ISSN: 2586-6036 © 2021 KODISA & JWMAP.
http://www. welfareconvergence.or.kr
doi: http://dx.doi.org/10.13106/jwmap.2021.Vol4.no3.1

Development of Complex Module Device for Odor Reduction in Sewage

Young-Do KIM[1], Woo-Taeg KWON[2]

1. First Author Researcher, dnc-korea.com, Korea, Email: youngdo31@naver.com
2. Corresponding Author Professor, Department of Environmental Health & Safety, Eulji University, Korea, Email: awtkw@eulji.ac.kr

Received: August 14, 2021. Revised: September 29, 2021. Accepted: September 29, 2021.

Abstract

Purpose: This study was conducted to develop a module with higher removal efficiency and effectiveness by adapting two or more deodorization techniques for main cause of odor pollution exposed citizen living near water treatment facilities. **Research design, data and methodology:** To consider the standard, unity, electrical wire, compatibility of detachable device by installing two types of dry deodorization device within one module for easy replacement. Complex odor, H_2S, NH_3 were collected from sewage treatment facilities for evaluation of deodorization device. **Results:** Using the developed application in this study, removal efficiency of complex odor, H_2S, NH_3 were 93%, 100%, 82%, respectively. **Conclusions:** The H_2S removal efficiency of deodorization device was higher than bio-filter system, which were currently used by sewage treatment. Further, the device should be considered for use in efficient odor removal system.

Keywords : Complex odor, H_2S, NH_3,Water treatment, Complex module devices

JEL Classification Codes : I15, I18, I31

1. Introduction

In Korea, complaints about odor continued to increase at an average annual rate of 20% despite the enforcement of the Bad Odor Prevention Act in 2005. In 2016, it increased 21 times compared to 2005, and complaints about odor in the management area increased slightly. However, complaints about odor outside the management area have increased rapidly, accounting for 75.8% of the total complaints (Ministry of Environment, 2021).

Odor complaints are on the rise, mainly because (Ko et al., 2012) residents are closer to public treatment plants due to the expansion of urban areas. The recent trend of underground design of public treatment plants (Jang et al., 2017) is spreading in the metropolitan areas such as Gyeonggi-Do, Seoul, and Incheon. The main reason is that more efficient deodorization facilities are needed to cope with the increasing environmental complaints of local residents. In order to cope with the increasing number of complaints about odors, observatories are installed to dissipate and disperse the odor gas as a substitute for high chimneys. However, since the installation cost of the observatory is more than tens of billions of won, the cost is burdened, so the need for economical odor reduction technology is being developed. On the other hand, public treatment plants such as sewage treatment plant, industrial complex/wastewater treatment plant, food treatment plant, sludge incineration plant, and livestock manure plant are major places where odor reduction facilities must be installed inevitably in the design, development, construction, and operation of cities and housing complexes. In the past, public treatment plants were installed far away from the city center and housing complexes, so there were fewer complaints about odors.

However, recently, out of the old city center, various new housing districts and private houses are being built in the outskirts, such as near the existing public treatment plants. With the recent trend of increasing awareness of environmental issues among residents, the demand for health and clean air is increasing. In order to respond to these social changes, we intend to develop a complex reaction modular deodorization facility applicable to sewage treatment.

2. Literature Review

2.1. Characteristics of Odor in Sewage

Odor substances generated from sewage include aldehydes, ketones, carboxylic acids, nitrogen compounds, and sulfur compounds (Gostelow et al., 2001). The odor is mainly caused by the mixing of volatile sulfur compounds, volatile nitrogen compounds, and volatile fatty acids (Kim et al., 2006). In particular, H_2S and NH_3 are representative sewage-related odor substances (Jiang & Tay, 2010). Sulfur compounds such as H_2S are mainly generated when sewage is treated alone in a sewage treatment facility or a part of the treated water generated from a manure facility is treated in conjunction (Seo et al., 2013).Such H_2S corrodes concrete sewer pipes prematurely, and NH_3 is detected by bioprocessing in water treatment facilities (Abalos et al., 1999).In addition, H_2S and NH_3 are colorless, harmful substances with high toxicity, corrosiveness, and irritation, and have very low initial values for odor detection (Kim et al., 2002). Table 1 shows the odor intensity and corresponding concentrations, odor detection initial values, and threshold limit values (TLVs) of H_2S and NH_3 (Gandu et al., 2021; Han et al., 2019; Kim et al., 2002).

In the odor generated from sewage, H_2S has a positive correlation ($r=0.677$, $p<0.01$) with the complex odor.H_2S mainly contributes to the formation of complex odors, and there is no correlation between the two pollutants and NH_3 (Lee et al., 2018; Ko et al., 2012).In livestock odor, NH_3 has a positive correlation with complex odor (R^2=0.64-0.642), and when NH_3 concentration is high, the compound odor tends to be high (Sun et al., 2008; Yeo et al., 2019). In addition, the complex odor is related to BOD ($R^2=0.956$) and COD ($R^2=0.985$) (Zarra et al., 2012), H_2S ($R^2=0.978$) and NH_3 ($R^2=0.991$) are related to the flow rate of the treatment plant (Alinezhad et al., 2019). It would be desirable to conduct sewage-based odor research in consideration of water quality factors in the future.

2.2. Reduction Method of Odor in Sewage

The main methods of sewage treatment are bio-filter, bio-trickling filter, and bio-scrubber (Shammay et al., 2016). The bio-filter adsorbs odor substances to the carrier filled with soil and compost in the filter tower and then removes them using microorganisms (Liang et al., 2016). The bio-trickling filter inoculates the inert filler with microorganisms in the wet scrubber, and the irrigation solution containing nutrients is circulated and sprayed to dissolve the odor substances in the sprinkling solution and then treated biologically. The bio-scrubber consists of two facilities: an absorption tower that dissolves odor substances in water and a bioreactor that decomposes odor substances dissolved in water (Won, 2007).

Bio-filter is a simple and inexpensive biological treatment method that requires low capital and operating costs, has effective removal performance and low pressure drop for low-concentration malodorous substances, and does not generate waste streams in the process. However, the filter bed must be replaced every 2-5 years, and it is not effective against high-concentration odor substances, it is difficult to control humidity and pH, and the bed can be clogged by fine dust. Bio-trickling filters, like bio-filters, are also simple and inexpensive methods, have low medium capital and operating costs, have low pressure drop, and can effectively remove acid-generating contaminants, including contaminants. However, if high concentrations of contaminants and nutrients are increased, the filter bed may become clogged as biomass grows (Barbusinski et al., 2017; Won, 2007).

Bio-scrubber is composed of small volume devices, so it is easy to control pH and temperature, there is no clogging problem, and it has the advantages of suitable capacity (Kennes & Thalasso, 1998). However, this method is economical only for compounds with high solubility, and it is difficult to obtain high treatment efficiency, can wash out slowly growing microorganisms, and has disadvantages of sludge disposal, complicated procedures in the beginning, and high operating costs (Won, 2007).

Table 1: Odor Intensity, Status, Corresponding Concentration of TLV of H_2S and NH_3

Odor intensity	Status	H_2S(ppm)			NH_3(ppm)		
		Conc.	Odor thresholds	TLV-TWA	Conc.	Odor thresholds	TLV-TWA
0	None	<0.0005			<0.15		
1.0	Threshold	0.0005			0.15		
1.5		0.0017			0.30		
2.0	Moderate	0.0056			0.59		
2.5		0.019			0.85		
3.0	Strong	0.063	0.0011	10	2.35	0.037	25
3.5		0.21			4.68		
4.0	Very Strong	0.72			9.33		
4.5		2.39			18.62		
5.0	Excessive strong	8.10			37.10		

Note: Unit of odor thresholds is ppmv

3. Research Methods and Materials

3.1. Experimental Devices and Operating Conditions

3.1.1. Composition of Complex Module

Its main function is to improve on-site operation and responsiveness of facilities with outdoor air variability through complex module configuration compared to fixed type facilities. In fact, the composition and environment of complex odors are different depending on the site. In order to solve the part where the efficiency of any deodorization method is not stable, it is very important to configure two or more deodorization methods to be variably applied to the field. A module with higher deodorization efficiency and field adaptability was constructed as presented in Figure 1. This device constitutes a complex module by arranging two types of dry deodorization equipment (catalyst, adsorbent) in one module. It is designed to increase the responsiveness to the components of complex odors and the environment, is designed in consideration of specifications and electrical wiring for easy replacement of internal parts.

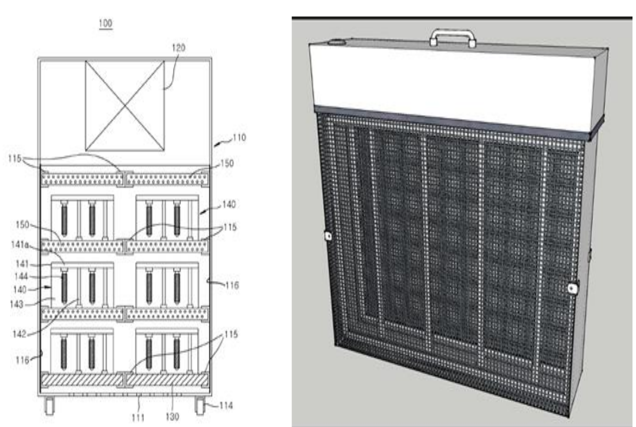

Figure 1: Design of Complex Module for Odor Reduction

3.1.2. Design of Zigzag Air Flow

In order to maximize the deodorization effect, the design method of expanding the contact area with the odor gas was applied by studying the zigzag method from the existing straight deodorizing airflow method. This design has higher efficiency even when the same number of reaction modules are installed. In addition, there is an effect of increasing the residence time to obtain the time required for the conversion of the intermediate oxide and O_3 into the O_2 and O_2 clusters as well as the increase of the contact area with the odor gas. This device was designed to maintain the airflow speed of 0.4-1.0m/sec, lower than the normal photocatalytic deodorization equipment airflow speed of 0.8-1.5m/sec (Figure 2).

The straight-line facility type has a short period of time for the gas to stay in the reaction room, so it moves to the reduction room before the oxidation reaction is finished, thereby reducing the deodorization efficiency. To overcome this phenomenon, the interior was designed in a zigzag shape, and the reaction room was designed to be long so that the contact reaction time of the gas could be delayed. The zigzag airflow design from the existing straight deodorizing airflow method maximizes the residence time and contact area of the odor gas. As shown in Figure 1, this device is designed to minimize catalyst poisoning by avoiding the frontal contact type, and it is judged that it is possible to secure the time required for the conversion of intermediate oxides and O_3 to O_2 due to the increase in residence time.

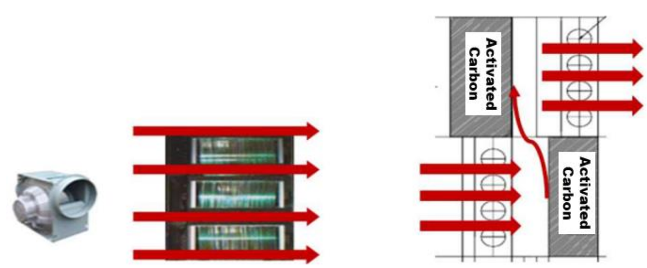

Figure 2: Application of Non-contact OxidationTechinque

3.1.3. Application of Optical-based Reflection Technique

The inside of the equipment has a zigzag structure, and a mirror reflector is installed inside to amplify the UV lamp light source of the photo-catalyst using the principle of specular reflection. When considering the amount of reflection, diffuse reflection and diffuse reflection are advantageous, but these two types of reflection have the disadvantage that it is difficult to achieve an economical effect because they require a coating of a different material, so specular reflection is adopted. In addition, this was configured to reduce ozone concentration to 0.07 ppm by applying MnO_2 catalyst and CuS catalyst plate to lower than 0.1 ppm.

3.2. Research Methods

In April-May 2021, in order to confirm the effectiveness of the deodorization facility with a treatment capacity of 80 m^3/min for one sewage treatment facility located in Suwon-City, Gyeonggi-Do, the complex odor, H_2S, and NH_3 samples at the inlet were collected before application of the device. A total of 5 samples were collected and analyzed. After the application of the device, the complex odor, H_2S, and NH_3 samples at the outlet were irradiated the same number of times, and the residual O_3 samples were collected and analyzed 5times to confirm the reduction in O_3 generation at the outlet. For complex odor, odor samples judged to be of the highest instantaneous intensity were collected within 5minutes from the outlet, site boundary, and damage point. It was analyzed according to the air dilution factory method according to the standard method of odor compounds.

Panelists were determined by performing proficiency test with 1.0 wt%-acetic acid, 0.1 wt%-trimethylamine, 1.0 wt%-β-phenylethylalcohol. Dilution factor was calculated by equation of air dilution olfactory method (National Institute of Environmental Research, 2019). Sampling volume of air samples for determination of H_2S, NH_3 was 10 L, H_2S samples were collected using the suction box method and analyzed using GC/FPD according to the low temperature concentration-capillary column GC method. When analyzing sulfur compounds, GC-FPD method is more effective. The advantage of using FPD is low interfering reaction with other substances, selectively quantifiable in separation and detection (Lee et al., 2009). Therefore, sampled air samples were concentrated by using liquid gas until below -183 ℃. After allowing the refrigerants to desorb, this prepared samples were injected into the GC (National Institute of Environmental Research, 2018b). NH_3 gas was sampled by using 0.5% Boric acid, then the solution was agitated with sodium nitroprusside solution and sodium hypochlorite solution. NH_3 concentration was determined by measurement difference in absorbance of indophenol group using a UV/Vis spectrometer at 640 nm (National Institute of Environmental Research, 2018a). Residual O_3 gas sampled using the sampling pump with PTFE filter. Sampled O_3 was measured using the Ultraviolet Photometric Method according to Standard Methods for the Measurements of Air Pollution in Korea. O_3 concentration was determined by measurement of difference in absorbance of O_3 in cell using a light source selected by short wavelength ultraviolet (254 nm) with applying an optical filter(National Institute of Environmental Research, 2021). Table 2 summarizes the sampling media and analytical instrument in determination of pollutants.

Since the number of data collected was too small, the concentration of the contaminant was presented as the median value. The performance of the deodorization facility was calculated and presented according to the following removal efficiency equation (1) (Shammay et al., 2016).

$$Removal\ Efficiency = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \times 100 \tag{1}$$

C_{inlet} is the average concentration at the inlet, and C_{outlet} is the average concentration at the outlet.

Table 2: Sampling Media and Analytical Instrument Used in this Study

Material	Sampling media/instrument	Analytical instrument
Complex odor	Suction box Polyester bag	-
H_2S	Tedlar bag	GC/FPD (GC-2010 Plus, ShimadzuCorporation, Japan)
NH_3	Absorption liquid (0.5 % Boric acid)	UV-Vis spectrometer (UV-1201, ShimadzuCorporation, Japan)
O_3	Model 202, 2B Technologies Inc., USA	

4. Results and Discussion

4.1. Levels of Odorous Pollutants before and after Application of Deodorization Device

4.1.1. Levels of Complex Odor

The complex odor level at the inlet before the deodorization facility was applied was 250-300 OU/m^3, and after the deodorization facility was applied, it was reduced to 10-30 OU/m^3, and the removal efficiency was 88-97% (Figure 3a). The difference between before and after facility application is shown as a box plot in Figure 4a. The complex odor concentration at the inlet is 300 OU/m^3, 48public sewage treatment facilities in Korea (122-6,694 OU/m^3), sewage treatment facilities near Daegu Industrial Complex (3.7-11.8 OU/m^3), leather located in Ansan, Gyeonggi-Do compared to the initial concentration of wastewater from the manufacturing facility (3,000 OU/m^3), a pig farm in Chungcheongbuk-Do (5.5-448.1 OU/m^3), and a pig factory in Canada (818-3,822 OU/m^3), the level was not low (Ko et al., 2012; Lee et al., 2018; Jung et al., 2018; Yeo et al., 2019; Sun et al., 2010). It was lower than the minimum value of 500 OU/m^3, which is the minimum value of the complex odor standard at the outlet, and the research target facility was being managed. The compound odor concentration at the outlet was 21 OU/m^3, which was lower than the result of applying the ultrasonic-air ejector pretreatment unit (120 OU/m^3) (Jung et al., 2018).

4.1.2. Levels of Hydrogen Sulfide

The H_2S level at the inlet before the deodorization facility was applied was 0.29-0.56 ppm, and after the deodorization facility was applied, it was reduced to 0 ppm and the removal efficiency was 100% (Figure 3b). The difference between before and after facility application is shown as a box plot in Figure 4b. The H_2S concentration at the inlet was 0.39 ppm, public sewage treatment facilities (0-6.23 ppm), sewage treatment facilities (0-41.97 ppm), leather manufacturing facilities (1.5 ppm), the H_2S level of the poultry farm in USA (0-0.005 ppm), Canadian pig farm (0.017-0.041 ppm), and 0.06 ppm, the maximum value of the designated odor substances, were higher than the level, which was not low (Ko et al. , 2012; Lee et al., 2018; Jung et al., 2018; Lee et al., 2020; Sun et al., 2010).The H_2S concentration at the outlet was not detected as 0 ppm. Ionizer (108-139 ppm), adsorption tower (5.9-7.7 ppm), combined deodorization device (4.4-15.8 ppm) through H_2S gas with a flow rate of 1.5 m^3/min (Lee et al., 2017), ultrasonic-air ejector device (0.1 ppm) was lower than the result of applying (Jung et al., 2018).

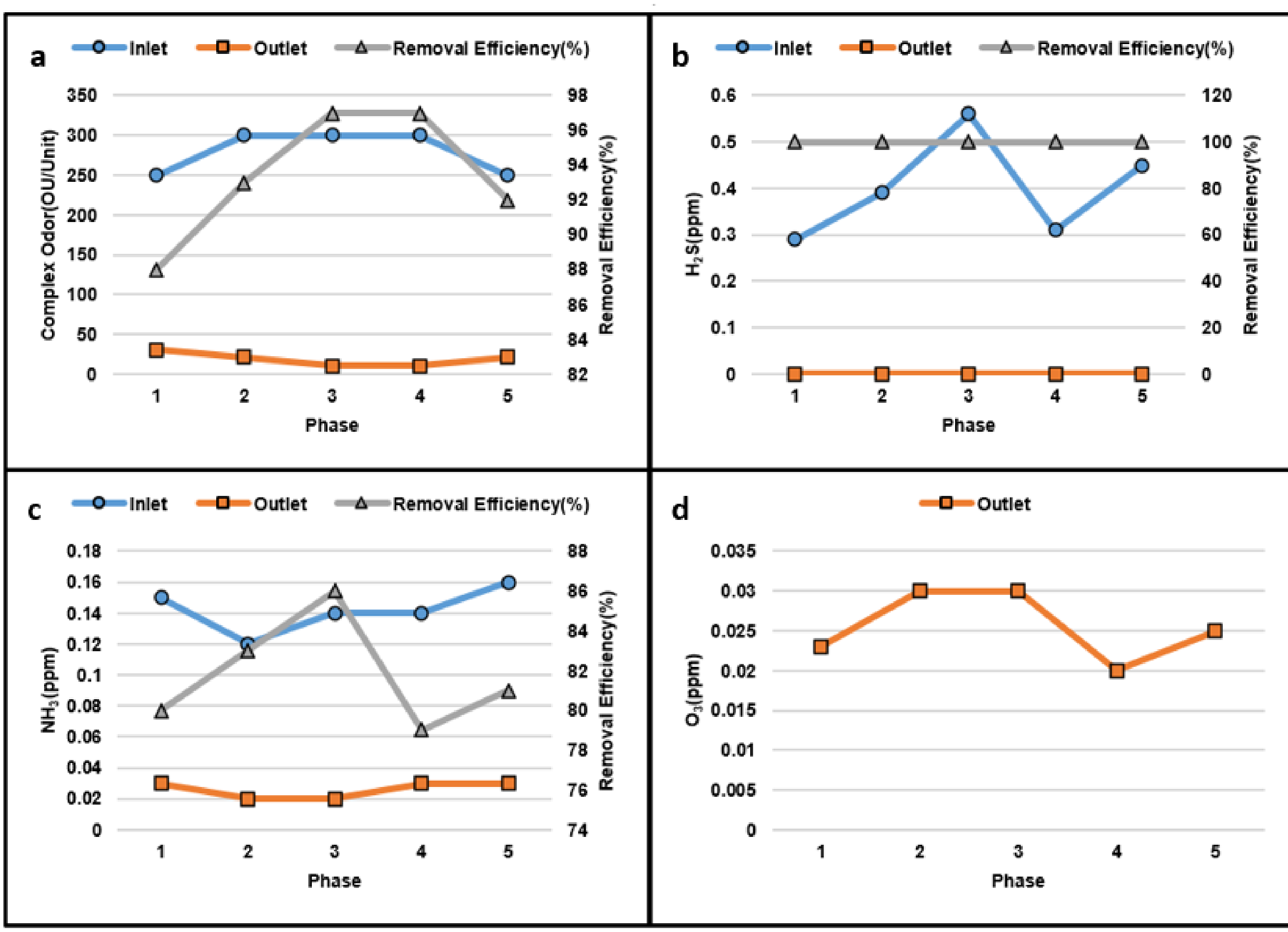

Figure 3: Removal of Odorous Pollutants and Emission of Residual O_3 by Deodorization Device.
(a) Complex Odor and (b) H_2S and (c) NH_3 and (d) Residual O_3

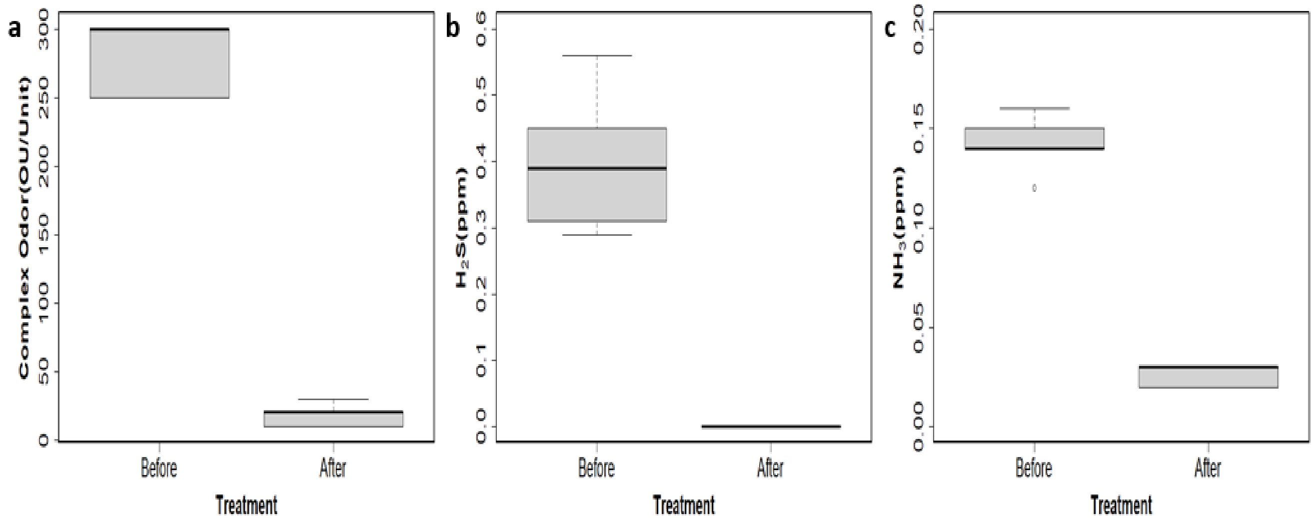

Figure 4: Boxplot on (a) Complex Odor, (b) H_2S, (c) NH_3 before and after Application of Deodorization Device for the Investigated Sewage

4.1.3. Levels of Ammonia

The NH_3 level at the inlet before the deodorization facility was applied was 0.12-0.16 ppm, and after the deodorization facility was applied, it was reduced to 0.02-0.03 ppm. The removal efficiency was 79-86% (Figure 3c), and the difference between before and after facility application is shown as a box plot in Figure 4c.The NH_3 concentration at the inlet is 0.14 ppm, the NH_3 level of the Daegu sewage treatment facility (11.48-40.36 ppm), the leather manufacturing facility in Gyeonggi-Do (0.6 ppm), the pig farm in Chungcheongbuk-Do (6.0-20.7 ppm), and the poultry farm in the United States (23±3 ppm), lower than that of pig farms in Canada (7-22 ppm) but measured concentration was higher than outdoor area of the center office near the water regeneration center in Korea (0.1 ppm) (Lee et al, 2018; Jung et al., 2018; Yeo et al., 2019; Lee et al., 2020; Sun et al., 2010; Kim et al., 2021). It is lower than the minimum level of 1 ppm among the standards for designated odor substances, indicating that the research facility is well managed. The NH_3 concentration at the outlet through the deodorization facility is 0.03 ppm, and the ionizer (9-21 ppm), the adsorption tower (11-16 ppm), and the combined deodorizer (1-15 ppm) (Lee et al., 2017), and the ultrasonic-air ejector device (0.1 ppm) was lower than the result (Jung et al., 2018).

4.1.4. Levels of Residual Ozone

The residual O_3 level at the outlet was 0.02-0.03 ppm (Figure 3d), which was lower than the 8-hour average of 0.06 ppm among domestic air environment standards. In Figure 5, the residual O_3 level was slightly decreased or increased in response to the increase or decrease of NH_3 (Kang et al., 2020).

4.2. Performance of Odorous Pollutants by Deodorization Device

Figure 6 summarizes the removal efficiency for reduction methods of odorous pollutants (Morral et al., 2021; Jung et al., 2018; Lee et al., 2017; Easter et al., 2005). The performance was calculated by mean. The combined odor removal efficiency by applying the deodorizing device was 93%. This performance was lower than application of soil media (95%) to the bio-filter system and the ultrasonic-air ejector pretreatment device (96%), but organic media (72%) and inorganic/inert media (< 70%) in the bio-filter system was lower than the applied performance results in this study. The H_2S removal efficiency applied to the device was 100% that is more effective rather than bio-filter system (96-99%), the ionizer (0-7.9%), an adsorption tower (92.7-95.4%), a combined deodorizer (95%), an ultrasonic-air ejector pretreatment device (93.3%). The removal performance of NH_3 by device for odor reduction was 82% that lower than biotechnologies (94.4-94.5%), an ultrasonic-air ejector pretreatment (83.3%), however, this efficiency was higher than other odor reduction methods (51.4-79%).

However, performance of deodorazation device in this study was performed without considering water quality factor such as pH, BOD, COD. Further, we were not considered operational parameter such as loading rate, retention time (Kim et al., 2008). These factors is crucial for the reduction of odor in water treatment.

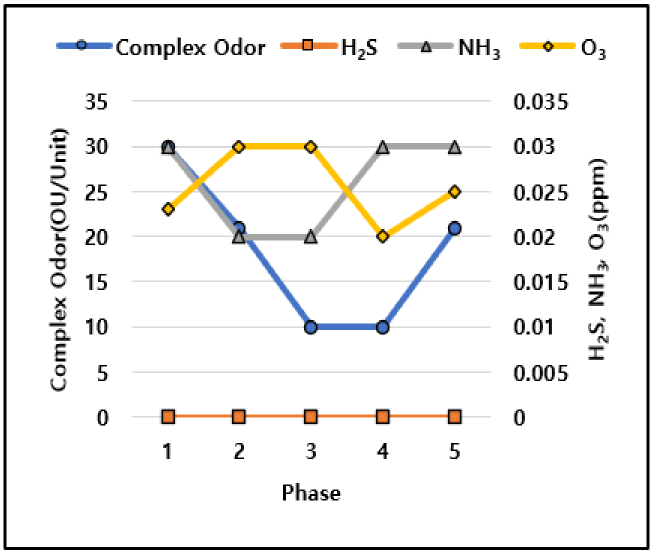

Figure 5: Levels of Odorous Pollutants and Residual O_3 in Outlet of Sewage

5. Conclusions

Since the composition and environment of the complex odor are different for each site, the effectiveness of the deodorization method can be applied differently. Since it is difficult to easily determine a suitable installation type to deal with a complex odor, which is a combination of chemical components, it is configured to variably apply two or more deodorizing methods to the field. Therefore, it is composed of a module with higher deodorization efficiency and field adaptability. That is, two types of dry deodorization equipment were installed in one module and research was conducted considering the standard of parts, standard unification, electrical wiring, and compatibility with attachable and detachable devices so that they can be easily replaced. The performance of the sewage complex odor, H_2S, and NH_3 to which the deodorization facility manufactured in this study was applied was 93%, 100%, and 82%, respectively, and the residual O_3 level was 0.02-0.03 ppm. Major substances generated by existing sewage treatment facilities are complex odor, H_2S, and NH_3, and most sewage treatment plants use biological processes to treat them.

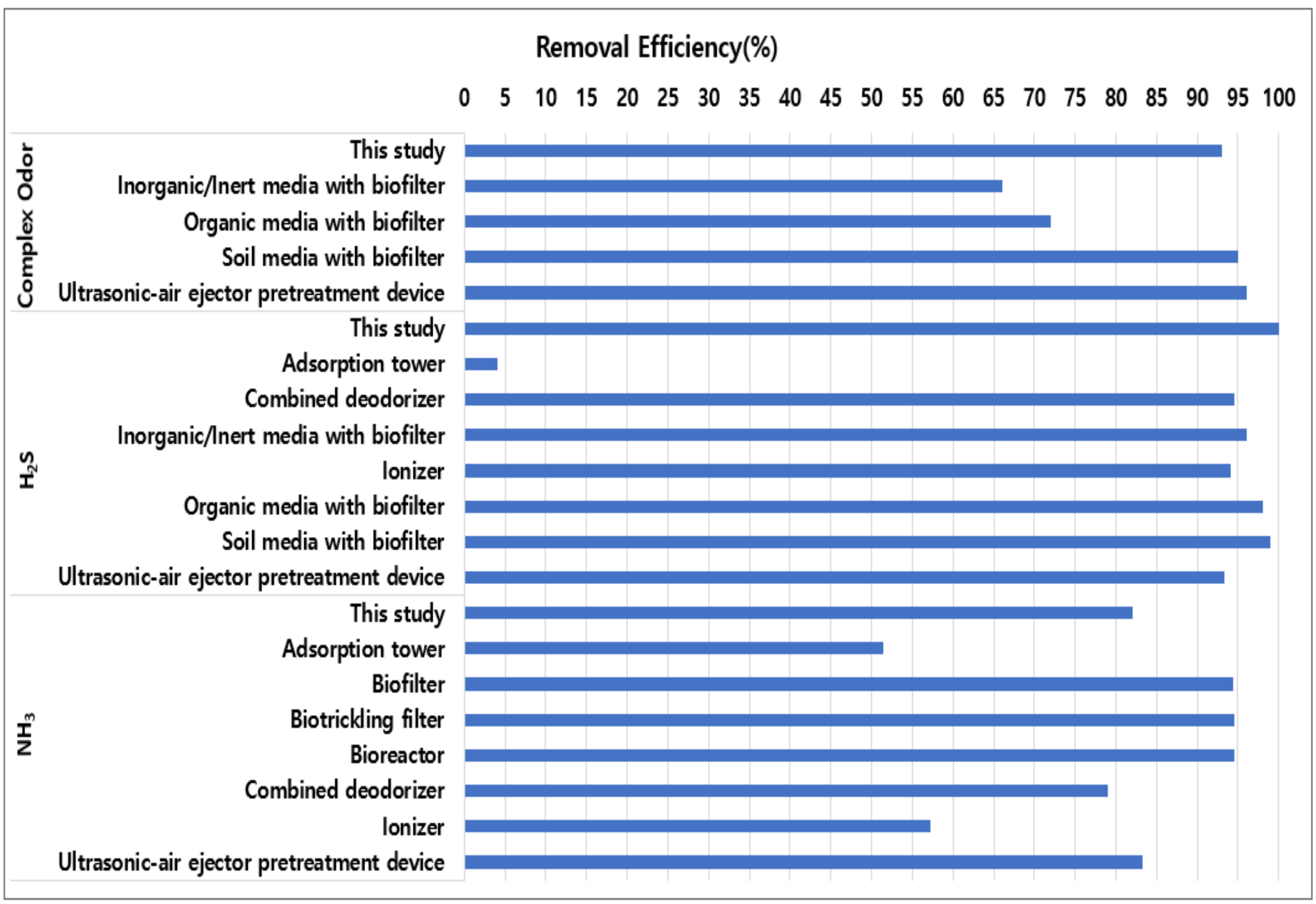

Figure 6: Performance Data for Reduction Methods of Odorous Pollutants in Water Treatment

Although the removal performance of complex odor was higher than that of the deodorization facility of this study, the H_2S performance was higher than that of the deodorization facility, so it is thought that the inconvenience of residents due to the bad smell caused by applying the developed product to the sewage treatment facility will be reduced. On the other hand, in the case of NH_3, the performance of the developed device was higher than that of the ionizer and the adsorption tower, but it was not higher than the combined deodorization device and the ultrasonic-air ejector pre-treatment device. Hence, future research have to be carried out to collect a large sample and to consider water quality factor, operational parameter for improvement of performance in deodorization device.

References

Ábalos, M., Bayona J. M., & Ventura, F. (1999). Development of a Solid-Phase Microextraction GC-NPD Procedure for the Determination of Free Volatile Amines in Wastewater and Sewage-Polluted Waters. *Analytical Chemistry, 71,* 3531-3537. doi: 10.1021/ac990197h

Alinezhad, E., Mohsen, H., Rahmani, F., Keshizadeh, H., Abdi, M., & Naddafi, K. (2019). Technical and economic investigation of chemical scrubber and bio-filtration in removal of H_2S and NH_3 from wastewater treatment plant. *Journal of Environmental Management, 241*, 32-43. doi: 10.1016/j.jenvman.2019.04.003

Barbusinski, K., Kalemba, K., Kasperczyk, D., Urbaniec, K., Kozik, V. (2017). Biological methods for odor treatment - A review. *Journal of Cleaner Production, 152*, 223-241. doi: 10.1016/j.jclepro.2017.03.093

Easter, C., Quigley, C., Burrows, P., Witherspoon, J., &Apgar, D. (2005). Odor and air emissions control using biotechnology for both collection and wastewater treatment systems. *Chemical Engineering Journal, 113*, 93-104. doi: 10.1016/j.cej.2005.04.007

Gandu, B., Palanivel, S., Juntupally, S., Arelli, V., Begum, S., & Anupoju., G. R. (2021). 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, 56*, 625-634.

Gostelow, P., Parsons, S.A., & Stuetz, R.M. (2001). Odour measurements for sewage treatment works. *Water Research, 35*(3), 579-597. doi: 10.1016/S0043-1354(00)00313-4

Han, Z., Qi, F., Wang, H., Li, R., & Sun, D. (2019). Odor assessment of NH_3 and volatile sulfide compounds in a full-scale municipal sludge aerobic composting plant. *Bioresource Technology, 282*, 477-455.

Jang, H., Kim, S., Lee, J. K., Oh, N., & Song, J. (2017). Estimating the odor emission factors of the grit removal chambers of publicly-owned wastewater treatment plants. *Journal of Odor and Indoor Environment, 16*(4), 393-400. doi: 10.15250/joie.2017.16.4.393

Jiang, X., & Tay, J. H. (2010). Operational characteristics of efficient co-removal of H_2S and NH_3 in a horizontal bio-trickling filter using exhausted carbon. *Journal of Hazardous Materials, 176,* 638-643. doi: 10.1016/j.jhazmat.2009.11.079

Jung, M. J., Kim, Y. D., Kwon, L. S., Lee, W. S., & Kwon, W. T. (2018). A Study on Cost-effective Treatment of Wastewater and Odor Reduction for Southeast Asian Market Entry. *International Journal of Industrial Distribution & Business, 9*(12), 23-29.

Kang, S. W., Lee, J. S., Lee, K. S., Lim, H. A., Kim, J. S., Lee, J. D., Park, W. S., & Park, Y. K. (2020). Decomposition of odor using atmospheric-pressure plasma. *Journal of the Korea Academia-Industrial Cooperation Society, 21*(7), 708-718. doi: 10.5762/KAIS.2020.21.7.708

Kennes, C., & Thalasso, F. (1998). Review: Waste gas biotreatment technology. *Journal of Chemical Technology & Biotechnology, 72*, 303-319. doi: 10.1002/(SICI)1097-4660(199808)72:4<303::AID-JCTB903>3.0.CO;2-Y

Kim, H., Kim, Y. J., & Chung J. S. (2002). Long-Term Operation of a Bio-filter for Simultaneous Removal of H_2S and NH_3. *Journal of the Air & Waste Management Association, 52,* 1389-1398. doi: 10.1080/10473289.2002.10470871

Kim, J., Sekyama, K., Lee, D., & Kim, H. (2006). Odors from Wastewater Treatment Plants. *Korean Journal of Odor Research and Engineering, 5*(3), 180-192.

Kim, K.-O., Kim, Y.-J., & Won, Y.-S. (2008). Removal of VOCs and H_2S from Waste Gas with Biotrickling Filter. *Journal of Industrial and Engineering Chemistry*, 19(5), 519-525.

Kim, S.-H., Lee, S.-H., Yun, Y.-J., Choi, S.-Y., Jung, M.-J., & Kwon, W.-T. (2021). A Study on the Sewage Sludge Odor Control System. *Journal of Wellbeing Management and Applied Psychology*, 4(2), 19-25.

Ko, B. C., Lee, J. K., Lee, Y. S., Lee, M. G., & Kam, S. K. (2012). A Study on Odor Emission Characteristics of Domestic Sewage Treatment Facilities Using Composite Odor Concentration and Hydrogen Sulfide Concentration. *Journal of the Environmental Sciences, 21*(11), 1379-1388. doi: 10.5322/JES.2012.21.11.1379

Lee, B. K., Lee, S. H., Tak, S. J., & Lee, B. K. (2017). The Study on the Removal of Odor Emitting Environmental Fundamental Facility. *Journal of Climate Change Research, 8(*1), 5-56.

Lee, M. S., Kang, D. H., Keum, J. L., Kwon, B. Y., Jo, H. W., Lee, C. H., Kim, E. D., Lim, H. J., & Song, H. B. (2018). Emission Characteristics of Odor Compounds from a Sewage Treatment Plant Near an Industrial Complex Area in Daegu City. *Journal of Environmental Health Sciences, 44*(2), 178-187. doi: 10.5668/JEHS.2018.44.2.178

Lee, M., Li, P., Koziel, J. A., Ahn, H., Wo, J., Chen, B., Meiirkhanuly, Z., Banik, C., & Jenks, W. S. (2020). Pilot-Scale Testing of UV-A Light Treatment for Mitigation of NH_3, H_2S, GHGs, VOCs, Odor, and O_3 Inside the Poultry Barn. *Frontiers in Chemistry, 8*, 613.

Lee, T., Lee, J., & Lee, J. (2009). Determination of Major Reduced Sulfur Gases Emitted from Wastes Stored in Environmental Facility Using GC/FPD. *Journal of the Korean Geo-Environmental Society*, 10(2), 37-43.

Liang, J. Cheng, G., & Feng, H. (2016). Engineering practices of deodorization for odor in urban sewage treatment plants in China. *Advances in Economics, Business and Management Research, 30*, 86-91.

Ministry of Environment(MOE). (2021). Environment Statistics

Portal. Retrieved July 23, 2021 (actual access data), from http://stat.me.go.kr/nesis/mesp2/webStatistics/stat_main.jsp?tblID=DT_106N_99_2400002&inq_gubun=1&lang=kor&list_id=106H_01_002014&l_interval=2

Morral, E., Gabriel, D., Dorado, A. D., & Gamisans, X. (2021). A review of biotechnologies for the abatement of ammonia emissions. *Chemosphere*, 273, 128006.

National Institute of Environmental Research(NIER). (2018a). Standard Method of Odor Compounds ES 09302.1a ammonia - boric acid solution absorption - ultraviolet/visible spectrometry.

National Institute of Environmental Research(NIER). (2018b). Standard Method of Odor Compounds ES 09303.1a sulfur compounds - cold trap - capillary GC method.

National Institute of Environmental Research(NIER). (2019). Standard Method of Odor Compounds ES 09301.b air dilution olfactory method.

National Institute of Environmental Research(NIER). (2021). Standard Methods for the Measurements of Air Pollution ES 01607.1a Method for the Determination of Ozone in Ambient Air - Ultraviolet Photometric Method.

Seo, B. R., Jeon, H. S., Park, Y. S., Yun, B. R., Jang, T., & Kim, T. (2013). The Emission Characteristics and Management of Odor Compounds from Public Sewage Treatment Facility. *Journal of Korean Society of Odor Research and Engineering, 12*(3), 97-109.

Shammay, A., Sivret, E. C., Le-Minh, N., Fernandez, R. L., Evanson, I., & Stuetz, R. M. (2016). Review of odour abatement in sewer networks. *Journal of Environmental Chemical Engineering, 4,* 3866-3881. doi: 10.1016/j.jece.2016.08.016

Sun, G., Guo, H., & Peterson, J. (2010). Seasonal Odor, Ammonia, Hydrogen Sulfide, and Carbon Dioxide Concentrations and Emissions from Swine Grower-Finisher Rooms.*Journal of the Air & Waste Management Association, 60*, 471-480. doi: 10.3155/1047-3289.60.4.471

Sun, G., Guo, H., Peterson, J., Predicala, B., & Laguë, C. (2008). Diurnal odor, ammonia, hydrogen sulfide, and carbon dioxide emission profiles of confined swine grower/finisher rooms. *Journal of the Air & Waste Management Association, 58,* 1434-1448. doi: 10.3155/1047-3289.58.11.1434

Won, Y. S. (2007). Biotreatment Technologies for Air Pollution Control. *CLEAN TECHNOLOGY*, 13(1), 1-15. doi: 10.1007/s10098-010-0342-0

Yeo, U. H., Lee, I. B., Ha, T. H., Decano, C., Kim, R. W., Lee, S. Y., Kim, J. G., Choi, Y. B., & Park, Y. M. (2019).Evaluation of Odor Dispersion from Livestock Building through Field Experiment. *Journal of the Korean Society of Agricultural Engineers, 61*(6), 21-30.

Zarra, T., Giuliani, S., Naddeo, V., & Belgiorno, V. (2012). Control of odour emission in wastewater treatment plants by direct and undirected measurement of odour emission capacity. *Water Science & Technology, 66*(8), 1627-1633. doi: 10.2166/wst.2012.362