

Remote monitoring and real-time abatement of odor emitted from sewer using odor sensors, wireless communication technique and microbial deodorant

Park S.J.*

School of Rail-road Construction & Environmental Eng., Woo Song University, Daejeon 34606, Republic of Korea

Received: 30/04/2018, Accepted: 30/10/2018, Available online: 02/11/2018

*to whom all correspondence should be addressed: e-mail: sjpark@wsu.ac.kr

<https://doi.org/10.30955/gnj.002740>

Abstract

In this study, a new technology was introduced to monitor the odor occurrence situation at the remote site in real time and the technology to reduce sewage odor by using microbial deodorant. Long-term monitoring and full-scale test was carried out to investigate the odor concentration in the combined sewer using the real - time odor monitoring device which consist of 3 odor sensors with the wireless communication technique, and to investigate the effect of the microbial deodorant on the reduction of sewer odor. The odor monitoring device, which was fabricated using metal oxide semiconductor sensors and code division multi access communication technique, was installed at three sites of the gravity-flow type combined sewer (depth 3 m and width 5 m) in Gangnam, Seoul. Odor monitoring in field was carried out at the interval of 10 minutes for 304 days over the autumn, winter and summer. The measured results were transmitted to Woosong odor research center about 100 km away from the site. The measured sensor value was converted to olfactory odor concentration by the co-relation equation of the sensor value and the olfactory odor concentration. As the monitoring results, more than 40,000 sewage odor data were obtained. The average odor concentration of raw sewage in combined sewer was 464 OU_k , which was 321 OU_k in winter and 412 OU_k in autumn and 659 OU_k in summer. The commercial microbial deodorant used in this study was the mixture culture of 48 microbial strains, and the microbial deodorant of $1\text{ m}^3\text{ d}^{-1}$ to $2\text{ m}^3\text{ d}^{-1}$ was mixed with raw sewage at the 1.5 km upstream of the site where odor complaints occurred. As the experimental results, the average odor concentration of sewage mixed with microbial deodorant was 113 OU_k , which was 102 OU_k in winter and 298 OU_k in autumn and 153 OU_k in summer. It was estimated that the odor reduction effect of sewer odor by microbial deodorant is about 74%.

Keywords: Sewer odor, odor sensor, microbial deodorant, odor abatement, olfactory odor estimation.

1. Introduction

Malodorous gases emitted from sewer system is attracting attention as a major social issue that takes from the quality of living environments. Sewer and its facilities such as manholes and basins which discharge odor in an urban area are making it difficult to reduce odor. Most of old large cities have combined sewer systems, and organics in sewage are likely to deposit in the bottom of sewer during a dry season because of low sewage velocity in a sewer, so it is easy to generate malodorous gas such as H_2S in anaerobic conditions. In addition, septic tanks and building drainage tanks connected to sewer pipes are causing the sewer odor to increase (Japan Association of Odor Environment, 1992).

The Odor Prevention Law was enacted in 2005, a lot of R&D projects related to odor have been carried out. As a result, odor problems of factories in industrial complexes have been almost solved, but in recent years, odor emitted from living environments such as direct fire roast restaurants and sanitary sewer have become major causes of civil complaints. When the G20 Summit was held in Seoul in 2010, sewer odor problems of the downtown area were raised to be a very urgent issue to resolve (Seoul Development Institute, 2009; Seoul Seocho District, 2010; Seoul Metropolitan City, 2018).

Many studies to reduce sewage odor have been studied for long time. The abatement technology of sewer odor can be classified into liquid-phase control technique and vapor-phase control technique. Liquid phase techniques have been reported by the injection of air, oxygen, oxidant chemicals such as H_2O_2 , $NaOCl$ and $KMnO_4$, and by the adjustment of pH such as $NaOH$, including the injection of iron salts such as $FeCl_3$ and Fe_2O_4 , $Ca(NO_3)_2$. Chen *et al.* (2000) reported a case of reducing sewage odor by injecting oxygen into a 1.5 km gravity sewer. Dan *et al.* (2008) reported a case study of iron salts injection methods to effectively remove H_2S in sewers. Mathioudakis *et al.* (2006) reported that H_2S was reduced economically and effectively by continuously injecting $10\text{ kg NH}_4\text{NO}_3\text{ hr}^{-1}$ into a 6.7 km combined sewer pipe.

Penter *et al.* (1999) reported that H₂S was effectively reduced by Ca(NO₃)₂ injection into a 2,500 feet pressure sewer. Schattovits *et al.* (2000) reported a case study comparing the odor reduction effect by injecting calcium nitrate and ferric sulfate/nitrate into an 18 km pressure sewer. Lehua *et al.* (2008) reported a H₂S control using a microbial fuel cell (MFC) in a more economical way than previously used. The vapor phase technique includes ventilation, collection of sewage odor and removal using a treatment device such as a scrubber, an adsorption tower or biofilter. Robert *et al.* (2002) reported a case in which sewage odor complaints were reduced by using vapor phase control such as dry scrubber with liquid phase control techniques which inject iron salts and nitrate compounds to solve the sewer odor problem, simultaneously. However, most of the studies that have been carried out so far are few cases of biological treatment with microbial deodorant as chemical treatment using chemicals.

In order to manage the sewage odor, even if various abatement techniques are applied in the field, a means for effectively evaluating the abatement effect is needed. Generally, odor is evaluated using human olfactory. In Europe, USA and Australia, dynamic olfactometer is used. In Japan, Korea and China, air dilution bag method is used. However, since these methods are carried out by collecting the samples from the field and analyzing them by the laboratory, there are limitations in understanding the odor occurrence situation due to time variation and effectively responding to the odor complaints. Recently, a real-time and on-line odor monitoring technique in the field using odor sensor has been widely used. Various sensors have been used for an odor analysis, including a portable H₂S sensor and H₂S continuous measurement device in the field. In addition, as IT techniques have developed, an odor sensor device with wireless communication technique has been used. Cipriani *et al.* (2017) reported the case of measuring the H₂S concentration by H₂S electronic sensor for one month while investigating the removal by chemical oxidants. Park *et al.* (2009) reported that the H₂S continuous measuring instrument with data logger inside the manhole was installed inside the sewer manhole and continuously monitored H₂S concentration and the effect of the H₂S reduction by microbial deodorant. Pan *et al.* (2009) report on the real-time monitoring of livestock odor using electric network system. Son *et al.* (2015) report real-time monitoring of odor compounds in water using bio-electronic sensors. Ishida *et al.* (2000) reported a case study of real-time imaging of odor flow in a space using a gas sensor array. It is known that H₂S is a representative odor substance generated in sewer, but Kim *et al.* (2006) reported that not only H₂S but also other odorous substances are mixed in sewage, and Witherspoon *et al.* (2017) report that when establishing San Mateo city sewerage measures, it also established a reduction scheme for non-hydrogen sulfide in addition to hydrogen sulfide.

Although gas sensors for odor measurement are widely used for MOS sensors and EC sensors, and PID sensors for VOC measurement, it is known that MOS sensor is more effective for mixed odor measurement than EC sensors that react only with specific compounds. Lei *et al.* (2014) reports positive characteristics of cross-sensitivity, broad spectrum response and low-cost characteristics for MOS gas sensor, and Joo *et al.* (2006) reported that a MOS gas sensor is effective for evaluating sewage odors in which many malodorous compounds are mixed in addition to H₂S.

However, the measurement of MOS odor sensor has an advantage to detect the tendency of odor generated in the sewer in a short time, but there is a limitation in evaluating the odor concentration of sanitary sewer by sensor measurement value or H₂S concentration. In order to respond to odor complaints felt by humans, it is necessary to provide a means of expressing the measured sensor value as sensory odor concentration. Shakoorjavan *et al.* (2016) reported the correlation between sensor measurements and olfactory evaluation values and reported the results of a study to diagnose odor concentration using sensor measurement results.

Under the background above, this study was carried out to evaluate continuously odors emitted from a combined sewer in real-time, using an on-site odor sensor and a wireless communication technique rather than off-line odor evaluation by grab sampling and analysis. Another purpose of this study was to investigate the degree of sewage odor reduction by injecting microbial deodorant into the sewage rather than injecting the chemicals that have been used so far.

2. Material and methods

2.1. Sewer conditions of the study area

This study was conducted in the downtown of Seoul Gang Nam district, and the target sewer in this study is a box culvert and a gravity-flow combined sewer. The inside and outside of the box culverts were surveyed to understand the condition of the target sewer. According to the survey results, the amount of flowing sewage in the sewer during the dry season was about 10% ~ 30% of the cross section of the sewer, and the average flow rate was about 9 m³ min⁻¹ and the average flow velocity 0.137 m min⁻¹. Benthic deposits in the sewer varied from 10% to 83% of the depth of the water, and the mean depth of sediments was 0.223 m. Figure 1 shows the location of the study area, and the target sewer condition of odor monitoring points is shown in Table 1.

2.2. Real time odor monitoring by odor sensor device with wireless communication technique

Odor sensor device to monitor inner odor concentration of sewer was fabricated with the collaboration of metal oxide semi-conductor sensor (Figaro TG 2602, Italy) Odor sensor data measured at 10 minute intervals on the site were designed to be transmitted to the Woo Song University Odor Research Center located in Daejeon city, 100 km away from the study area, using code division multiple access

technique which enables two-way communication in a real time.



Figure 1. Location of the study area

Table 1. Surveyed results of the target combined sewer in this study

Site	Diameter (width × height, m)	Water depth (m)	Benthal deposits (m)	Flow rate (m ³ sec ⁻¹)	Mean velocity (m sec ⁻¹)
1	5.0×2.5	0.28	0.14	0.217	0.310
2	2.0×3.0	0.6	0.50	0.009	0.047
3	5.0×3.5	0.94	0.10	0.224	0.053
Average		0.517	0.233	0.15	0.137

2.3. Olfactory odor estimation by air dilution sensory method of Korea

In Korea, air dilution sensory method has been used as an olfactory odor estimation technique. The air dilution sensory method is divided into three stages: the first stage is to select five panelists, the second is that odor detection is performed according to the dilution rate of raw odor sample by each panelists, and the third is that odor concentration is calculated using the estimated results of five panelists. The person to match the type of smell and the odor intensity required in the test criteria for the four reagents is selected as the panelist. Acetic acid, Trimethylamine, Methylcyclopentenolone and B-Penylethylalcohol are used as representative reagents for the panelist selection. The odor intensity is divided into five levels using 0.1 ml/L of 300 ml/L n-Butanol solution and headspace method. The evaluation of the odor concentration of the site sample was performed by providing two bags collected with odor free air and one bag injected with diluted site samples, and then five panelists record the number of the bag injected with the odor sample. The dilution test of the field sample is carried out until the panelist who has the correct answer becomes one person. In the calculation of the odor concentration of the odor sample, the data of the first and the last panelist of the wrong answer delete in the evaluation results of five panelists, and calculates the geometric mean of the evaluation results of the remaining three panelists. The dilution rate of the geometric mean calculated is used as odor concentration, and is expressed in units of OU_k. Table 2 shows the estimation process of odor sample by air dilution sensory method in Korea, and

the process of calculating odor concentration OU_k of samples by using analytical results is shown in Table 3.

Table 2. Evaluation process of odor sample in Korea (example)

Panelist	1 st Test		2 nd Test (x30)	3 rd Test (x100)	Remark
	(x10)	(x10)			
A	X	O			Dilution rate in parenthesis
B	O	O	O	O	
C	O	X			O is correct answer
D	O	O	O		
E	O	O	X		X is wrong answer

Table 3. Calculation process of odor concentration, OU_k in Korea (example)

Panelist	Calculation of OU _k	Remark	OU _k of the sample
A	(3 × 10) ^ 0.5 = 5.477	Not use the minimum	
B	100	Not use the maximum	(5.477 × 30 × 10)^(1/3) = 11.8
C	(3 × 10) ^ 0.5 = 5.477	Use	
D	30	Use	
E	10	Use	

2.4. Evaluation of the sensory odor concentration in a sewer using the monitoring results by odor sensors at field

The odor sensor used in this study is a device to measure potential difference caused by contact oxidation of metal oxide semiconductor surface with odor substances contained in gas. For this reason, odor sensor value provided in mV cannot offer directly sensory odor concentration expressed as OU_k or olfactory odor intensity that a human smells.

To obtain the conversion equation of the sensor value and the sensory odor concentration OU_k, nine samples prepared by the on-site odor sample and odor free air were evaluated at the same time. The sensor value data for 9 samples were obtained from 3 on-site odor sensor devices and the olfactory odor concentration was measured at laboratory using the air dilution sensory test method of Korea (National Institute of Environmental Research, 2005). Using the experimental results obtained at the same time, correlation equation between the sensor measurement value mV and the olfactory odor concentration OU_k was made. Figure 2 shows the procedure of deriving the correlation equation between the sensor measurement value and the sensory odor concentration, and Figure 3 is the working photograph for deriving the correlation equation in the field.

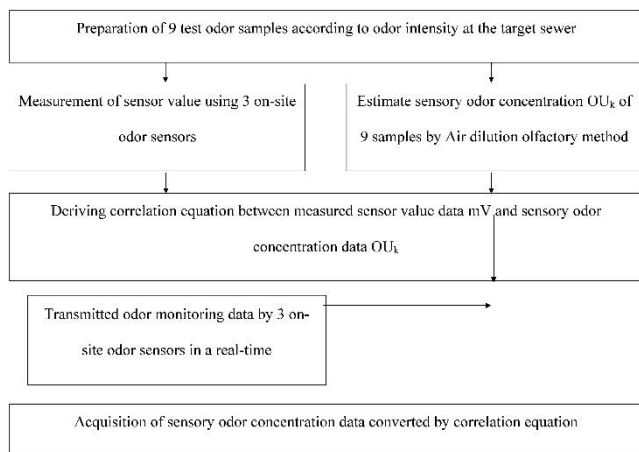


Figure 2. Procedure of deriving the correlation equation between the measured sensor value and the sensory odor concentration

2.5. Microorganism deodorant used in this study to abate sewer odor intensity

Microbial deodorants used in this study was determined from the previous study results. In the previous study, the lab-scale H₂S removal test was carried out for four microbial deodorants on the market. As the experimental results, the microbial deodorant KS50 (Geon-nong Co., Korea) showed the highest removal efficiency for a raw sewage odor that the concentration of H₂S was decreased to 50% at about 90 minutes after the KS50 injection (Park S.J., 2010). The selected microbial deodorant KS50 is a mixed culture of 48 Bacillus strains which is shown in Table 4. During the experimental period of this study, 1 m³ to 2 m³ of KS50 in a day was injected into the sewer at 1.8 km upstream, considering the flow rate of sewage and inner odor intensity in the sewer.



Figure 3. The working photograph to investigate the on-site odor sensor data and the sensory odor concentration data

2.6. Full-scale experimental condition to investigate the effect of microbial deodorant KS50

As shown in Table 5, total 5 tests were performed to investigate the inner odor concentration of combined sewer which raw sewage (or sewage mixed with microbial

deodorant KS50) is flowing, according to the seasonal variation - summer, autumn, and winter. Test #1, Test #3 and Test #4 were conducted to investigate the odor concentration emitted from, and Test #2, Test #5 to investigate the inner sewer odor concentration after reduction of odor concentration by the microbial deodorant KS50 in the combined sewer.

Field tests were conducted for 304 days during autumn, winter and summer. Odor concentration of raw sewage was investigated for 151 days, and sewage mixed with microbial deodorant KS50 for 153 days. In order to investigate the optimum dilution rate of microbial deodorant injected into sewage, dilution rate of raw KS50 solution was divided into 50 times (Test # 2-A), 30 times (Test # 2-B) and (Test # 2-B) 20 times respectively. In the final experiment (Test # 5), the optimal dilution rate was determined to be 30 times, and the Test #5 experiment was performed in the summer which the highest odor concentration in the sewer occurs.

3. Results and discussion

3.1. Sewer odor monitoring results in real-time and remote by odor sensor device and wireless communication technique

Test #1 experiment was conducted for 50 days to investigate odor concentration emitted from a raw sewage, and then Test # 2 was performed while microbial deodorant KS50 by dilution conditions of raw KS50 solution was mixed with the flowing sewage for 90 days. Test #3 was conducted for 45 days in order to investigate the odor concentration of raw sewage at the condition of low temperature in winter. In order to investigate the odor concentration of raw sewage in summer which relatively high odor is generated, the experiment of Test #4 for 56 days was carried out. In order to investigate the odor reduction effect by the microbial deodorant KS50, The experiment of Test #5 for 56 days was carried out continuously. Even though the study area was located 100 km from the odor control center, the real-time odor data monitored by on-site odor sensor was downloaded in the form of an excel file to the desktop PC by code division multiple access communication technique, as shown in Figure 4. During the 304 days of this experiment, the odor data of 131,328 in total from three sites was collected by three odor monitoring devices. Figure 5 illustrates the screen of desk-top PC showing the time-course variation of odor generation in the target sewer at 3 sites for 192 days during the period of Test #1 (A) to Test #3 (E). In Figure 5, A (Test #1) and E (Test #3) show the status of odor generation of raw sewage in sewer, while Test #2 (B, C, D) shows the reduced odor concentration by the microbial deodorant KS50. As shown in Figure 5, comparing observed odor data of Test #1 (A) and Test #3 (E) and Test #2 (B,C,D), it was appeared that there was a significant difference of odor concentration in sewer, depending on the microbial deodorant KS50 injection. And the abatement of microbial deodorant KS50 to sewer odor was found to be different according to the dilution ratio of raw KS50 solution. As shown in

Figure 5, it was appeared that the reduction effect of 20 times (Test #2©) and 30 times (Test #2©) of dilution rate were higher than the one of 50 times (Test #2 ©). In addition, the results of the seasonal experiments show that the monitored odor data of Test #1(Ⓐ) in summer

were higher than the one of Test #3(Ⓔ) in winter. Based on these monitoring data, it was obviously estimated that odor intensity of sewer odor in summer is stronger than the one in winter.

Table 4. Microbial strains in microbial deodorants KS50 used in this study

No	Microbial strain	No	Microbial strain	No	Microbial strain
1	Actinomyces sp.	17	Bacillus thermoamylovorans	33	Micrococcus sp.
2	Bacillus anthracis	18	Bifidobacterium sp.	34	Norcadia sp.(IFM0137)
3	Bacillus badius	19	Bordetella avium	35	Paenibacillus cineris
4	Bacillus badius	20	Bordetella hinzii	36	Pediococcus pentosaceus(LM263)
5	Bacillus cereus	21	Bordetella petrii	37	Ralstonia detusculanense
6	Bacillus licheniformis	22	Clostridium butyricum	38	Actinomyces sp.
7	Bacillus marismortui	23	Enterobacter hormaechei	39	Bacillus anthracis
8	Bacillus megaterium	24	Enterobacter sp.	40	Bacillus badius
9	Bacillus oleronius	25	Enterobacter sp.(B901-2)	41	Bacillus badius
10	Bacillus sonorensis	26	Enterococcus faecalis	42	Bacillus cereus
11	Bacillus sp. KS-1(TUT1206)	27	Lactobacillus acidophilus	43	Bacillus licheniformis
12	Bacillus sp. KS-2	28	Lactobacillus sp.	44	Bacillus marismortui
13	Bacillus sp. KS-3(Q-12)	29	Leuconostoc paramesenteroides	45	Bacillus megaterium
14	Bacillus sp.(NK13)	30	low G+C Gram positive bacterium(M51)	46	Bacillus oleronius
15	Bacillus subtilis	31	Microbacterium estermaticum	47	Bacillus sonorensis
16	Bacillus subtilis	32	Microbacterium sp.(YK18)	48	Bacillus sp. KS-1(TUT1206)

3.2. Odor concentration of malodorous gas emitted from raw sewage in a combined sewer

Table 6 shows the summarized results of the odor concentration data of raw sewage in the target sewer measured at 10-minute intervals at 3 sites for 151 days over the autumn, winter, and summer. As shown in Table 6,

even though there are some differences depending on the time and on the site, the odor concentration of raw sewage in a gravity flow-type combined sewer varied from 261 OU_k to 894 OU_k on average 464 OU_k. By the season, it was appeared that average odor concentration in summer is 659 OU_k, 321 OU_k in autumn and 321 OU_k in winter.

Table 5. Experimental conditions to investigate the odor concentration emitted from raw sewage and the sewage mixed with the microbial deodorant KS50

Test	Source	Dilution rate to raw KS50 solution	Period (days)	Season	Mark in Figure 5.
#1	Raw sewage	-	`09.09.01 ~ `09.10.20 (50)	Autumn	Ⓐ
#2	Sewage mixed with KS50	50 times	`09.10.21 ~ `09.11.05 (57)		Ⓑ
		30 times	`09.11.06 ~ `09.12.03 (27)	Ⓒ	
		20 times	`09.12.04 ~ `09.12.17 (13)	Winter	Ⓓ
#3	Raw sewage	-	`09.12.18 - `10.02.28 (45)		Ⓔ
#4	Raw sewage	-	`10.06.01 - `10.07.26 (56)		-
#5	Sewage mixed with KS50	30 times	`10.07.26 - `10.09.20 (56)	Summer	-

Figure 4. On-line monitoring odor data transmitted in the form of an excel file by on-site odor sensor devices

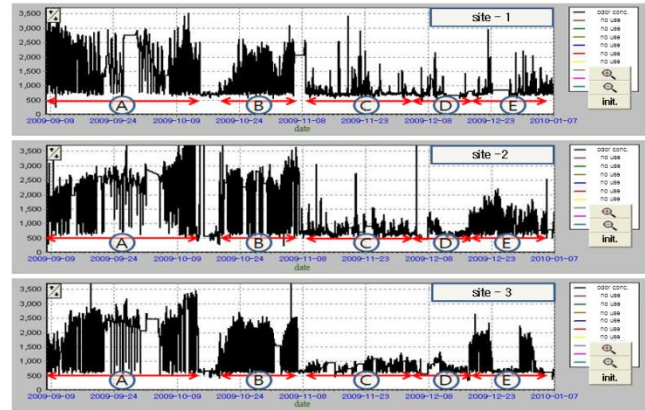


Figure 5. Time-course variation graph of sewer odor data monitored by on-site 3 odor sensors which display in the computer screen

Table 6. Odor concentration of malodorous gas emitted from raw sewage in a gravity-flow combined sewer

Test	Date	Period (days)	Odor concentration of gas emitted from raw sewage (OU _k)				Season
			Site-1	Site-2	Site-3	Avg.	
#1	`09.09.01 - `09.10.20	50	498	415	323	412	Autumn
#3	`09.12.18 - `10.02.28	45	261	391	311	321	Winter
#4	`10.06.01 - `10.07.26	56	361	894	722	659	Summer
Avg.			373	567	452	464	

Table 7. Odor concentration of malodorous gas emitted from sewage mixed with microbial deodorant KS50 in a gravity-flow combined sewer

Test	Dilution rate to raw KS50 solution (times)	Date	Period (days)	Odor concentration of sewage mixed with microbial deodorant KS50 (OU _k)				Season
				Site-1	Site-2	Site-3	Avg.	
#2	#2-A	50	`09.10.21 ~ `09.11.05	186	235	174	198	Autumn
	#2-B	30	`09.11.06 ~ `09.12.03	66	57	47	57	Winter
	#2-C	20	`09.12.04 ~ `09.12.17	55	37	45	46	Winter
#5	30	`10.07.26 - `10.09.20	103	229	127	153	Summer	
Avg.				103	140	98	113	

3.3. Odor concentration of malodorous gas emitted from sewage mixed with microbial deodorant KS50 in the combined sewer

Table 7 summarizes the results of odorant concentration survey in sewage mixed with microbial deodorant KS50. As shown in Table 7, the average odor concentration of sewage mixed with microbial deodorant in the experimental period was 113 OU_k, which was 102 OU_k in winter and 298 OU_k in autumn and 153 OU_k in summer. On the other hand, the odor reduction effect showed a large difference according to the dilution rate to raw KS50 solution. The mean odor concentration when diluted 50 times was found to be 198 OU_k, whereas it was 57 OU_k and 46 OU_k when diluted 20 times and 30 times. It also showed a large difference depending on the season. Even when diluted 30 times, the mean odor concentration was 57 OU_k in winter and 153 OU_k in summer, which is about 2.7 times

higher than that in winter. The average odor concentration of Test #2-A in autumn was 198 OU_k, which was higher than that of Test #5 153 OU_k conducted in the summer. This is because the dilution rate of the Test #2-A experiment is 50 times higher than 30 times of Test #5, which is considered to be due to the fact that the odor reduction effect by the microbial deodorant is much lowered.

3.4. Evaluation of abatement effect of sewer odor by microbial deodorant KS50

Table 8 summarizes the odor reduction effect of microbial deodorant KS50 by season, using the odor concentration in the raw sewage and the odor concentration in sewage mixed with microbial deodorant KS50. In autumn, the odor reduction rate by the microbial deodorant KS50 of 50 times diluted was 52%, which was not so high. When the dilution rate was 20 times and 30 times to raw KS50 solution in winter, the odor reduction rate was

individually 82% and 86% and showed the very high removal efficiency, comparing than other tests. In the experiment conducted at 30 times of dilution rate in summer with relatively high concentration of sewer odor,

the odor reduction rate was about 77%. Judging comprehensively, it is estimated that the sewage odor reduction efficiency of microbial deodorant KS50 is about 75%.

Table 8. Evaluation of odor reduction effect by microbial deodorants KS50

Test	Source	Dilution ratio to raw KS50 solution	Date	Period (days)	Odor concentration in average (OU _k)				Season
					Site-1	Site-2	Site-3	Avg.	
#1	Raw sewage	-	`09.09.01 - `09.10.20	50	498	415	323	412	Autumn
#2-A	Sewage mixed with KS50	50 times	`09.10.21 ~ `09.11.05	57	186	235	174	198	Autumn
Removal Efficiency (50 times)					63%	43%	46%	52%	
#3	Raw sewage	-	`09.12.18 - `10.02.28	45	261	391	311	321	Winter
#2-B	Sewage mixed with KS50	30 times	`09.11.06 ~ `09.12.03	27	66	57	47	57	Winter
#2-C	Sewage mixed with KS50	20 times	`09.12.04 ~ `09.12.17	13	55	37	45	46	Winter
Removal Efficiency (30 times)					75%	85%	85%	82%	
Removal Efficiency (20 times)					79%	91%	86%	86%	
#4	Raw sewage	-	`10.06.01 - `10.07.26	56	361	894	722	659	Summer
#5	Sewage mixed with KS50	30 times	`10.07.26 - `10.09.20	56	103	229	127	153	Summer
Removal Efficiency (30 times)					71%	74%	82%	77%	
Removal Efficiency in average								74%	

4. Conclusions

It would have been very difficult to investigate more than 1000 odor samples, if the existing technology such like dynamic olfactometer of Europe or triangular bag method of Japan were used for the collected grab samples in this study.

This study shows the new technology to monitor the odor occurrence situation at the remote site in real time and the technology to reduce sewage odor by using microbial deodorant. Long-term monitoring and full-scale test was carried out to investigate the odor concentration in the combined sewer using the real - time odor monitoring device which consist of 3 odor sensors with the wireless communication technique, and to investigate the effect of the microbial deodorant on the reduction of sewer odor. Odor monitoring in field was carried out at the interval of 10 minutes for 304 days over the autumn, winter and summer. The measured results were transmitted to odor research center in Woo Song University about 100 km away from the site. The measured sensor value was converted to olfactory odor concentration by the co-relation equation of the sensor value and the olfactory odor concentration.

As the study results, the new technology was very useful to monitor automatically odor occurrence situation in real-

time. Since the odor monitoring was performed at the interval of 10 minutes during the experimental period, it was possible to accumulate more than 40,000 odor data and could be monitored the complaints possibility due to sewer odor in real time.

On the basis of the analyzed results of the observed sewer odor data, the average odor concentration of raw sewage in combined sewer was 464 OU_k, which was 321 OU_k in winter and 412 OU_k in autumn and 659 OU_k in summer. The commercial microbial deodorant used in this study was the mixture culture of 48 microbial strains, and the microbial deodorant of 1 m³ d⁻¹ to 2 m³ d⁻¹ was mixed with raw sewage at the 1.5 km upstream of the site where odor complaints occurred. As the experimental results, the average odor concentration of sewage mixed with microbial deodorant was 113 OU_k, which was 102 OU_k in winter and 298 OU_k in autumn and 153 OU_k in summer. It was estimated that the odor reduction effect of sewer odor by microbial deodorant is about 74%.

On the other hand, in the experiment of sewer odor abatement technique using microbial deodorant, since microbial deodorant injection into the sewer was carried out by manpower, there were many limitations to operate effectively in the field. If the automatic injection technique of adding microbial deodorant is added to this technology, when high concentration odor in the sewer is detecting by

the odor sensor in real time, this technology which consists of odor sensor monitoring device and microbial deodorization technique can be used more effectively in the future.

Acknowledgments

This study was conducted under the support of Woosong University and Seoul Metropolitan City. I would like to appreciate the two organizations for their research fund and field experiments support.

References

- Chen G.H. and Leung D.H. (2000), Utilization of oxygen in a sanitary gravity sewer, *Journal of Elsevier Science*, **34**, 3813-3821.
- Cipriani M., Schiavi R. and Santos F. (2017), A successful experience in Sorocaba city – Brazil, *Proceeding of 7th IWA Odours and Air Emissions Conference Abstracts List*, 4B(4).
- Dan F., Eran F. and Ori L. (2008), Control of sulfide in sewer system by dosage of iron salts: comparison between theoretical and experimental results, and practical implications, *Science of the Total Environment*, **392**, 145-156.
- Forbes R.H., Hux D., Cummings L. and Goodwin S.M. (2002), Three-step process to success in controlling wastewater collection system odors in Gastonia, North Carolina, *2002 Water Environment Federation*. Retrieved from <https://www.researchgate.net/publication/272275392>. Three-step process to success in controlling wastewater collection system odors in gastonia North Carolina.
- Ishida H., Yamanaka T., Kushida N., Nakamoto T. and Moriizumi T. (2000), Study of real-time visualization of gas odor flow image using gas sensor array, *Journal of Sensors and Actuators*, **B65**, 14-16.
- Japan Association of Odor Environment. (1992), Manual of practice: odor prevention technology of septic tank and building pit.
- Jin P.S. and Youl K.S. (2014), Odor Characteristics of Malodorous Sulfur-containing Gas Emitted from a Sewer and Its Outlet. *Journal of Korean Society of Environmental Health*, **40**, 477-483.
- Jin P.S. and Youl K.W. (2017), Characteristics and Concentration of Malodorous Volatile Organic Compounds Emitted from a Sewer and Its Outlet. *Journal of Korean Society of Environmental Health*, **43**, 457-466.
- Joo S.W. and Park S.J. (2006), Recent development of e-nose as odor sensors, *Korean Journal of Odor Research and Engineering*, **5**, 171-179.
- Kim J., Sekyama K., Lee D.W. and Kim H.W. (2006), Odors from Wastewater treatment plants, *Korean Journal of Odor Research and Engineering*, **5**, 180-192.
- Mathioudakis V.L., Vaiopoulou E. and Aivasidis A. (2006), Addition of nitrate for odor control in sewer networks: Laboratory and field experiments, *Global NEST Journal*, **8**, 37-42.
- National Institute of Environmental Research. (2005), Standard method of odor estimation and malodorous compounds in Korea.
- Pan L. and Simon X.Y. (2009), An Electronic Nose Network System for Online Monitoring of Livestock Farm Odors, *Journal of ASME Transactions on Mechatronics*, **14**, 371-376.
- Peter C. and David E. (1999), Hydrogen sulfide odor control in wastewater collection systems, *NEWEA Journal*, **33**, 57-63.
- Schattovits G., Nowak R. and Rupp R. (2000), Solving the problem of odour emission from Vienna's sewer system: Three case studies, *Proceeding of 1st IWA International conference on odour and VOCs: Measurement, Regulation and Control Techniques*, 295-302.
- Seoul Development Institute. (2009), A study on the reduction solution for sewer foul odor discharged from a septic tank.
- Seoul Metropolitan City. (2018), Innovative technology seminar to abate odor emitted from sanitary sewer in downtown of city.
- Seoul Seocho District. (2010), Full-scale project to reduce odor problem of the sanitary trunk sewer in Seocho district of Seoul city.
- Shakoorjavan S., Akbari S., Kish M.H. and Akbare M. (2016), Correlation of sensory analysis with a virtual sensor array data for odour diagnosis of fragrant fabrics, *Journal of Measurement*, **90**, 396-403.
- Son M., Cho D., Lim J.H., Park J., Hong S., Ko H.J. and Park T.H. (2015), Real-time monitoring of geosmin and 2-methylisoborneol, representative odor compounds in water pollution using bioelectronic nose with human-like performance, *Biosensors and Bioelectronics Journal*, **74**, 199-206.
- Witherspoon J.R., Densing W., Siczka J., Zammit C. and Underwood B. (2017), Integrating odour nuisance impacts and combined control strategies from city of San Mateo's wastewater conveyance system through wastewater treatment plant processes, *Proceeding of 7th IWA Odours and Air Emissions Conference Abstracts List*, 4B(3).
- Zhang L., Schryver P.D., Gussem B.D., Muynck W.D., Boon N. and Verstraete W. (2008), Chemical and biological technologies for hydrogen sulfide emission control in sewer systems: A review, *Journal of Water Research*, **42**, 1-12.
- Zhang L., Tian F.-C., Peng X.-W. and Yin X. (2014), A rapid discreteness correction scheme for reproducibility enhancement among a batch of MOS gas sensors, *Journal of Sensors and Actuators*, **A205**, 170-176.