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Full Length Research Paper

Efficiency assessment of operational and maintenance techniques to optimize sewer gas amount

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The study presented here is a preliminary effort to compare sewer operational and maintenance techniques to assess their efficiency in optimizing the amount of gases (that is, H_2S and O_2) in sewage collection networks in Mashhad-Iran. Field tests were carried out using high-pressure water jet cleaning (HPWJC), portable blower ventilation (PBV), and water flushing (WF) techniques at specific intervals. The outcomes revealed that proactive maintenance is useful to optimize the range of gases in sewers; that is, H_2S < 1 ppm and O_2 > 20%. The results obtained from performing the designed methods showed that test No.2 (2 times/30 days), test No.6 (3 times/30 days), and test No.8 (2 times/30 days) for HPWJC, PBV, and WF techniques respectively are efficient enough to satisfy H_2S and O_2 ranges at headspace of the networks. However, among these, WF technique with the application of 2 times/30 days was nominated as the most effective method due to its safety to the network and its performance in leading the H_2S amount to less than 1 ppm and O_2 percentage by more than 20%.

Key words: High-pressure water jet cleaning, hydrogen sulfide, oxygen, portable blower ventilation, sewage network management, sewer gas, water flushing.

INTRODUCTION

Environmental protection has become one of the most important factors in ensuring the health of mankind (Al-Shammiri, 2004). Sewage collection networks, due to the nature of their functions, carry various concentrations of gases. Sewer gas (e.g. hydrogen sulfide (H_2S), ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), biological organisms, and water vapor) is a generic name for a complex mixture of toxic and non-toxic gases which generally comes from anaerobic decomposition, wastewater turbulence, and some byproducts of biologically mediated processes seen in sewage networks. The presence and concentration of these components can vary with time, composition of the sewage, temperature, and pH changes (Hutter, 1993; Metcalf and Eddy, 2004; WDHFS, 2002).

Hydrogen sulfide (H_2S) is an inorganic sulfide, a highly toxic, and colorless gas which produces an unpleasant rotten egg smell (Firer et al., 2008) and provides several problems to the environment such as biogenic corrosion of concrete structure, release of obnoxious odors to the urban atmosphere, and toxicity to sewer workers (Nielsen and Keiding, 1998; Nielsen et al., 1998; US EPA, 1994; Zhang et al., 2008). It is easily detectable at low concentration due to the rapid onset of olfactory discomfort and paralysis. Any condition in the sewer that leads to oxygen depletion, such as low flow, long retention period, or large wet walls is conducive to the development of anaerobic conditions, with the resultant formation of hydrogen sulfide (Al-Shammiri, 2004).

H_2S generated in the aqueous phase of sewers (from biofilm layer) is invariably emitted to the atmosphere of manholes, head space of gravity sewers, and pumping stations wet wells where it poses a risk to maintenance personnel. Since it is denser than air, it tends to accumulate at the bottom of poorly ventilated spaces (ATSDR, 1999). Long term exposure at a lower concentrations can result in eye irritation, sore throat and cough, nausea, shortness of breath, fluid in the lunges, loss appetite, headache, dizziness, and poor memory (Al- Shammiri, 2004;Ramasamy et al., 2006). The hydrogen sulfide recognition threshold is 0.0047 ppm but the reported odor threshold varies greatly (McGavran, 2001; Metcalf and Eddy, 2004). The National Institute for Occupational

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Table 1. Test methods based on technique and work schedule to perform at designed periods at the field study area.

Technique	Method	Field study area	Performance day
	Test No. 1		1^{st} day (1 time/30 days)
HPWJC	Test No. 2	SB	1^{st} , 15^{th} day (2 times/30 days)
	Test No. 3		1^{st} , 10^{th} , 20^{th} day (3 times/30 days)
	Test No. 4		1^{st} day (1 time/30 days)
PBV	Test No. 5	EB	1^{st} , 15^{th} day (2 times/30 days)
	Test No. 6		1^{st} , 10^{th} , 20^{th} day (3 times/30 days)
	Test No. 7		1^{st} day (1 time/30 days)
WF	Test No. 8	ES47	1^{st} , 15^{th} day (2 times/30 days)
	Test No. 9		1^{st} , 10^{th} , 20^{th} day (3 times/30 days)

Safety and Health (1977) recommended a permissible exposure limit for hydrogen sulfide amount at workspace; that is, an 8-hour exposure to a maximum of 10 ppm, short time (15 min) exposure to a maximum of 15 ppm, and one time per 10 min exposure for a maximum level of 50 ppm of hydrogen sulfide gas.

Every year, sewer workers are injured or killed due to exposure to toxic/lethal levels of hydrogen sulfide. Between 1983 and 1992, for instance, more than 29 H_2S-related deaths and over 5500 exposures occurred in the United State (Snyder et al., 1995). Oxygen is toxic to anaerobic organisms with the optimum range of around 20.9% (Brown et al., 2003). If sufficient oxygen is presented in sewage networks, H_2S will not be generated (Chwirka and Satchell, 1990; Collins and Lewis, 2000). Additionally, in sewage collection networks, at very low oxygen concentrations (<12%), unconsciousness and death may occur very quickly and without warning (Brown et al., 2003).

Engineers worldwide are coming to the view that proactive and preventive strategies against sewer issues are cost effective. Inevitably, as the sewage pipes under the ground continue to age, there will be growing concerns due to their continuous performance and the risks of future failure. Strategies need to be developed to focus maintenance activity on those parts of the network where it will be most effective (Dakers, 1980; Fenner, 2000). Valid condition assessments are keys to developing good planning and programming for a successful sewage network maintenance and operation (Grigg, 1994). In such a case, routine maintenance of some sewer lines is necessary if their slope or flow is particularly low. Sewers on flat grades or with a history of problems should be inspected every 3 months, while the others should be monitored once or twice a year (McGhee and Steel, 1991). Hence, preventive strategies (e.g. preventing the sewer air from reaching crews) can be performed to provide a safe condition in sewers. Among these, regular and accurate operational and maintenance methods can be helpful to overcome the sewers gas issues. Several techniques such as high pressure water jet cleaning (HPWJC), ventilation by portable blower (PBV), and water flushing (WF) are common in sewer maintenance which can provide optimum amount of sewer gases.

These techniques were employed using three procedures/tests as listed in Table 1 to deplete hydrogen sulfide amount and increase oxygen percentage in headspace of sewage network in Mashhad. The main objective of this study was to determine effectiveness of the techniques in optimizing the sewer gases amount. Three methods/tests were applied to each technique and comparison between the methods was performed to identify the most effective case.

METHODS

Field study area

The study was conducted in Mashhad, the second largest city in Iran with a population of around 3 million, located at the center of the Khorasan Razavi province (east part of Iran). The main sources of water supply in Mashhad is drilled wells and dams (Binesh et al., 2009). Western part of Mashhad (with approximately 900 km sewage networks) has an old sewer networks which carry sewage from residential and commercial areas to the Parkand Abad treatment plants. Sewage networks within the Emamat and Ghasem Abad zones (with approximately 600 km sewage networks) with high gas emission were detected according to the primary monitoring. Hence, the amount of H_2S and O_2 percentage at Elahiye Blv. (EB), Shariaty Blv. (SB), and 47 Emamat St. (ES47) networks within the field study area were measured at designed manholes (Figure 1). Concrete pipes have been used in the above networks.

Techniques description

High-pressure water jet cleaning (HPWJC) technique

A common cleaning technique is hydraulic scouring by high-pressure water jets, scraping with mechanical tools, and in certain circumstances adding the chemicals (Campbell and Fairfield, 2008).

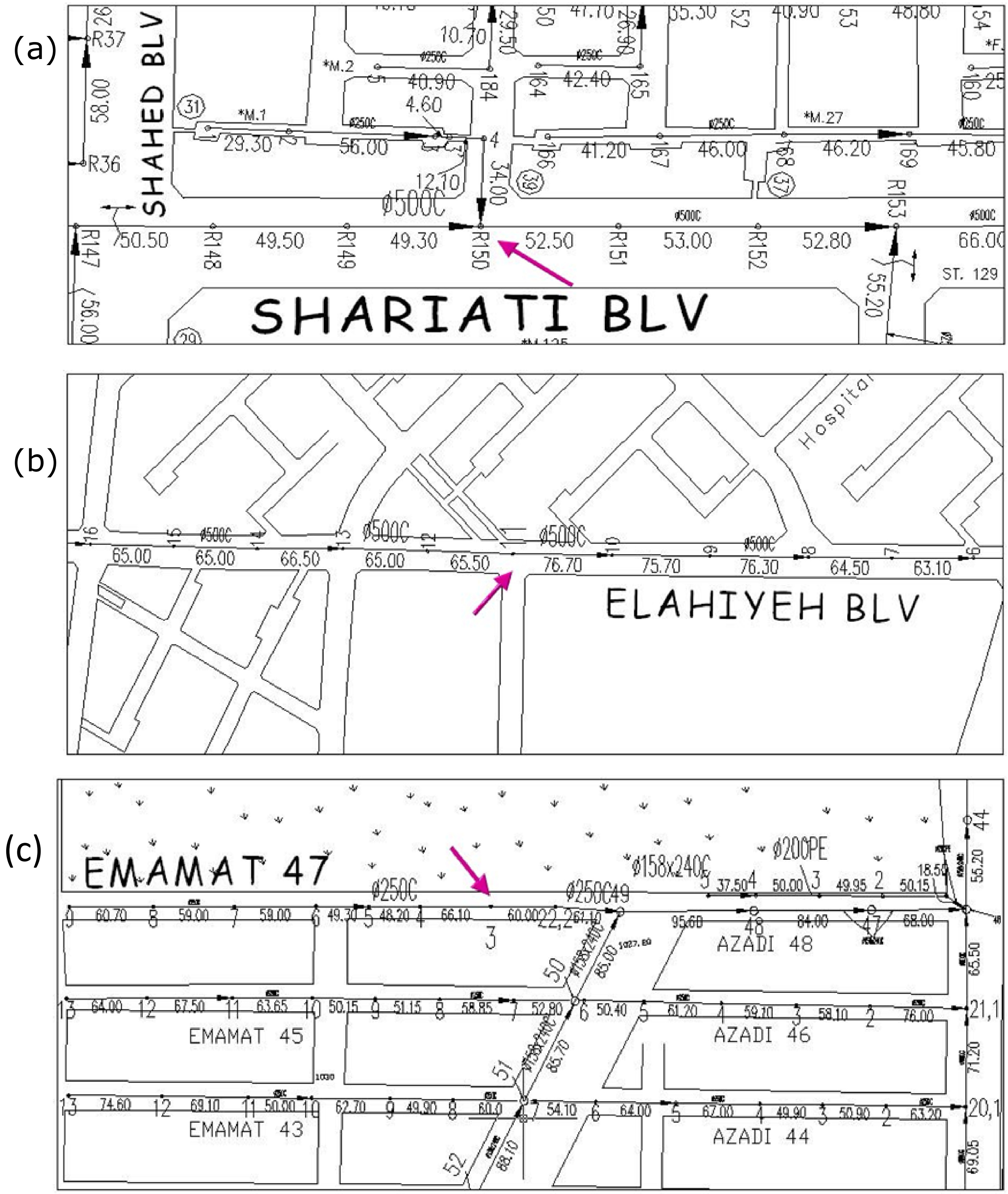

Figure 1. Tests area plan and selected manholes for monitoring the amount of designed gases ((a) SB area plan and selected manhole (MH R150) at Ghasem Abad zone performing HPWJC technique, (b) EB area plan and selected manhole (MH 11) at Ghasem Abad zone performing PBV technique, (c) ES47 area plan and selected manhole (MH 3) at Emamat zone performing WF technique).

Water is pumped through the hose and ejected out through orifices on the rear of the nozzle at a specific pressure. The resulting force thrusts the nozzle through clogging materials as the jets of water break up the solids. By slowly withdrawing the nozzle, the pipe cleaning process is completed by washing the dislodged materials back into the manhole. Radial nozzles are used for general cleaning (Campbell and Fairfield, 2008). This technique is effective in cleaning and removing biofilm from the surfaces of pipes but erosion may occur during application. HPWJC technique was performed at SB network (Figure 1(a)) from upstream (MH R147) to downstream (MH R153) plus the junction path 31 (MH 1- MH R150). A high-pressure water jet system, typical of that used in UK (Campbell and Fairfield, 2008) and Iran drain and sewer cleaning practice, was used with utmost care using Shargh Dej Gostar Toos (SDGT) Company water jet machine having a maximum pressure of 200 MPa and water volume capacity of 5 m^3 to carry out the test described herein. The water jet machine pressure was adjusted to 90 MPa during the test. Gases amount was recorded from manhole R150. The accuracy of performing this technique was investigated by CCTV monitoring.

Ventilation by portable blower (PBV) technique

It is sometimes possible to provide optimum amount of gases in sewers by applying forced ventilation (sewer air refreshment) using portable blowers (Folwell, 1916). Edwini- Bonsu and Steffler (2006) used this technique to provide a design on air flow rate in sewers and control the odor. Different ways of performing this method has been discussed in the literature (Pescod and Price, 1982; Olson et al., 1997).

There are a large number of variables involved in predicting air movement in sewer systems. The variables are affected by distance, hydraulic flow variations, pipe constrictions and diameter, environmental conditions, etc. The dynamics of PBV is assumed to be time variant. Isolation of the selected sewer network (Figure 1b) for PBV technique was carried out based on Edwini-Bonus and Steffler (2006) method. The portable blower performance depends on a number of factors (e.g. speed, motor horsepower). RAMFAN UB20 portable ventilation blower with the air flow of 45 – 50 m^3/hr (the air flow for a maximum of 6 h continuous working) was used for this technique. PBV technique was employed from network's upstream manhole (MH 16). During the operation, manholes' cover were opened regularly (manhole 15 to manhole 6) to let the sewer air exit. In this technique, parameters such as the required time for entering adequate volume of air to the network, pipe diameter, length of network, and manholes' specifications are important. The amount of gases was measured at manhole 11 (MH 11). Due to the operational way of PBV technique, CCTV monitoring is not useful to investigate the accuracy of performance. Thus, the methods were employed with utmost care using Edwini-Bonus and Steffler (2006) method.

Water flushing (WF) technique

In water flushing technique, a relatively large volume of water is accumulated and then released into the immediately down-gradient sewer main. This technique has been known as a preventive maintenance for sewers. This technique is able to clean sewers, increase the flow, and refresh the sewer air (Agbulos et al., 2006; Grant, 1937). The WF was performed from the manhole 9 (without inlet) on the work site at ES47 (Figure 1(c)) using SDGT Company tanker with 10 m^3 capacity. To calculate the required water volume to perform this technique, flushing speed, pipe diameter, and length of pipe are important. Based on water volume, the appropriate place of network was blocked by a stopper, and after filling up the path behind, the stopper was released to carry out the goal in this part. Here, the gases amount was measured at manhole 13 (MH 13). CCTV monitoring was carried out to investigate the accuracy of WF technique performance.

Experiments were done in the morning due to more gas emission and odor generated from the networks. All the three techniques were repeated in three methods/tests as listed in Table 1. The amount of H_2S and O_2 gases was recorded using portable Multi-Gas Detector (PMGD BWQua, iTX) with special sensors (minimum detection levels of 0.1 ppm for hydrogen sulfide and 0.1% for oxygen) with 5-day intervals for the period of 30 days. The results associated here can be useful for environmental protection management and healthcare purposes.

RESULTS AND DISCUSSION

In general, the production rate and transport of gases within sewer systems depends on design. An important consideration in sewer design is the velocity obtained in sewers. Experiences indicate that a velocity of not less than 0.6 m/s is required in sanitary sewers in order to prevent settlement of the sewage solids and increase the air flows in sewers which can result in the optimum range of sewer gases. Field experiments were conducted to investigate the efficiency of designed methods in optimizing the amount of H_2S and O_2 percentage in sewer networks. In practice, to provide a condition in sewer networks using various technologies to deplete the amount of H_2S (ppm) to zero is almost impossible. Also, due to the generation of various gases in sewer network, the O_2 percentage is often variable. Accordingly, in this study the H_2S amount less than 1 ppm and O_2 percentage more than 20% were picked as the safe range of response to evaluate the experimental results for designed methods.

The recorded amount of these gases before and after performing the tests for three different techniques (HPWJC, PBV, and WF) is presented in Table 2. Figures 2, 3, and 4 show the percentage changes of H_2S and $O_2$with respect to the monitoring day.

From Table 2, the initial primary amount of H_2S and O_2 percentage was measured as 11 ppm and 14.1%, respectively using HPWJC technique. It can be seen clearly from the table that initially all designed test decreased the H_2S amount to zero (ppm). Thereafter, some variations on the amount of H_2S can be seen. For test No.1, the amount of H_2S steadily increases after day-5th and reaches a maximum value 1.3ppm after 30 days. Test No.2 gives a fluctuating amount of H_2S, while test No. 3 depletes the entire H_2S amount through the monitoring period. Figures 2(a) shows the decrement of H_2S in percent compared to the initial amount of H_2S after performing the tests. It can be seen clearly from this figure that all the tests demonstrate 100% reduction of H_2S gas during the first 5-day. The final reduction of H_2S gas is around 88% at day-30th for test No.1. The fluctuating amount of H_2S gas can be clearly seen from Figure 2(a) for test No.2. The minimum H_2S reduction during this test was measured as 95% at day 15. For test No.3, the amount of H_2S stays constantly at zero ppm, a 100%

Table 2. The recorded amount of hydrogen sulfide (ppm) and oxygen (%) before and after performing the tests at monitoring day.

Technique	Test No.	Hydrogen sulfide (ppm)							Oxygen (%)						
		IA#	5	10	15	20	25	30	IA#	5	10	15	20	25	30
HPWJC	No.1	11	0	0.1	0.5	0.7	1.1	1.3	14.1	20.6	20.5	20.5	20.3	20.2	20.0
	No.2	11	0	0.1	0.5	0	0	0.3	14.1	20.7	20.7	20.4	20.8	20.7	20.5
	No.3	11	0	0	0	0	0	0	14.1	20.7	20.6	20.8	20.7	20.9	20.7
PBV	No.4	8	1.0	2.9	3.8	4.2	4.7	5.1	13.2	20	19.3	18.9	18.4	18.2	17.9
	No.5	8	1.1	2.7	3.5	0.5	1.1	1.9	13.2	20.3	19.9	19.7	20.4	19.9	19.3
	No.6	8	0.9	2.1	0.1	0.9	0	0.8	13.2	20.4	20.0	20.6	20.1	20.3	20.0
FW	No.7	9	0	0.2	0.6	1.3	2.0	3.7	12.9	20.3	20.0	19.6	19.3	19	18.8
	No.8	9	0	0.2	0.8	0	0	0.8	12.9	20.5	20.3	20.0	20.6	20.3	20.1
	No.9	9	0	0.1	0	0	0	0	12.9	20.5	20.4	20.8	20.6	20.9	20.7

IA# is the initial amount of H_2S and O_2 percentage before tests and (5 - 30) are the monitoring days after performing the tests.

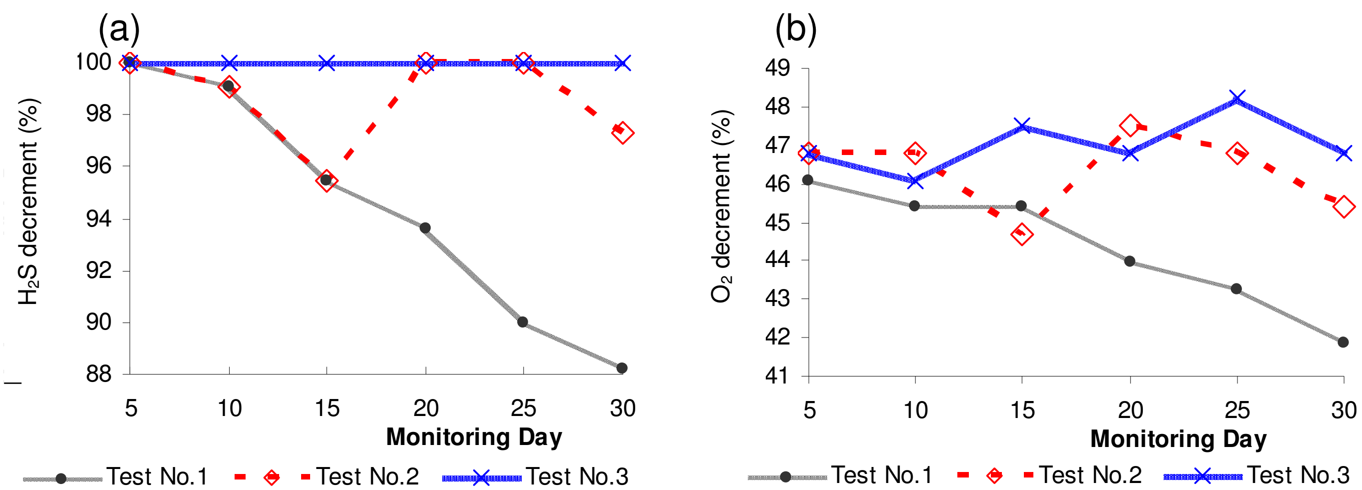

Figure 2. (a) Hydrogen sulfide decrement percentage and (b) Oxygen increment percentage alterations vs. monitoring days using HPWJC technique.

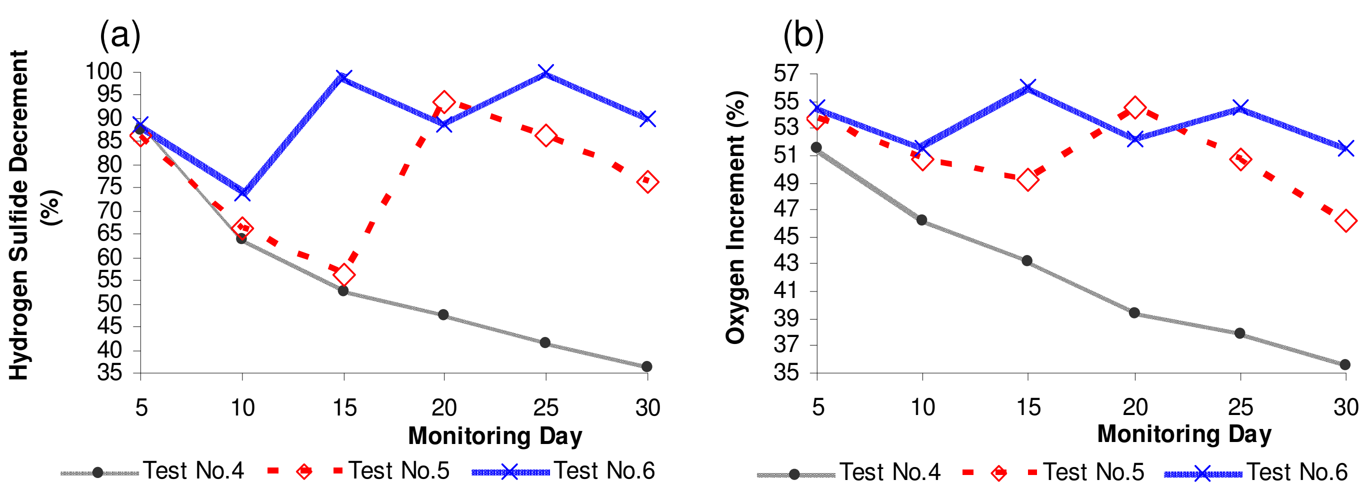

Figure 3. (a) Hydrogen sulfide decrement percentage and (b) oxygen increment percentage changes observed at different monitoring days by PBV technique.

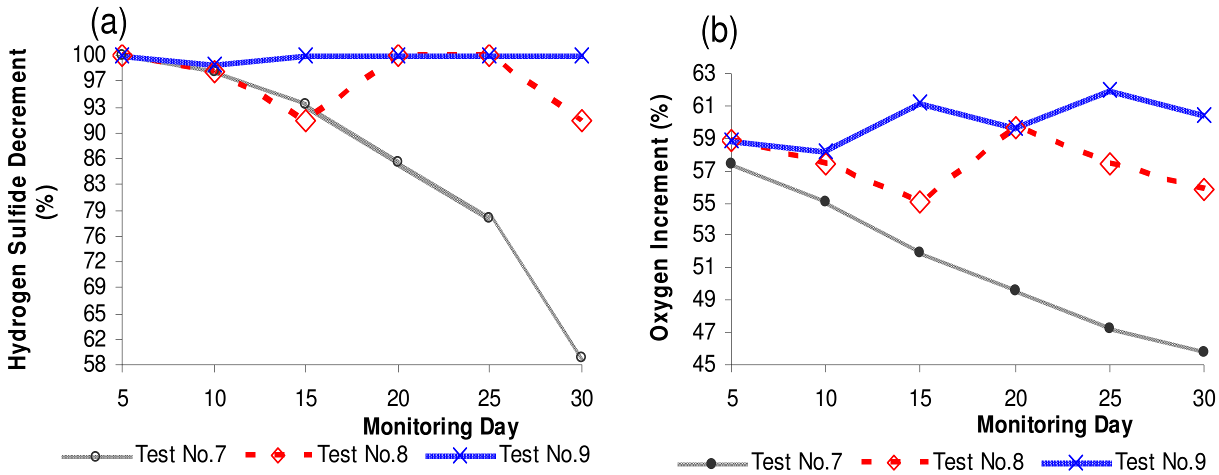

Figure 4. (a) Changes of hydrogen sulfide decrement percentage and (b) oxygen increment percentage vs. monitoring days using WF technique.

reduction, irrespective of the monitoring days.

It can be seen from Table 2 that the oxygen percentage increased drastically from the initial 14.1% to 20.6% for test No.1 and to 20.7% for tests Nos. 2 and 3. Thereafter, it remains between 20 - 20.9% for all tests. The increment of oxygen in percent is shown in Figure 2(b). According to the results, it can be concluded that test No.2 is sufficient to decrease the amount of to H_2S to 0.5 ppm (below 1 ppm) and increase the percentage of O_2 to more than 20% during the test procedure for HPWJC technique.

In PBV technique, the time required to enter adequate volume of air into the network is important. This time can be estimated by equation (1).

$$t_a = \frac{(V_p + V_{MH}) \times 1.20}{V_{PB}} \times t_{PB} \qquad (1)$$

where t_a represents the time needed for ventilation, V_p is the pipe volume (≈147.26 m^3), V_{MH} is the manholes volume (≈12.44 m^3) at study field (EB), V_{PB} represents the air volume entering the network by portable blower (=45 m^3), t_{PB}= 1 h, and 1.20 is the coefficient for wasted air during application.

Using equation (1), the time required for adequate air to enter into the network to perform the tests (Nos. 4, 5, and 6) is 260 min. In this technique, all the tests reduce the amount of H_2S at day 5. A substantial reduction for H_2S has been attained for all tests initially as demonstrated in Table 2, whereby the amount of H_2S drops drastically from 8 ppm to around 1 ppm at day 5. Thereafter, the amount of H_2S increases and reaches the maximum of 5.1 ppm after 30 days for test No. 4. Test Nos. 5 and 6, however, demonstrate a fluctuation of H_2S amount. The maximum amount of H_2S is 3.5 ppm at day 15 for test No. 5. The maximum depletion of this gas (0 ppm) was calculated at day 25 using the test No. 6 method. Figure 3(a) indicates the alteration of H_2S decrement percentage vs. monitoring day for the designed tests. It can be seen from the figure that maximum percentage of H_2S decrement (88%) has been achieved during the first 5 days for Test No. 4. Thereafter, the percentage of H_2S reduction decreases to a minimum value of 36% at day 30. For test Nos. 5 and 6, the maximum percentage of H_2S reduction is 94 and 100% respectively.

The amount of oxygen increases to more than 20% after these tests have been performed compared to the initial value of 13.2% as indicated by Table 2. Test No. 4 increases the oxygen percentage by approximately 52%; while tests Nos. 5 and 6 raise the oxygen percentage to more than 54% as shown in Figure 3(b) at day 5. Thereafter, the value of oxygen percentage increment decreases slightly and stays around 50% for test Nos. 5 and 6; while this value reached 35% for test No. 4. Based on the results, it can be said that test No.6 is the most efficient for PBV technique since it provides the lowest amount of H_2S and more than 20% oxygen. Overall, this technique is recommended for short periods of indoor maintenance to refresh the sewer air and protect network crews from danger.

For WF technique, Grant (1937) reported that the optimum amount of water needed to clean sewage networks and refresh the sewers' air can be estimated using Equation (2). He concluded that for 200 m network length (l_1) with the pipe diameter 200 mm (A_1= 0.03 m^2), 2.4 m^3 (V_{W1}) water is required.

$$V_{W2} = V_{W1} \times \left(\frac{l_2 \times A_2}{l_1 \times A_1}\right) \qquad (2)$$

where V_{W2} represents water volume needed for flushing study field (ES47) network, l_2 (=463.4 m) and A2 (=0.05 m^2) are length of network for cleaning and area of sewer pipe.

Using Equation (2), 9 m^3 water is required for this method based on the network specifications. Moreover, to perform the tests Nos. 7 to 9, Equation (3) was used to estimate the location where the network should be blockaded (here, the pipe friction was ignored).

$$l_s = \frac{V_{W2} - V_{Ms}}{A_2} \quad (3)$$

where l_s is length of network before stopper and V_{Ms} presents total volume of manholes before stopper.

In such a way, the stopper was fixed at the inlet path of manhole 7 as shown in Figure 1(c). The amount of H_2S and oxygen (%) during the tests is presented in Table 2. Table 2 shows that the initial primary amount of hydrogen sulfide and oxygen percentage as 9 ppm and 12.9%, respectively. It can be seen from the table that all designed tests are successful in depleting the H_2S amount to zero ppm at day 5. The outcomes here are quite similar to HPWJC technique results. The amount of H_2S increases steadily for test No. 7, fluctuates for test No. 8, and approximately constant for test No. 9. The oxygen percentage increases significantly to more than 20% from the initial value of 12.9%. Moreover, it can be seen from Table 2 that apart from test No.7, oxygen percentage remains between 20 - 20.9% after day 5 for tests Nos. 8 and 9. Figures 4(a) and (b) demonstrate percentage changes of H_2S and O_2 gases vs. monitoring day after employing the tests Nos. 7 to 9 using WF technique respectively. Although, test No. 7 was initially able to reduce the amount of H_2S completely, the reduction percentage continued to decrease and reached minimum of 59% at day 30. The fluctuating reduction percentage of H_2S can be seen from Figure 4(a) for test No. 8. The minimum percentage reduction of this gas was measured as 91% at day 15 and day 30. For test No. 9, the reduction percentage of H_2S mostly stays constant at zero with a slight deviation at day 10. Figure 4(b) indicates that the oxygen percentage range increased rapidly at day 5 by approximately 57% for test No. 7 and 59% for tests Nos. 8 and 9. Thereafter, the increment percentage in oxygen does not vary very much and it stays more than 55% for test Nos. 8 and 9. Based on the discussion above, it can be concluded that test No. 8 is sufficient to fulfill the goal for this technique since the amount of H_2S is less than 1 ppm while more than 20% for oxygen.

According to the outcomes revealed from various parts of the study, the most efficient methods were selected as test Nos. 2, 6, and 8, according to the three techniques individually. Based on the results presented in Table 2, the averages of H_2S amount for these tests were calculated as approximately 0.2, 0.8 and 0.3 ppm; and in addition, the averages of O_2 percentage were determined by 20.6, 20.2 and 20.3%, respectively. Accordingly, these tests are rated as tests No. 2 followed by 8 and then 6. On the other hand, Campbell and Fairfield (2008) reported that HPWJC technique used for test No. 2 can cause erosion and pipe deterioration during the technique procedure. They concluded that by using HPWJC technique with a pressure of 35 MPa, the erosion rate of 20.6 µm/s would occur in concrete pipes. They also mentioned that longer duration jetting caused more damages. Hence, test No.8 using WF technique is recommended as the most effective method.

Conclusion

The presence of sewer gas at significant concentration levels may cause dangerous conditions. Some of the designed methods proved a promising way to optimize the amount of H_2S and O_2 percentage in sewers at specific intervals. H_2S amount less than 1 ppm and O_2 percentage more than 20% were considered as the safe range of response to evaluate the experimental results for designed methods. The results obtained from performing the designed methods showed that test No. 2 (2 times/30 days), test No. 6 (3 times/30 days), and test No. 8 (2 times/30 days) for HPWJC, PBV, and WF techniques respectively are efficient enough to satisfy H_2S and O_2 ranges at headspace of the networks. As has been explained above, water flushing (WF) technique with application of 2-time/30-day (test No. 8) is the most effective method in comparison to other practical methods. This method depleted the initial amount of H_2S to less than 0.8 ppm and raised the oxygen percentage to more than 20% during the test procedure.

Limitations and suggestion for future research

While the findings of this study could be beneficial, these are generally according to the environmental conditions in a part of Mashhad sewer networks; hence, it may have some limitations in generalizing to other sewer networks worldwide. In addition, the use of different equipments to conduct the study and measure the gases amount and/or employ the tests may lead to some differences in the results obtained. Accordingly, more investigations are recommended to generalize the results revealed in this study.

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