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

**SANG JIN PARK†**

School of Rail-road Construction & Environmental Eng., Woo Song University, Daejeon 34606, Republic of Korea
e-mail: sjpark@wsu.ac.kr

**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 3m and width 5m) 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 100km 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 $m^3\ d^{-1}$ to 2 $m^3\ d^{-1}$ 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 Metropolitan City, 2018; Seoul Development Institute, 2009; Seoul Seocho District, 2010).

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 $Fe_5O_4$, $Ca(NO_3)_2$. 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 H2S in sewers. Mathioudakis et al. (2006) reported that H2S was reduced economically and effectively by continuously injecting 10 kg $NH_4NO_3$ $hr^{-1}$ into a 6.7 km combined sewer pipe. Penter *et al*. (1999) reported that $H_2S$ was effectively reduced by $Ca(NO_3)_2$ 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 $H_2S$ 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 $H_2S$ sensor and $H_2S$ 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 $H_2S$ concentration by $H_2S$ electronic sensor for one month while investigating the removal by chemical oxidants. Park *et al*. (2009) reported that the $H_2S$ continuous measuring instrument with data logger inside the manhole was installed inside the sewer manhole and continuously monitored $H_2S$ concentration and the effect of the $H_2S$ 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 $H_2S$ is a representative odor substance generated in sewer, but Kim *et al.* (2006) reported that not only $H_2S$ 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 $H_2S$.

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 $H_2S$ 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 $m^3$ $min^{-1}$ and the average flow velocity 0.137 m $min^{-1}$. Benthal deposits in the sewer varied from 10% to 83% of the depth of the water, and the mean depth of sediments was 0.223m. Fig. 1 shows the location of the study area, and the target sewer condition of odor monitoring points is shown in Table 1.


**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 |

*2.2. 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.

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

**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 x 10) ^ 0.5 = 5.477 | Not use the minimum | (5.477x30x10)^(1/3) = 11.8 |
| B | 100 | not use the maximum | |
| C | (3 x 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. Fig. 2 shows the procedure of deriving the correlation equation between the sensor measurement value and the sensory odor concentration, and Fig. 3 is the working photograph for deriving the correlation equation in the field.

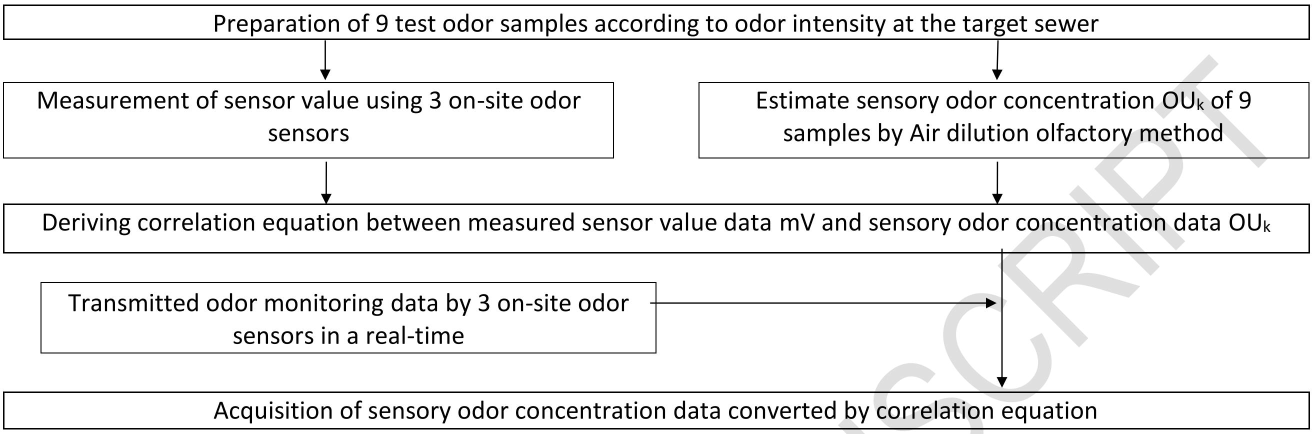



**Figure 2.** Procedure of deriving the correlation equation between the measured sensor value and the sensory odor concentration

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

*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 $H_2S$ 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 $H_2S$ 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 $m^3$ to 2 $m^3$ 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

**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) |

*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.

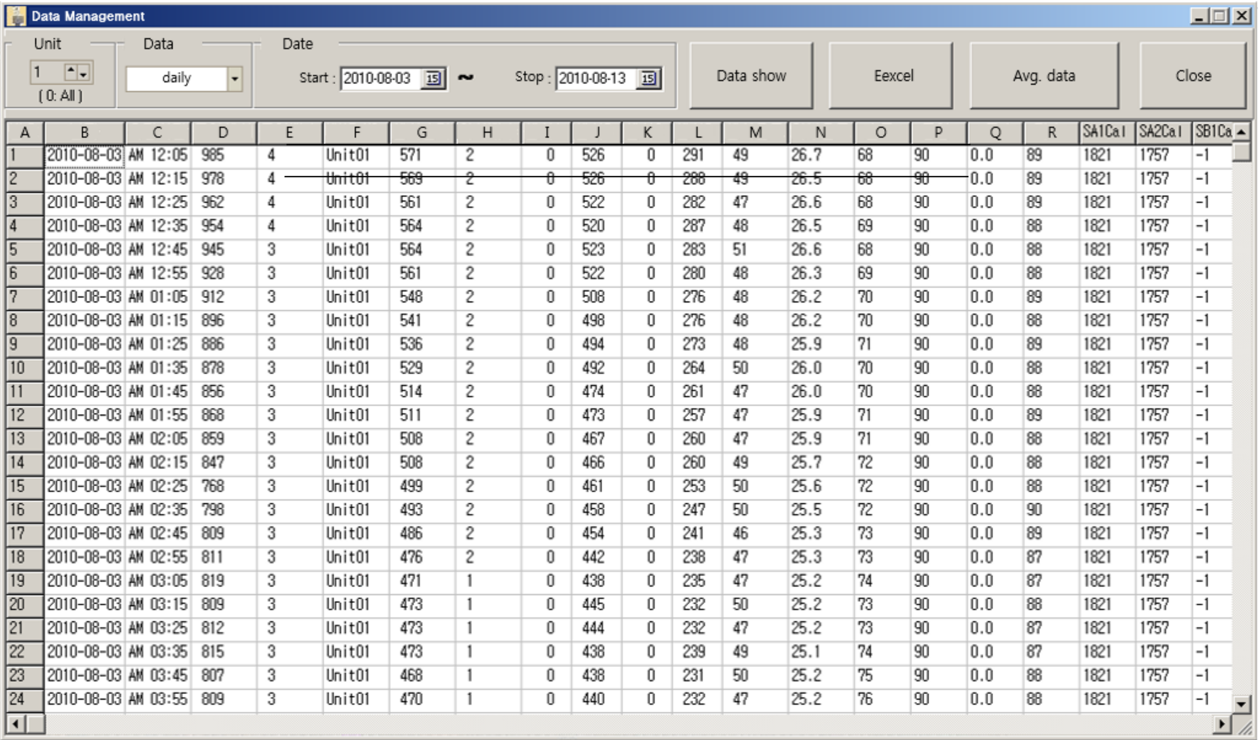
**Table 5.** Experimental conditions to investigate the odor concentration emitted from raw sewage and the sewage mixed with the microbial deodorant KS50

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

## 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 solutionwas 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 Fig. 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. Fig. 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(Ⓐ) to Test #3(Ⓔ). In Fig. 5, Ⓐ(Test #1) and Ⓔ(Test #3) show the status of odor generation of raw sewage in sewer, while Test # 2 (Ⓑ, Ⓒ, Ⓓ) shows the reduced odor concentration by the microbial deodorant KS50. As shown in Fig. 5, comparing observed odor data of Test #1(Ⓐ) and Test #3(Ⓔ) and Test #2(Ⓑ,Ⓒ,Ⓓ), 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 Fig. 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.




| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | SA1Cal | SA2Cal | SB1Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2010-08-03 | AM 12:05 | 985 | 4 | Unit01 | 571 | 2 | 0 | 526 | 0 | 291 | 49 | 26.7 | 68 | 90 | 0.0 | 89 | 1821 | 1757 | -1 |
| 2 | 2010-08-03 | AM 12:15 | 978 | 4 | ~~Unit01~~ | ~~569~~ | ~~2~~ | ~~0~~ | ~~526~~ | ~~0~~ | ~~288~~ | ~~49~~ | ~~26.5~~ | ~~68~~ | ~~90~~ | 0.0 | 89 | 1821 | 1757 | -1 |
| 3 | 2010-08-03 | AM 12:25 | 962 | 4 | Unit01 | 561 | 2 | 0 | 522 | 0 | 282 | 47 | 26.6 | 68 | 90 | 0.0 | 89 | 1821 | 1757 | -1 |
| 4 | 2010-08-03 | AM 12:35 | 954 | 4 | Unit01 | 564 | 2 | 0 | 520 | 0 | 287 | 48 | 26.5 | 69 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 5 | 2010-08-03 | AM 12:45 | 945 | 3 | Unit01 | 564 | 2 | 0 | 523 | 0 | 283 | 51 | 26.6 | 68 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 6 | 2010-08-03 | AM 12:55 | 928 | 3 | Unit01 | 561 | 2 | 0 | 522 | 0 | 280 | 48 | 26.3 | 69 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 7 | 2010-08-03 | AM 01:05 | 912 | 3 | Unit01 | 548 | 2 | 0 | 508 | 0 | 276 | 48 | 26.2 | 70 | 90 | 0.0 | 89 | 1821 | 1757 | -1 |
| 8 | 2010-08-03 | AM 01:15 | 896 | 3 | Unit01 | 541 | 2 | 0 | 498 | 0 | 276 | 48 | 26.2 | 70 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 9 | 2010-08-03 | AM 01:25 | 886 | 3 | Unit01 | 536 | 2 | 0 | 494 | 0 | 273 | 48 | 25.9 | 71 | 90 | 0.0 | 89 | 1821 | 1757 | -1 |
| 10 | 2010-08-03 | AM 01:35 | 878 | 3 | Unit01 | 529 | 2 | 0 | 492 | 0 | 264 | 50 | 26.0 | 70 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 11 | 2010-08-03 | AM 01:45 | 856 | 3 | Unit01 | 514 | 2 | 0 | 474 | 0 | 261 | 47 | 26.0 | 70 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 12 | 2010-08-03 | AM 01:55 | 868 | 3 | Unit01 | 511 | 2 | 0 | 473 | 0 | 257 | 47 | 25.9 | 71 | 90 | 0.0 | 89 | 1821 | 1757 | -1 |
| 13 | 2010-08-03 | AM 02:05 | 859 | 3 | Unit01 | 508 | 2 | 0 | 467 | 0 | 260 | 47 | 25.9 | 71 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 14 | 2010-08-03 | AM 02:15 | 847 | 3 | Unit01 | 508 | 2 | 0 | 466 | 0 | 260 | 49 | 25.7 | 72 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 15 | 2010-08-03 | AM 02:25 | 768 | 3 | Unit01 | 499 | 2 | 0 | 461 | 0 | 253 | 50 | 25.6 | 72 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 16 | 2010-08-03 | AM 02:35 | 798 | 3 | Unit01 | 493 | 2 | 0 | 458 | 0 | 247 | 50 | 25.5 | 72 | 90 | 0.0 | 90 | 1821 | 1757 | -1 |
| 17 | 2010-08-03 | AM 02:45 | 809 | 3 | Unit01 | 486 | 2 | 0 | 454 | 0 | 241 | 46 | 25.3 | 73 | 90 | 0.0 | 89 | 1821 | 1757 | -1 |
| 18 | 2010-08-03 | AM 02:55 | 811 | 3 | Unit01 | 476 | 2 | 0 | 442 | 0 | 238 | 47 | 25.3 | 73 | 90 | 0.0 | 87 | 1821 | 1757 | -1 |
| 19 | 2010-08-03 | AM 03:05 | 819 | 3 | Unit01 | 471 | 1 | 0 | 438 | 0 | 235 | 47 | 25.2 | 74 | 90 | 0.0 | 87 | 1821 | 1757 | -1 |
| 20 | 2010-08-03 | AM 03:15 | 809 | 3 | Unit01 | 473 | 1 | 0 | 445 | 0 | 232 | 50 | 25.2 | 73 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 21 | 2010-08-03 | AM 03:25 | 812 | 3 | Unit01 | 473 | 1 | 0 | 444 | 0 | 232 | 47 | 25.2 | 73 | 90 | 0.0 | 87 | 1821 | 1757 | -1 |
| 22 | 2010-08-03 | AM 03:35 | 815 | 3 | Unit01 | 473 | 1 | 0 | 438 | 0 | 239 | 49 | 25.1 | 74 | 90 | 0.0 | 87 | 1821 | 1757 | -1 |
| 23 | 2010-08-03 | AM 03:45 | 807 | 3 | Unit01 | 468 | 1 | 0 | 438 | 0 | 231 | 50 | 25.2 | 75 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |
| 24 | 2010-08-03 | AM 03:55 | 809 | 3 | Unit01 | 470 | 1 | 0 | 440 | 0 | 232 | 47 | 25.2 | 76 | 90 | 0.0 | 88 | 1821 | 1757 | -1 |

(Legend) A : No., B : Date, C : Time, D : Sensor value, E : Odor degree, F : Unit no., G : Sensor ouput, H : Odor intensity, I : Sensor A
J : Sensor B, K : Sensor C, L : Sensor D, M : Sensor temp., N : Air temp., O : humidity, P : Wind direction, Q : Wind velocity, R : Gas

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

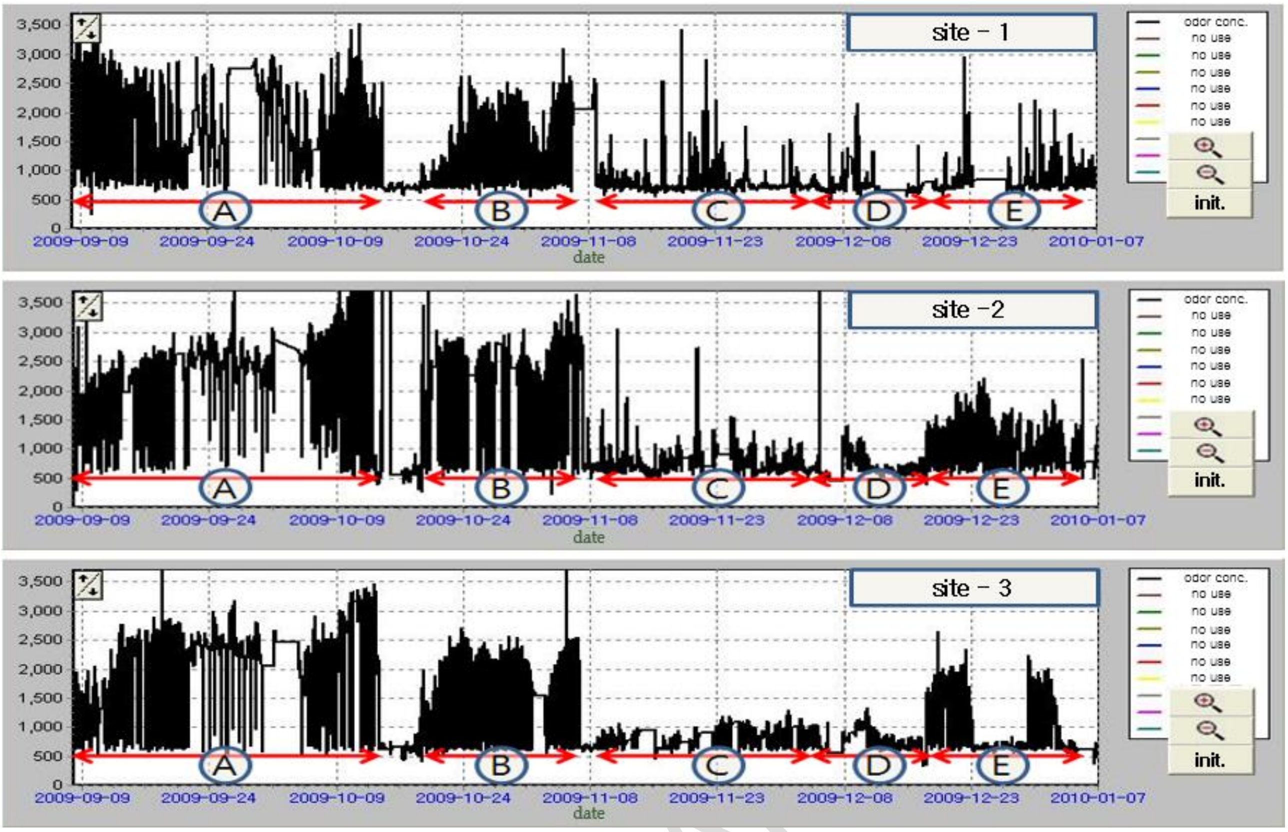


**Figure 5.** Time-course variation graph of sewer odor data monitored by on-site 3 odor sensors which display in the computer screen

*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 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 | |

*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.

**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 | 57 | 186 | 235 | 174 | 198 | Autumn |
| | #2-B | 30 | `09.11.06 ~ `09.12.03 | 27 | 66 | 57 | 47 | 57 | Winter |
| | #2-C | 20 | `09.12.04 ~ `09.12.17 | 13 | 55 | 37 | 45 | 46 | Winter |
| #5 | | 30 | `10.07.26 - `10.09.20 | 56 | 103 | 229 | 127 | 153 | Summer |
| Avg. | | | | | 103 | 140 | 98 | 113 | |

*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 $m^3$ $d^{-1}$ to 2 $m^3$ $d^{-1}$ 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.

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### List of Table



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