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Survey on Odorous Mineral Gases in the Air Around the Wastewater Treatment Plant: A Case Study in a Stabilization Pond

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Abstract

Malodors are one of the problems of water and wastewater treatment plants, especially in the vicinity of residential areas. Mineral compounds like hydrogen sulfide (H_2S) and ammonia (NH_3) produce unpleasant smells in the wastewater treatment plants. These gases also have adverse effects on both humans and the environment. After field visits around the plant, a number of 12 sampling stations were determined. Sampling stations were selected from 4 cardinal directions with regard to permanent trade winds and on distances of 0, 2 and 4 km from the plant. Sampling was performed in the morning and evening during the four seasons. Jacob and Indophenol methods were used for measuring the concentration of H_2S and NH_3.

According to analysis of variance (ANOVA) and Tukey test, and concentrations of NH_3 and H_2S during different seasons, the emissions were more significant in the warm seasons and caused more malodors ($P = 0.011$, $P = 0.004$ for NH_3 and H_2S, respectively). Moreover, there was a significant relationship between the concentration of NH_3 and sampling sites ($P = 0.000$). However, the relationship between the concentration of H_2S and sampling stations was not significant ($P = 0.179$).

According to the results, the concentrations of H_2S and NH_3 in all the seasons except for winter were within the threshold limits. The concentration of H_2S in the summer and the concentration of NH_3 in all the seasons were higher than USEPA standards and World Health Organization (WHO) guidelines.

Keywords: Wastewater treatment plant, Malodor, Hydrogen sulfide, Ammonia

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1. Introduction

Odor production has long been considered as one of the concerns of the operation of water and wastewater industrial installations established near human societies (1). Operational wastewater treatment plants produce inorganic gases generating unpleasant odors, such as hydrogen sulfide (H_2S) and ammonia (NH_3), under anaerobic and unfavorable aerobic conditions. As a result of the operation, sulfate-reducing bacteria (SRB) such as desulfovibrio and desulfotamaculumturn reduce sulfate ions into the H_2S. H_2S is associated with the distinct odor of rotten eggs (2-4). NH_3 is also an important odorous gas in the wastewater treatment system, which is a byproduct of the decomposition of organic compounds containing nitrogen (5). If weather conditions are unfavorable, the concentrations of the odorous gases will be increased in the air around the treatment plant. Krzysztof et al showed that H_2S also could be produced besides NH_3 in the compost production processing and poultry complexes (6). These compounds have adverse effects on humans and the environment. In scientific terms, the odor is considered as the smell recognized by receiving stimuli through the olfactory system (7-9). Human is sensitive to odorant chemical compositions. The sensitivity depends on the concentration and features of the compositions (7-10). According to studies, gaseous emissions from wastewater treatment plants especially H_2S would jeopardize the health of residents in areas adjacent to the facility. These effects include headache, loss of consciousness, and gastrointestinal disorders. Economic losses caused by the smell of sewage facilities are one of the environmental and operational problems in Iran as well as the world (1). In cases where odors are very severe, they lead to a drop in property values, and a decrease in commercial, and tax revenues (11). Odorous compounds have a threshold odor number (TON). The threshold is the concentration of odorous gases under which odors cannot be detected by the human olfactory (12). The World Health Organization (WHO) guidelines for H_2S and NH_3 are 0.2-2 μg/m^3 and 4.65-8.49 μg/m3, respectively (13,14). The odor threshold for H_2S is 0.5 ppb, and its permissible limit in outdoor air is 5 ppb based on

the smell in an average time of 30 minutes (13). While the United States Environmental Protection Agency (USEPA) recommends the exposure to H_2S to be 1.5 ppb for the public and its maximum permissible limit in one hour to be about 0.14 ppm (2). The odor threshold for H_2S has been reported to be between 0.00047 and 4.6 ppm (12). The permissible concentration for NH_3 recommended by EPA is 0.13 ppm (6). The odor threshold for NH_3 is between 1 and 46.8 ppm (12).

Given the importance of odor in terms of health, environmental and economical impacts, the question is how much are the concentrations of these compounds in the actual operation of wastewater treatment and on the treatment plants. Hence, this study aimed to determine the concentration of odor generating-inorganic elements and also to compare them with the standards and guidelines for wastewater treatment plants.

2. Materials and Methods

This descriptive-analytical study was conducted during 2015-2016 at Faculty of Health, Qazvin University of Medical Sciences, Iran. The field visits were first carried out to determine the sampling stations around the treatment plant. Since the release of odors around the treatment plant occurs through spreading mechanism or convection (15), constant wind direction, the area topography, and surrounding settlements were considered to determine the sampling stations. Therefore, 12 stations were selected around the treatment plant in North, South, East, and West at zero distance (inside the treatment plant), and at distances of 2 and 4 km from the treatment plant. Sampling was done in the morning and afternoon in spring, summer, autumn, and winter. The samples were collected 8 times for each pollutant gas from each station during the one-year of study period. A total of 96 samples were collected for each pollutant. Therefore, 192 samples were collected around the treatment plant for these 2 gaseous pollutants. Sampling was performed passively. A calibrated sampling pump supplied the required flow rate. The pump was a low volume pump manufactured by SKC England. The pump flow was 3 L/min which had been calibrated by a soap bubble flow meter. Sampling was carried out at the height of 1.5 meters above ground level according to Sather et al and Srivastava et al (16,17).

In order to measure the concentration of H_2S, the method of Jacobs et al known as Methylene Blue method was used (6,18). To measure the concentration of NH_3, Indophenol method was used (19,20). For sampling H_2S, the polluted air was passed through impingers, each containing 45 mL absorption solution, for a time of 30 minutes with a flow rate of 3 L/min. In order to ensure the full absorption of H_2S in solution, 2 or 3 impingers were used in series. After transmission to the laboratory, the samples were discharged into 50 mL volumetric flasks. Then, 0.6 mL of amine-sulfuric acid reagent was added to each of the flasks. After mixing, 3 drops of ferric chloride were added to them and mixed again. The flasks were then brought to a volume of 50 mL with the absorption solution, and it took 30 minutes to complete the reaction. Finally, the absorption rate of the samples was read with control solution at a wavelength of 670 nm by a UV-VIS spectrophotometer (6,18). The spectrophotometer used in this study was T80 + UV-VIS manufactured by PG-instruments Ltd, UK.

For sampling the NH_3 in the air, 20 mL of absorption solution of 0.1 normal sulfuric acid was poured into impinger. A certain volume of air was then passed through the impinger for 30 minutes with a flow rate of 3 L/min. In order to ensure the full absorption of NH_3 in the absorption solution, 2 or 3 impingers were used in series (9). After transmission to the laboratory, the samples were discharged into 50 mL volumetric flasks. Then, 4 mL of buffer solution, 10 mL of phenol, and 5 mL of sodium hypochlorite solution were added and thoroughly mixed at each stage. The resulting solution was then placed in a dark room for 30 minutes to complete the reaction. Then, the absorbance of samples was read at a wavelength of 630 nm by a spectrophotometer (19, 21).

To determine the concentration of NH_3 and H_2S measured in units of ppm, volume was modified taking into account the actual conditions and with the help of equation (1) for different seasons due to changes in temperature. In equation (2), the modified volume was used for calculation (22).

$$\frac{\mu g}{m^3} = \frac{ppm \times M \times 10^3}{V} \quad (1)$$

$$V_1T_2 = V_2T_1 \quad (2)$$

M = molecular weight

V = volume

T = temperature

It should be noted that all the trials were done 3 times and the mean data obtained from them was announced. All the chemicals used in this study were purchased from Merck and/or Sigma-Aldrich. Data were analyzed via Excel and SPSS version 20.0 using *t* test, analysis of variance (ANOVA), and Tukey test. To demonstrate the fluctuations of pollutant concentrations around the wastewater treatment plant, Kriging method was used in this study, by the ARC GIS 9.2 software to interpolate the concentrations of pollutants.

3. Results and Discussion

The mean and standard deviation (SD) of the concentrations of measured gases around the wastewater treatment plant, at various intervals throughout the year and in different cardinal directions, are shown in Table 1.

In Fig. 1, the concentrations of NH_3 (ppm) in wastewater treatment plant in different seasons, distances, and cardinal directions are shown. According to Fig. 1, the highest concentration of NH_3 was inside the treatment

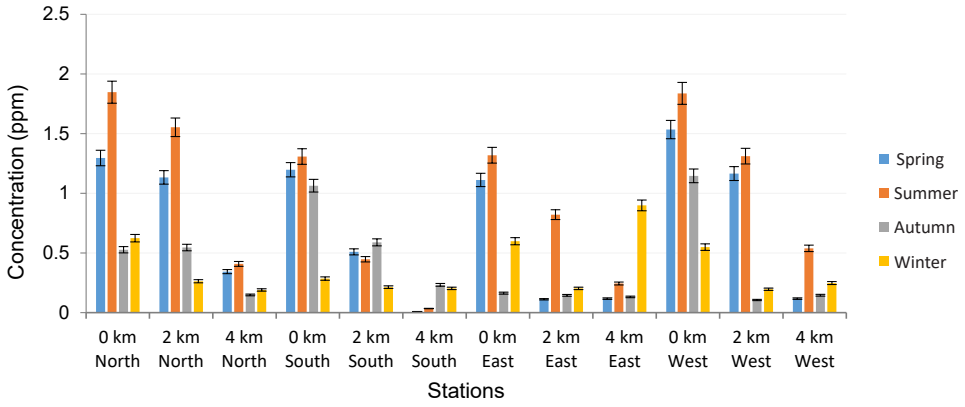

Fig. 1. Concentrations of Ammonia According to the Season, Distance and Cardinal Directions of the Wastewater Treatment Plant.

Table 1. The Mean and Standard Deviation of Concentrations of H_2S and NH3 in the Wastewater Treatment Plant for Different Distances During the Year

Sampling Station	Concentrations of NH_3 (ppm)	Concentrations of H_2S (ppm)
0 Km North	0.67±1.07	0.47 ±0.28
2 Km North	0.59±0.87	0.009 ±0.006
4 Km North	0.23±0.27	0.009 ±0.005
0 Km South	0.43±0.96	0.46 ±0.22
2 Km South	0.35 ±0.44	0
4 Km South	0.108 ±0.119	0
0 Km Eastern	0.53±0.79	0.27 ±0.10
2 Km Eastern	0.31±0.32	0
4 Km Eastern	0.52±0.34	0.015 ±0.008
0 Km Western	0.56±1.26	0.45 ±0.2
2 Km Western	0.59±0.69	0.20 ±0.08
4 Km Western	0.25±0.26	0

plant, and its concentrations decreased by increasing the distance from the plant.

Analysis of variance showed that the relationship between the concentration of NH_3 and the distances from the plant was significant (P = 0.000). The maximum, minimum, and average concentrations of the NH_3 during different seasons in the wastewater treatment plant are shown in Table 2.

The results showed that there was a significant relationship between the concentrations of NH_3 and different seasons (P < 0.011). According to Tukey test, there was a significant difference between the summer and the autumn (P = 0.031) and also between the summer and the winter (P = 0.018).

Fig. 2 shows the concentration of H_2S (ppm) in wastewater treatment during different seasons and at different distances according to cardinal directions.

According to Fig. 2, the highest concentration of H_2S was inside the treatment plant, and its concentration decreased with an increase in the distances from the plant. Analysis of variance showed that there was no significant relationship between the distance from the plant and the concentration of H_2S (P = 0.193). Moreover, the relationship between the concentration of H_2S and sampling stations was not statistically significant (P = 0.179). The maximum, minimum, and average concentration of H_2S during different seasons in the wastewater treatment plant is shown in Table 3.

Analysis of variance showed that the relationship between the concentration of H_2S and different seasons

Table 2. Tukey Test Between Different Seasons and Concentrations of Ammonia in Wastewater Treatment Plant

Season	Concentrations of NH_3 (ppm) Mean ± SD	Minimum	Maximum	*P* Value	
Spring	0.72 ± 0.56	0.009	1.53	0.573	Summer
				0.4	Autumn
				0.296	Winter
Summer	0.97 ± 0.63	0.034	1.84	0.573	Spring
				0.031	Autumn
				0.018	Winter
Autumn	0.41± 0.36	0.105	1.14	0.4	Spring
				0.031	Summer
				0.997	Winter
Winter	0.37 ± 0.23	0.19	0.89	0.296	Spring
				0.018	Summer
				0.997	Autumn

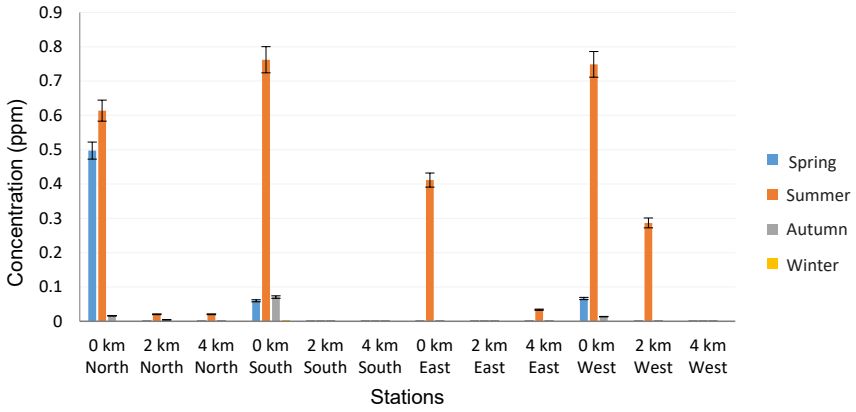

Fig. 2. Concentrations of Hydrogen Sulfide According to the Season, Distance, and Cardinal Directions of the Wastewater Treatment Plant

was significant (P = 0.004). According to the results of Tukey test, there was not a significant difference between the spring and summer seasons (P = 0.051). The difference between the summer and winter seasons were significant (P = 0.009 and P = 0.007, respectively).

T test results on the concentrations of H_2S and NH_3 in the air around the wastewater treatment plant (for 2 periods of morning and evening) are given in Tables 4 and 5.

T test results showed that there was not a significant difference between the average concentration of H_2S in the mornings and its concentration in the evenings during the spring (P = 0.071). While there were significant differences between the average concentration of H_2S in the morning and its concentration in the evening during summer, autumn and winter; P values are 0.000, 0.037, and 0.039, respectively.

T test results showed that the concentration of NH_3 in the evening was higher than that in the morning. The difference was statistically significant in the winter

Table 3. Results of Tukey Test Between Different Seasons and Concentrations of Hydrogen Sulfide in Wastewater Treatment

Season	Concentrations of H_2S ppm) Mean & SD	Minimum	Maximum	*P* Value	
Spring	0.052 ± 0.14	0	0.49	0.051	Summer
				0.911	Autumn
				0.863	Winter
Summer	0.24 ± 0.31	0	0.76	0.051	Spring
				0.009	Autumn
				0.007	Winter
Autumn	0.008 ± 0.02	0	0.07	0.911	Spring
				0.009	Summer
				0.999	Winter
Winter	0.0003 ± 0.001	0	0.003	0.863	Spring
				0.007	Summer
				0.999	Autumn

Table 4. Results of *T* Test Between the Concentration of Hydrogen Sulfide and the Parameters of Morning and Evening (During Different Seasons in Wastewater Treatment)

Time	Mean	SD	T	*P* Value
Spring morning	0.011	0.023	-1.125	0.071
Spring evening	0.098	0.26		
Summer morning	0.044	0.06	-2.385	0.000
Summer evening	0.43	0.56		
Autumn morning	0.0024	0.0057	-1.248	0.037
Autumn evening	0.015	0.35		
Winter morning	ND *	0	-1	0.039
Winter evening	0.0006	0.0021		

* Not detected.

Table 5. Results of *T* Test Between the Concentration of Ammonia and the Parameters of Morning and Evening (During Different Seasons in Wastewater Treatment)

Time	Mean	SD	T	*P* Value
Spring morning	0.62	0.60	-0.834	0.334
Spring evening	0.81	0.55		
Summer morning	0.87	0.68	-0.772	0.320
Summer evening	1.07	0.60		
Autumn morning	0.34	0.40	-0.801	0.3
Autumn evening	0.48	0.46		
Winter morning	0.21	0.04	-2.194	0.000
Winter evening	0.52	0.48		

(P= 0.000). However, this difference was not significant during other seasons (P> 0.05).

Correlation between the concentrations of 2 variables of NH_3 and H_2S in wastewater treatment plant was significant (P < 0.05, r = 1). Dispersion concentration of NH_3 and H_2S around the wastewater treatment plant is shown in Fig. 3. As seen in the figure, as the distance from the treatment plant increases, the concentration of both gases decreases (Fig. 3).

Comparing the concentration of NH_3 and the odor threshold in the morning and evening, we observed that the gas concentration was in the range of odor threshold in distances of 0 and 2 km north from the treatment plant in spring and summer. In autumn, the gas concentration was in the range of odor threshold just in the evening. In the southern and western directions of the treatment, the gas concentration was within the range of odor threshold only in 0 km and in the morning and evening in spring, summer, and autumn. In addition, the gas concentration was within the range of odor threshold in 2 km west in the morning and evening in spring and summer. In the eastern direction of the treatment plant, the gas concentration was within the range of odor threshold only in 0 km in the morning and evening in spring and summer. Comparing the average seasonal concentration of NH_3 (Table 2) showed that the highest concentration was in summer, and then the seasons of spring, autumn, and winter had the highest concentration, respectively. The gas concentration was in the range of odor threshold in all seasons except for winter.

The results showed that the concentration of NH_3 in wastewater treatment was significantly different during different seasons with the highest concentration in summer, which was a significant difference compared to those of autumn and winter. Salem et al measured the concentrations of NH_3 in wastewater treatment in the city of Al Ain and found that the concentration of NH_3 in warm seasons (spring and summer) was higher than that in cold seasons (autumn and winter). The researchers also reported that odor intensity was reduced during the purification process (14), which is inconsistent with the results of this research.

Comparing the average concentration of NH_3 in different cardinal directions (Table 1 and Fig. 1), it was observed that the concentration of NH_3 was at the highest level in the west direction. The concentration of NH_3 was respectively high in the northern, southern, and eastern sides of the treatment plant. Local winds were one of the causes of these differences.

By comparing the average concentration of H_2S in the morning and the evening with the odor threshold, it can be seen that the concentration of gas was within the range of odor threshold in 0 km north in the morning and evening in spring and 0 and 2 km only in the evening in autumn.

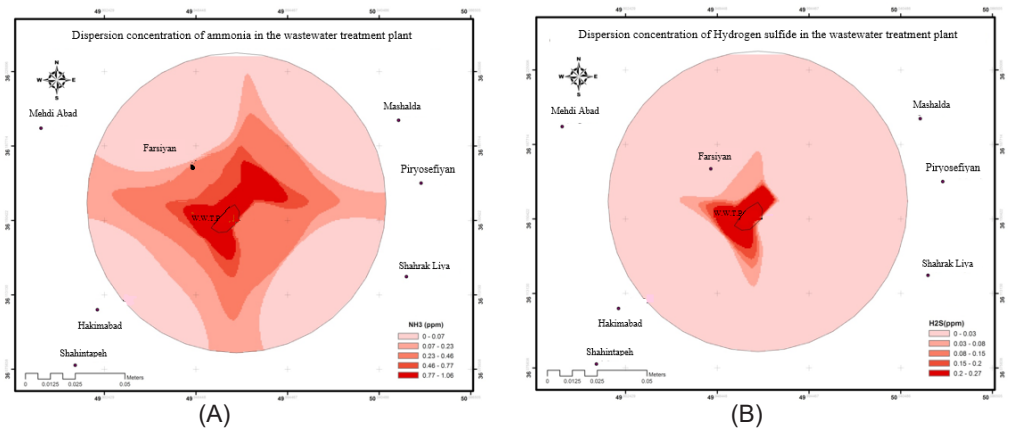

Fig. 3. Dispersion Concentration of (A) Ammonia and (B) Hydrogen Sulfide Around the Wastewater Treatment Plant.

In the summer, the concentrations in all distances studied in this study were within the range of odor threshold both in the morning and evening.

The concentration of H_2S in the southern side (0 km) was within the range of odor threshold both in the morning and evening during spring, summer, and autumn and just in the evening during the winter.

In eastern direction, the concentration of H_2S was within the range of odor threshold in distances 0 and 4 km from the treatment plant in the morning and evening during the summer. Low concentration of this gas at a distance of 2 km might be due to sectional changes in local winds or odor-generating sources such as poultry farming locations in a distance of 4 km because there was a rural residential area and their main profession was agriculture and animal husbandry.

In the west direction and a distance of 0 km from the treatment plant, the concentration of gas was within the range of odor threshold in the morning and evening during spring, summer, and autumn. In this direction in a distance of 2 km from the treatment, the concentration of gas was within the range of odor threshold only in the evening during spring and summer. By comparing the average seasonal concentration of H_2S (Table 3) and its odor threshold, it can be concluded that the average concentration of this gas was within the range of odor threshold during all seasons except for the winter.

Therefore, the staff of the treatment plant and residents of the surrounding villages would face problems caused by H_2S and NH_3 during all the seasons except for winter.

Biodegradation processes that take place in reactors of wastewater treatments, such as ponds and lagoons, are usually under the influence of ambient temperature, so that for each 10°C increase in the temperature of wastewater, the rate of biodegradation reactions almost doubles (23). Therefore, the smells of anaerobic biodegradation processes would be increased during the warm seasons causing health problems for the treatment plant staff and residents around the plant.

Santons et al studied H_2S emissions from the surface of waste stabilization ponds and showed that gas emissions had a significant relation with temperature. They also reported that where the winds had a low speed due to poor atmospheric dispersion, the concentration of odor emissions was higher and also there were more complaints about the malodors (24), which was consistent with the results of this study.

In agreement with the results of our study, Stellacci et al studied the odor emissions in wastewater treatment plant in Taranto, Italy and showed that complaints of unpleasant odors reduced with increasing the distance of residential quarters from the treatment plant. They also reported that during the warm seasons and bad weather conditions such as high humidity and stable conditions with a light breeze, the odor was higher (11). Comparing the mean values in cardinal directions (Table 1 and Fig. 2), it was found that the concentration of H_2S was at the highest level in the north. Since the wind direction is mostly from south to north and because of the accumulation of livestock waste from the farms located in the area, there would be an increase in the concentrations of gas in this direction, which is consistent with the results of Krzysztof et al (6).

After the north side, the west direction was in the second order, where the pumping station was located. Obstacles such as guard buildings and facilities can cause deviation of wind and release of more H_2S in this direction. The south direction was in the third order in terms of the concentration of H_2S, which might be due to anaerobic stabilization pond in this direction. East was the last in terms of the gas concentration. In fact, this direction included the final stages of treatment, when the wastewater entered chlorination steps and then transferred to the output section, and where no decomposition occurred.

In terms of the amount of odor in different units of the municipal wastewater treatment plant, Jeon et al showed that the odor emission was higher in the summer than that in the winter in all the units. Their results also showed that the amount of odor was reduced during the treatment process (7), which is consistent with the results of this study.

According to Tables 4 and 5, the average concentrations of H_2S and NH_3 were higher during the evenings. Since degrading bacteria were more active in the warm conditions and consequently the peak of microbial activity was in the afternoon, oxygen consumption would be increased in the biological treatment units, and it caused anaerobic conditions, in which H_2S and NH_3 production would be more likely, and this is consistent with the findings of Mesdaginia et al (25). By the way, according to Capelli et al, emission of odor-generating pollutants depends on the pollutant concentrations, air flow rate, and the rate of evaporation from the treatment plants, which is more intense during the evenings (8).

4. Conclusion

The data obtained from this study compared to standard values of odor thresholds for H_2S and NH_3 showed adverse conditions in terms of tremendous potential for odor generating around the plant and in the surrounding settlements, especially in the evening and during seasons of spring and summer, when they are exposed to the gases of H_2S and NH_3. By comparison of the results with the guidelines set by WHO and EPA, it can also be concluded that the concentration of H_2S was higher in warm seasons and the concentration of NH_3 was also higher than the permissible limit during all seasons. In terms of the concentration of the gases in all cardinal directions, it was concluded that problems caused by H_2S and NH_3 were higher in northern and western settlements. It is also recommended to identify and measure organic gases

generating odors in wastewater treatment plants.

Conflict of Interest Disclosures

The authors declare that they have no conflict of interests.

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