A Case Study in Portugal,” Case Studies in Chemical and Environmental Engineering, vol. 4, article no. 100152, December 2021.

[29] T. Zheng, L. Li, F. Chai, and Y. Wang, “Factors Impacting the Performance and Microbial Populations of Three Biofilters for Co-Treatment of H_2S and NH_3 in a Domestic Waste Landfill Site,” Process Safety and Environmental Protection, vol. 149, pp. 410-421, May 2021.