TECHNIUM

Technium Vol. 19, pp.21-32 (2024)
ISSN: 2668-778X
www.techniumscience.com

A case Study of Fat and Release of Hydrogen in Sewage Sulfide During the Management of Sewage Projects

S N HUSSEIN[1], R F. ALRUBAYE[2] , Y S NASSAR[3*]

[1]*University of Kufa, Najaf, Iraq.*
[2]*Department of Regional Planning, Faculty of physical Planning, University of Kufa, Najaf, Iraq*
[3]*Department of Urban Planning, Faculty of physical Planning, University of Kufa, Najaf, Iraq.*
***Corresponding Author: yasirs.radhi@uokufa.edu.iq**

Abstract. During sewage projects, management appears Hydrogen sulfide (H2S) emission-related odours have been a problem in sewage project networks for decades. One of the gases that directly harms employees and network infrastructure is hydrogen sulfide gas. Using the TOXCHEM software, the network of the Al-Hur project in Karbala, south of the Iraqi capital, Baghdad, was simulated for three main lines of different diameters 630, 315, and 1000 mm, each with a diameter of 1000 meters, they are connected to a main manhole by drop structure, and then to the lift station. Samples for these diameters were collected for two seasons (summer and winter) with all the necessary parameters of this network to be included in the model. The model was validated for the two seasons, and the results were very close to reality after being examined in a statistical way, where the results of R and RMSE were (0.821 and 0.821) and (0.000462 and 0.000184) for Summer and Winter, respectively. Sensitivity analysis studied wastewater characteristics with different levels of H2S loading rate, flow rate, suspended solid concentration, oil/grease concentration, and temperature. The results showed that all emissions in these networks are dangerous, especially in the summer when the emissions concentrations for pipe 315, pipe 630, pipe 1000, drop 315, drop 630 and the lift station were 7.6, 6.2, 2.5, 8.01, 3.78 and 6.06 ppm, respectively. By utilizing a TOXCHEM model, the study helped to understand the fate and emission of hydrogen sulfide gas in all parts of the networks.

Keywords: Network Projects, Sewage Projects Management Emission, Hydrogen Sulfide, TOXCHEM model, Fate.

1. Introduction

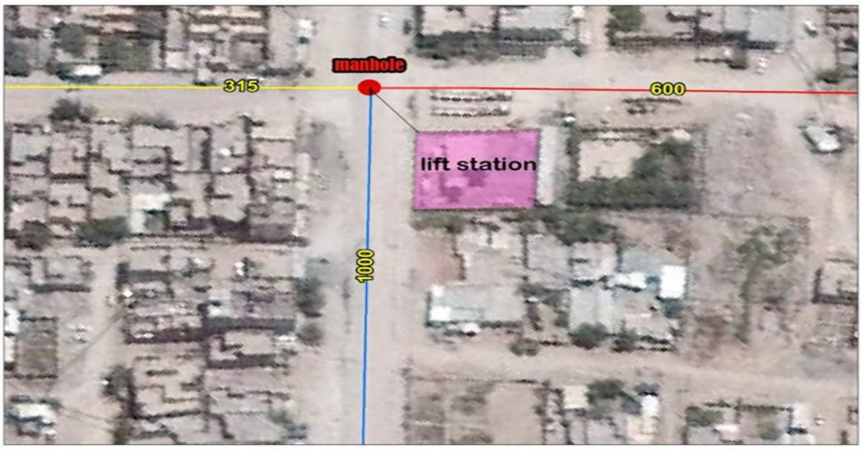
Sewage projects Anaerobic sewage can produce a complex mixture of odour-causing substances transported through sewer projects, including hydrogen sulfide (H2S), volatile organic sulfur molecules, and nitrogenous components. It is difficult to analyze and discern individual odours in this complex combination [1]. In fact, there is a lot of H2S about, and other odours are more likely to be present when it is. Thus, from an engineering perspective, H2S can be used to indicate odours detected in sewer networks. H2S is known to offer a major health danger, as well as problems with corrosion in buildings and microbiologically caused sewage, in addition to odour concerns [2]. The emission of molecular hydrogen sulfide, H2S(aq), from the water phase into the surrounding environment is what leads to the existence of gaseous hydrogen sulfide, H2S(g), in the sewer atmosphere. As long as the sulfide is in the aqueous phase, there are no odour or corrosion problems; however, this isn't always the case. Therefore, it is believed that the emission mechanism plays a significant role in H2S-related difficulties in sewage lines. Sulfate respiration by microorganisms, primarily in sediments and biofilms (sewer slimes), produces H2S in sewer projects [3]. It is necessary to have a better understanding of the fundamental mechanics underlying hydrogen sulfide emission during sewage transit in order to connect odour and corrosion concerns to sulfide generation in sewage. Using a predictive model to estimate H2S emission, engineers and managers will be able to assess the level of odour and corrosion concerns when running sewer projects [4].[5] investigated hydrogen sulfide emissions from a gravity sewer in a Chinese city. The H2S gas sensors measured the H2S gaseous. They made use of two sewer pipes. They discovered that the concentration of H2S was negatively connected with water flow and positively correlated with temperature, COD, and sulfide. [4] Using an adaptive neuro-fuzzy inference system, investigated hydrogen sulfide emission from a gravity sewer. The artificial gravity sewer was employed in the sensitivity analysis, along with considerations for temperature and hydraulic conditions. Using the model, [6] looked at the emission of H2S from a pump station in Kuwait. The effluent temperature, flow rate, and organic content were all subjected to sensitivity analysis. Any one of these parameters increased levels led to an increase in H2S concentration. [7] investigated the results of field monitoring research on the H2S levels in an upstream portion of a 3-km-long, drop-structure sanitary sewage project in Edmonton, Alberta, Canada. Sewage flow rate and diurnal H2S concentration patterns were shown to be positively associated. [8] carried out undertaken research to better understand hydrogen sulfide (H2S) emission and its movement in the sewage trunk with drops. It was shown that even extremely low sulfide levels might locally produce considerable H2S gas concentrations and that the sewer system dips had a significant impact on the release of H2S. In the Karbala governorate, there has never been a study of H2S gas emissions in the sewage networks in all of their components (pipes, drop structures, and lifting stations Increasing sulfate concentrations in the sewage networks of the city of Karbala, the anaerobic conditions within these networks, and sulfate-reducing bacteria (SRB) create hydrogen sulfide gas. In this region, substantial quantities of hydrogen sulfide gas are created in sewage networks, and these amounts have been responsible for numerous deaths of network employees [9]. This study aimed to know the fate and emission of hydrogen sulfide gas in sewage networks in all its parts (pipes, drains, and lift stations) and know the contribution of each part to the emission process. The task of this study was to find out the reasons that affected the emission of this gas, what are the necessary measures to reduce its emissions, and what are the concentrations of emissions in different diameters, drop structures, and lift stations. And determine the factors that influenced the gas emission in the sewage network projects. The TOXCHEM program was employed in this work for the first time.

2. Materials Method

2.1 Case study

The Al-Hur region in the province of Karbala, which is situated around 100 kilometers south of Baghdad, was chosen for the study. A 300 km long network of sewage pipes in Al Hur has diverse diameters ranging from 250 mm to 1000 mm. Al-Hur City spans over 2014.8 hectares in total. In this study, locations, where hydrogen sulfide gas emissions cause unpleasant odors to be released, were chosen in order to examine and determine the causes of these emissions. The Al-Waha lift station and the three main lines into which it flows were chosen, along with all its components, from the drop structures and main manhole. There are three main lines with diameters of 315 mm and 630 mm manufactured from Unplasticized Polyvinyl Chloride (UPVC) and a diameter of 1000 mm manufactured from Glass Reinforced Plastic (GRP), all of which flow into a main manhole with dimensions 3*3 meters. A line with a diameter of 315 pours into the manhole with a drop structure of 90 cm in height, while a line with a diameter of 630 pours into the same manhole with a drop structure of 37 cm, while a line with a diameter of 1000 mm without drop structure. Then the wastewater is transferred from the main manhole to the lift station. As shown in the Figure. 1.

Figure 1. The case study map of Al-Hur district in Karbala.



2.2 Sampling and analysis

The sewage network's required test parameters were obtained in order to investigate and research hydrogen sulfide emissions. The tests were completed on average across two seasons, in accordance with the criteria in the standard operating procedure for testing water and wastewater (APHA, AWWA, WEF, 2012, 22nd).The case study includes 12 experiments, conducted over summer and winter in the year (2022). Each season saw the completion of six experiments or two each month on average. Moreover, two samples are taken for each experiment; one before the beginning of the main lines and one after the lift station. The COD, BOD, TSS, pH, temperature, oil and grease, SO4, and H2S(aq) values were measured from a sample taken before the beginning of the main lines and entered into the TOXCHEM model. The TOXCHEM model was then used to predict H2S(aq) values after the lift station. The average of these data represents the predicted value of hydrogen sulfide concentration for two seasons. Then the predicted values of H2S(aq) from the TOXCHEM model were compared with the actual measured values of hydrogen sulfide concentration for each season as shown in Table 1 and the operational conditions are listed in Table 2.

Table 1. Characteristics of wastwater .

Study diameter	*Parameter*	*Unit*	*TOXCHEM Default value*	*Validation Summer*	*Validation winter*
D-315 mm	Flow	m^3/d	50000	1200	1500
	Reach dimeter	Mm	2000	315	315
	Slope	%	0.1	0.4	0.4
	Length	M	1000	1000	1000
	Roughness coefficient	-	0.014	0.009	0.009
	Number of CSTRs	-	1	1	1
	Ventilation ratio	Q_g/Q_l	0.5	0.55	0.65
D-630 mm	Flow	m^3/d	50000	2800	3200
	Reach dimeter	Mm	2000	630	630
	Slope	%	0.1	0.16	0.16
	Length	M	1000	1000	1000
	Roughness coefficient	-	0.014	0.009	0.009
	Number of CSTRs	-	1	1	1
	Ventilation ratio	Q_g/Q_l	0.5	0.6	0.5
D-1000 mm	Flow	m^3/d	50000	19000	22000
	Reach dimeter	Mm	2000	1000	1000
	Slope	%	0.1	0.1	0.1
	Length	M	1000	1000	1000
	Roughness coefficient	-	0.014	0.009	0.009
	Number of CSTRs	-	1	1	1
	Ventilation ratio	Q_g/Q_l	0.5	0.6	0.5
Drop 315mm	Tail water depth	M	0.5	0.09	0.1
	Drop Height	M	1.0	0.9	0.9
	Stream width	M	0.5	0.28	0.29
	Sewer Ventilation Rate	m^3/hr	100	100	90
Drop 630 mm	Tail water depth	M	0.5	0.128	0.158
	Drop Height	M	1.0	0.37	0.37
	Stream width	M	0.5	0.53	0.55
	Sewer Ventilation Rate	m^3/hr	100	100	90
Lift Station	Flow	m^3/d	50000	23000	26700
	Filling Time	hr/ d	12	8	8

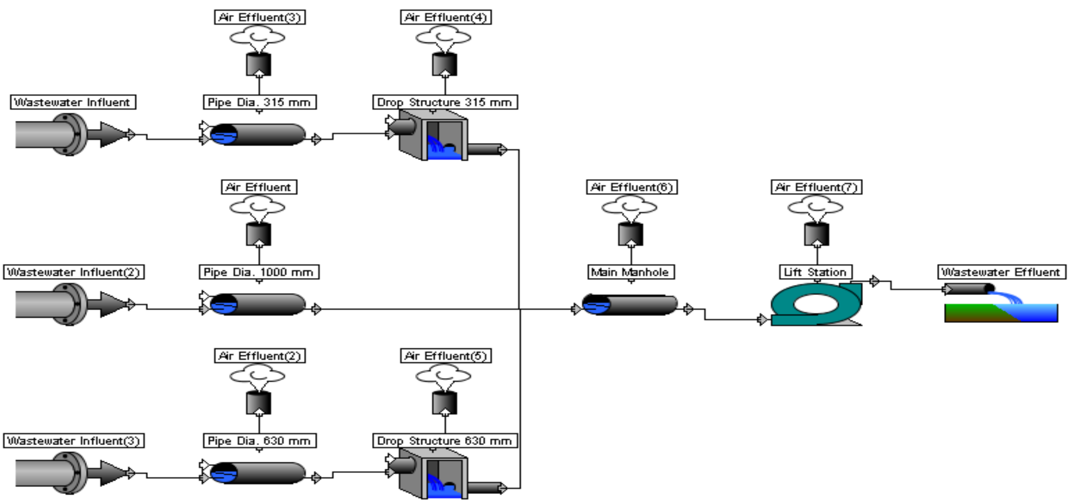
Table 2. Characteristics of network

Characteristics of wastewater	diameter of 315 mm	diameter of 630 mm	diameter of 1000 mm
Characteristics of wastewater of summer			
COD (mg/L)	320	327	420
BOD (mg/L)	180	187	250
TSS (mg/L)	167	160	220
pH (unitless)	6.8	6.8	6.8
Temperature (C°)	27	27	26
Oil & grease (mg/L)	27	27	31
SO_4 (mg/L)	500	600	700
H_2S (mg/L)	42	45	46
Characteristics of wastewater of winter			
COD (mg/L)	250	260	350
BOD (mg/L)	170	179	190
TSS (mg/L)	168	200	260
pH (unitless)	7	7.2	7
Temperature (C°)	17	18	17
Oil & grease (mg/L)	15	15	30
SO_4 (mg/L)	800	850	850
H_2S (mg/L)	33	33	34

2.3. Model development

In this study, the TOXCHEM V4.1 simulation was used to assess and study the emission of hydrogen sulfide gas in closed sewage networks in the Al-Hur district of the Karbala governorate during the summer and winter. The Toxchem program simultaneously solves the mass balance equations for each unit process in the treatment system in order to forecast the destiny and emission of the pollutants. Numerous process units that are frequently used in wastewater transportation, primary, secondary, and tertiary treatment are part of the Toxchem system. Along with the destiny and emission of harmful substances in lift stations, closed sewage networks, and open sewer networks. The pipes, manhole, and lift station of the study site are represented by the Toxchem model, as shown in Figure. 2

Figure 2. Study Site by TOXCHEM Model



2.4. Model validation

To ascertain how closely the actual outcomes match the projected results, validation is a crucial process. The Nash-Sutcliffe Efficiency, the root means square error (RMSE), the ratio of standard deviation, the mean absolute error, and the determination coefficient are only a few examples of statistical equations that can be used for this [10], All actual and forecast data were compared using the Chang and Hanna statistical parameters [11], to determine the accuracy of the data anticipated by TOXCHEM V4.1. The following equations demonstrate how the model was validated mathematically using RMSE and correlation coefficient (R):

$$R = \frac{\overline{(C_O - \overline{C_O})(C_P - \overline{C_P})}}{\sigma_{C_O}\sigma_{C_P}} \quad (1)$$

$$\text{RMSE} = \frac{\overline{(C_O - C_P)^2}}{\overline{C_O}\ \overline{C_P}} \quad (2)$$

Where:

Co mg/L is the actual data, $C_P\ mg/L$ is the modeled data, $\overline{C_O} mg/L$ is the average of actual data, and $\overline{C_P} mg/L$ is the average of modeled data, and σ is the standard deviation over the dataset.

The statistical criteria reasonable limits are $1 \geq R > 0.8$ and $0 \leq \text{RMSE} < 1.5$

2.5. Sensitivity analysis

Sensitivity analysis is one of many vital procedures to comprehend the impact of numerous operational parameters on the destiny and emission of H2S. The influencing factors on the emission of H2S in wastewater systems used in this investigation were wastewater characteristics including H2S loading rate, the flow rate, suspended solid, oil/grease, and temperature.

3 . The Experimental Al Results

3.1. Al-Hur city's general sewage characteristics.

The range for the average temperature that was measured was between 17 and 27 degrees Celsius, and Table 1 shows the general sewage quality. The high temperatures in the sewage of Al-Hur City increased the decomposition of organic substances in the network [12]. Due to the presence of suspended particles, which can occasionally approach 200 mg/L, the effluent is turbid. Wastewater effluent has a variety of chemical properties, both organic and inorganic. The amount of organic pollution in the wastewater for Al-Hur City is between 250 mg/L to 420 mg/L and 170 mg/L to 250 mg/L, respectively, according to COD and BOD measurements. Sulfate is transformed into hydrogen sulfide gas as a result of the high sulfate concentrations (500 mg/L to 850 mg/L) in the wastewater from Al-Hur City, the presence of organic materials, and the anaerobic conditions in the network. Hydrogen sulfide gas concentrations in wastewater from Al-Hur City can reach 33 mg/L in the winter and 46 mg/L in the summer. Not all of the hydrogen sulfide concentrations in the network were released since the pH of the effluent was close to 7. Between 15 mg/L and 31 mg/L of oil and grease are present in areas where the flow is stable. Figure. 3 and Figure. 4 show that all values in the summer are higher than they are in the winter, except for suspended solids, PH, and sulfates.

Figure 3. General Sewage Characteristics

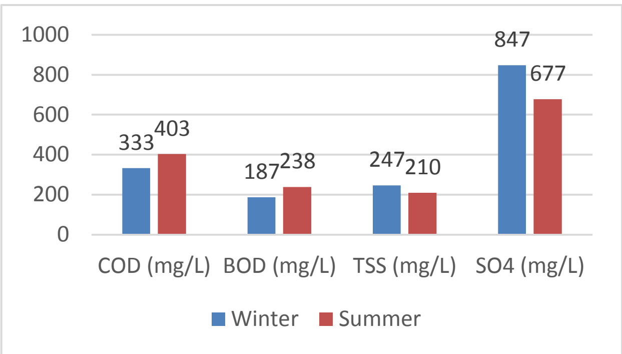
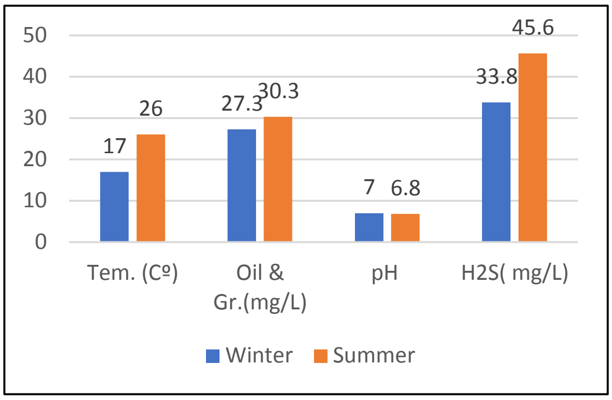


Figure 4. General sewage characteristics



3.2. Results validation

One of the finest models for predicting the fate and emission of volatile organic chemicals is the TOXCHEM model [13]. The network's H2S fate and emissions are simulated using the TOXCHEM V4.1 model. The model produced H2S fate (mg/L) and emission values (ppm) based on the inputs of influent characteristics and network operational circumstances. Model simulations were created based on these applied traits and operational variables and then compared to H2S analysis and dissolved H2S in effluent for the summer and winter seasons, as in the Figure.5 and Figure. 6. The effluent that was forecasted has been statistically validated, as shown in Table 3. In comparison, all of the data were verified within the parameters, and dataset RMSE and R were quite close to the perfect fit.

Figure 5. Comparison of Measured (x-axis) and Predicted (y-axis) H2S for Winter

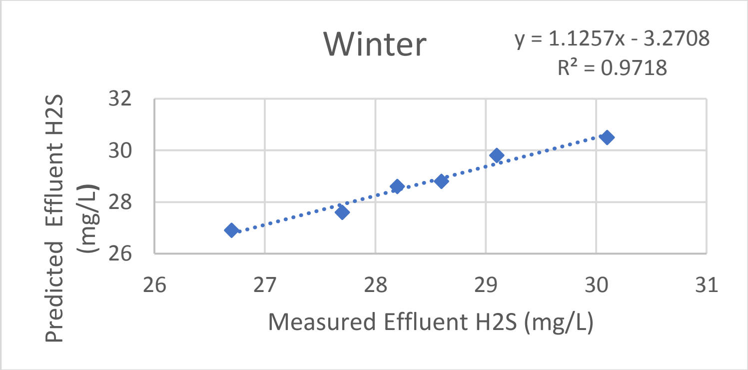
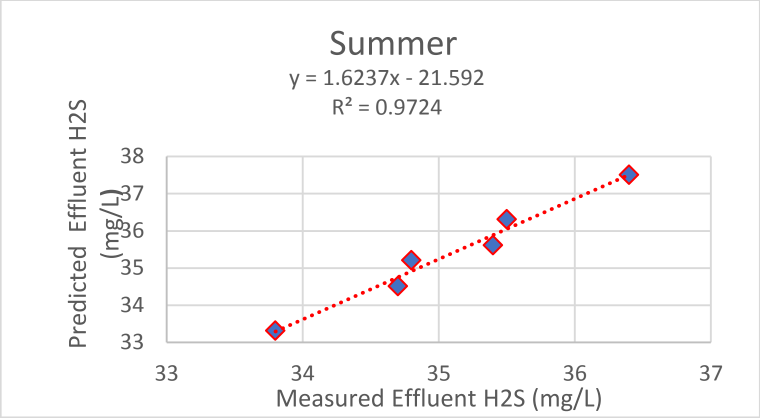


Figure 6. Comparison of Measured (x-axis) and Predicted (y-axis) H2S for Summer



Technium Vol. 19, pp.21-32 (2024)
ISSN: 2668-778X
www.techniumscience.com

Table 3. RMSE, R and R2 values after adjustment for Validation.

	Winter	*Summer*
RMSE	0.000184	0.000462
R	0.821	0.821

3.3. H2S fate and emission

Gaseous emissions from sewage networks, which also include odorants and greenhouse gases, are a source of emissions. Figure. 7 displays the H2S destiny (in %) for each section of the network. About 1000 kg of H2S is delivered to the research network each day. About 77 and 84%, and 22 and 15%, were determined to be discharged with wastewater and released into the atmosphere during summer (27 °C) and winter (17 °C), respectively as shown in Table 4 and Table 5. The findings showed that the main process going on is emission, where some of the H2S was released into the atmosphere by open surfaces' H2S stripping and vitalization.

Figure 7. Emission of H2S to Atmosphere from each part (%): (a) Winter and (b). Summer

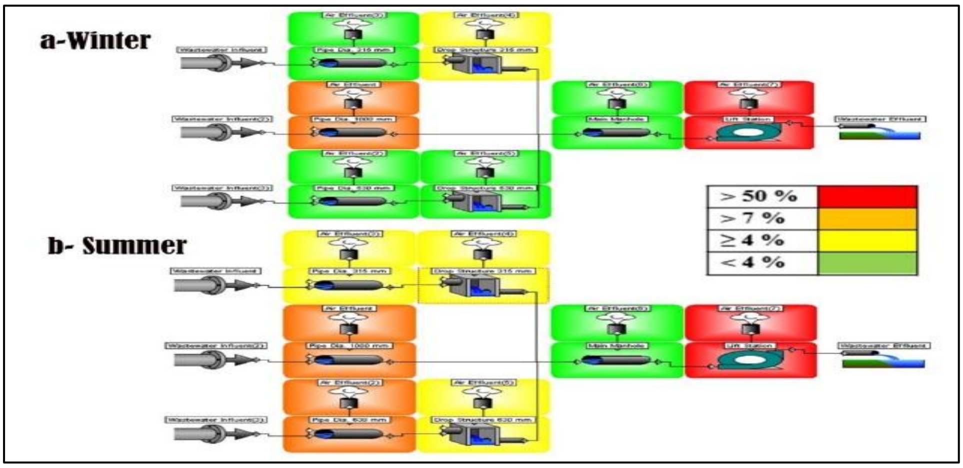


Table 4 and Table 5 present the predicted results from the TOXCHEM model for the summer and winter seasons, respectively. The process by which an odorant (H2S) is transmitted from a local source to the atmosphere is referred to as volatilization. Table 4 shows that about 232 kg/day (22%) of the research network's total H2S was volatilized to the atmosphere for the summer, and Table 5 shows that approximately 135 kg/day (15%) of the study network's total H2S was volatilized for the winter. The distribution of H2S emissions from each part is shown in Figure. 7 as a percentage of the overall emissions. The findings showed that summer had higher levels of H2S emissions than winter, with the majority of these emissions coming from lift stations (59% and 65%), followed by pipe 1000 mm (20.1% and 16%), pipe 630 mm (7.5% and 4.7%), drop 315 mm (4.1% and 5.3%), drop 630 mm (4.5% and 4.4%), pipe 315 mm (3.9% and 4.1%), and manhole (0.1% and 0.1%), for Summer and Winter, respectively.

Table 4. Predicted outcomes from TOXCHEM model of Summer

Part	*Unit*	*Incoming*	*To Air*	*To Wastewater*
Pipe 315 mm	g/d	50400	9064.36	41335.3
Pipe 1000 mm	g/d	874000	46835	827164
Pipe 630 mm	g/d	126000	17347.3	108652
Drop 315 mm	g/d	41335.3	9615.48	31719.8
Drop 630 mm	g/d	108652	10582.2	98069.9
Manhole	g/d	956954	142.369	956812
Lift Station	g/d	956812	139388	817423
Total	g/d	1050400	232975	817423
Total	%	100	22.18	77.82

TECHNIUM

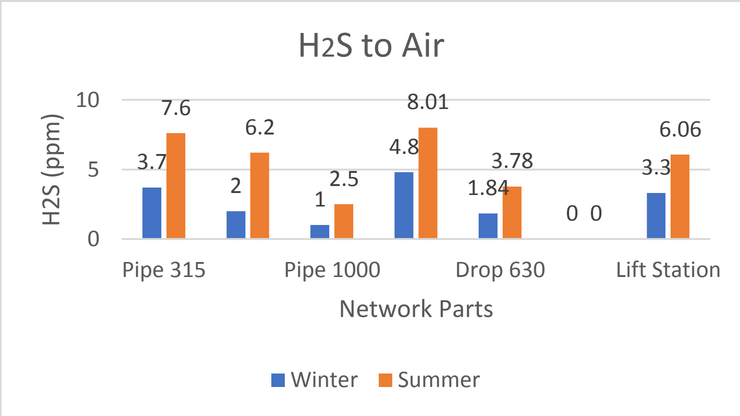
Technium Vol. 19, pp.21-32 (2024)
ISSN: 2668-778X
www.techniumscience.com

Table 5. Predicted Outcomes from TOXCHEM Model of Winter

Part	*Unit*	*Incoming*	*To Air*	*To Wastewater*
Pipe 315 mm	g/d	495000	5558.43	43941.4
Pipe 1000 mm	g/d	748000	21874	726126
Pipe 630 mm	g/d	105600	6377.21	99222.8
Drop 315 mm	g/d	43941.4	7209.71	36731.7
Drop 630 mm	g/d	99222.8	5896.99	93325.8
Manhole	g/d	856183	84.236	856099
Lift Station	g/d	856099	88476.9	767622
Total	g/d	903100	135477	767622
Total	%	100	15	85

Figure. 8 shows the concentration of H2S (ppm) emitted to the atmosphere from each part. At summer and winter, the total emission was 34.15 and 16.64 ppm, from the lift station were 6.04 and 3.3 ppm, from drop 315 mm were 8.01 and 4.8 ppm, from dop 630 mm were 3.78 and 1.84 ppm, from pipe 315 mm were 7.6 and 3.7 ppm, from pipe630 mm were 6.2 and 2 ppm, and from pipe 1000 mm were 2.5 and 1 ppm, respectively.

Figure 8. Emission of H2S to Atmosphere from each part (ppm) during Summer and Winter.



The results showed that, with the exception of the manhole, all sections had H2S emission levels that were higher than the human odor threshold (0.0005–1.5 ppm). Headache, nausea, and eye tearing may result from a long human exposure (8 h) to amounts more than 5 ppm (total emission in this investigation). Therefore, maintenance employees are at risk for health problems as a result of their exposure to high levels of H2S, which necessitated the installation of an odor control system (especially at pipe and drop 315 mm and lift station), a change in the way operations are carried out, or even a reduction in working hours.

3.4. Sensitivity analysis

The process of H2S emission in sewage networks is affected by many factors, such as the characteristics of wastewater including H2S loading rate, the flow rate, Suspended Solid, oil/grease, and temperature for the overall system, Figure. 9. shows the effect of dissolved H2S loading rate on the emission of hydrogen sulfide gas. When the dissolved H2S is at a loading rate of 16.5 mg/L, the emission of hydrogen sulfide gas in the network is 14.5 %, while if the dissolved H2S loading rate increases to 82.5 mg/L, the emission rate increases to reach 16.7%. The amount of aqueous H2S that can be released into the atmosphere or combined with wastewater increases as the dissolved H2S loading rate is increased.

Figure 9. Sensitivity Analysis of H2S Emission with Dissolved H2S.

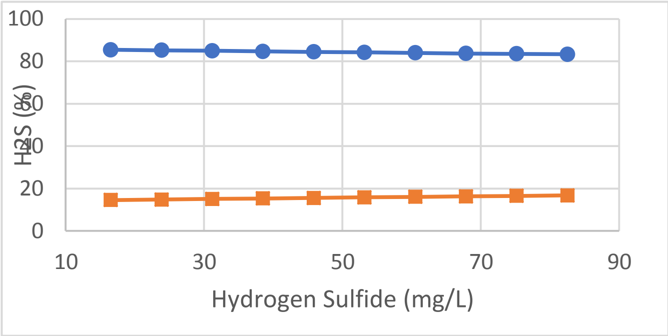


Figure. 10. shows the effect of flow rate on the emission of hydrogen sulfide gas. When the flow is at a discharge of 600 m3/d, the emission of hydrogen sulfide gas in the network is 21.6%, while if the discharge increases to 3000 m3/d, the emission rate increases to reach 23.24% for the overall system. Increasing the flow rate raises the network's flow velocity, and this velocity causes more stripping, which aids in the release of hydrogen sulfide gas.

Figure 10. Sensitivity Analysis of H_2S Emission with Flow Rate.

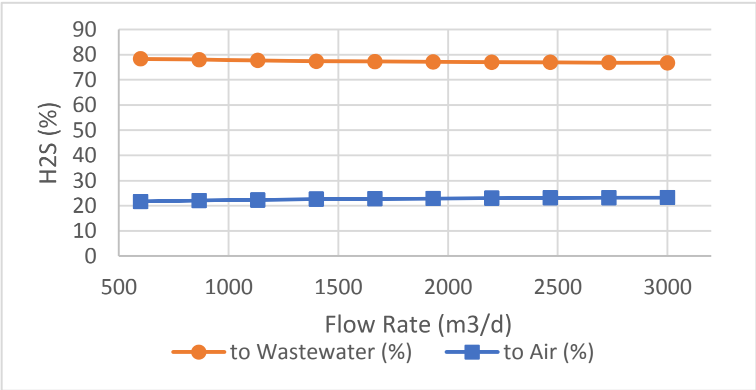


Figure 11 shows the effect of the Suspended Solid on the emission of hydrogen sulfide gas in the study network. It shows that at 83.5 mg/L the emission rate was 22.18% and when the Suspended Solid increased by 417 mg/L the emission rate also decreased to reach 22.15%. Another reason for the decline in emission is the rise in suspended solids concentrations. This concentration helps to absorb the gas, which results in a decline in emissions.

Figure 11. Sensitivity analysis of H2S emission with Suspended Solid.

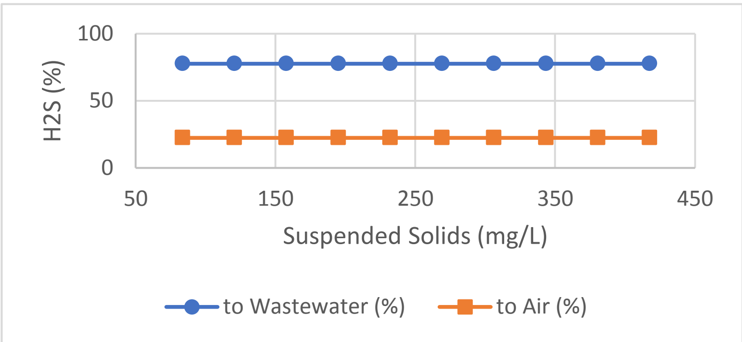


Figure 12 shows the effect of the Oil/Grease on the emission of hydrogen sulfide gas in the study network. It shows that at 13.5 mg/L the emission rate was 22.3927% and when the Oil/Grease increased by 67.5 mg/L the emission rate also decreased to reach 22.3908%. When oil/ grease is increased by 54mg/L, the emission will decrease by a very small percentage of 0.0019%. In locations where the flow is stable, a very thin coating of oil or grease accumulates on the surface of the sewage water, preventing the emission of hydrogen sulfide gas.

Figure 12. Sensitivity analysis of H_2S emission with Oil/Grease.

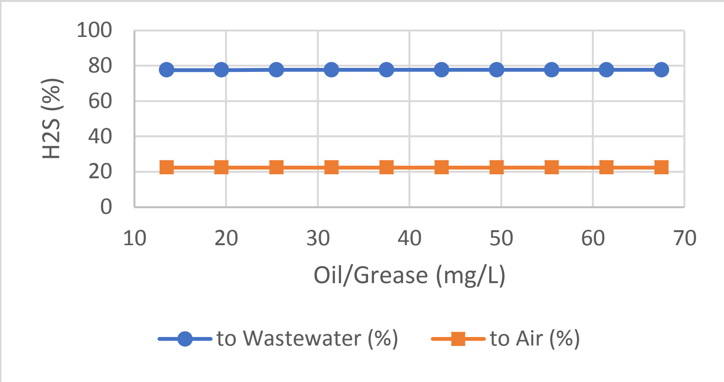
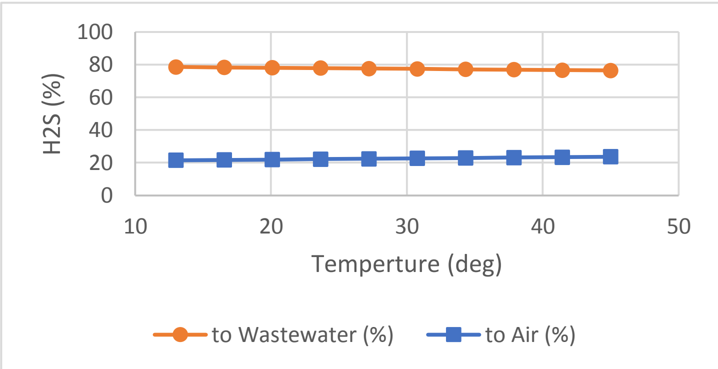


Figure 13 displays the effect of temperature on the emission and fate of hydrogen sulfide gas. At low temperatures of 13 C°, the emission rate is 21.48%, and at 45 C° the emission rate increases to 23.6%. It has been noted that as the temperature rises, emissions rise as a result of the reactions' increased speed, and hydrogen sulfide gas is discharged from the liquid phase into the gas phase.

Figure 13. Sensitivity analysis of H_2S emission with Temperature.



4. Conclusion

This study investigated the fate and emission of hydrogen sulfide in sewer systems in the Al-Hur neighbourhood of Karbala, which is located south of Baghdad, the capital of Iraq. All areas of the sewage network's spatial H2S emission were identified. The study's methodology was based on statistical analyses of data gathered over two seasons (winter and summer), as well as grab samples taken over a 12-day period from the study network's inlet and exit. The most significant factors of wastewater characteristics affecting hydrogen sulfide emission were the H2S loading rate, the flow rate, Suspended Solid, oil/grease, and temperature for the overall system. The temperature and H2S loading rate were major determinants of H2S emission in the study network, according to the TOXCHEM software, and temperature was found to be the most important characteristic. As a result of this study, the following conclusions were reached:

- The greatest emission of hydrogen sulfide occurs in summer up to twice as much due to the high temperatures (17 to 27) C, lower pH (7 to 6.8), and decreased flow (26700 to 23000) m3/d.
- Increasing the H2S loading rate, the flow rate, and the temperature of wastewater will raise the emission of hydrogen sulfide gas in the sewage network.
- Less hydrogen sulfide gas is released in the sewage network at higher Suspended Solid, and oil/grease concentrations.
- The results showed that all emissions in these networks are dangerous, especially in the summer when the emissions concentrations reach about 8 ppm, which are high and dangerous concentrations and cause health problems for the workers maintaining the sewage networks, it is necessary to use one of the control methods to reduce these emissions in the network.

The findings of this study will be useful in developing sewage odor control methods. To completely explain some of the reported occurrences, such as the H2S burst at several sites, more investigation is needed. Liquid field samples should also be collected and evaluated, together with sewage biofilm data, to learn more about the H2S synthesis process and its rates of emission.

Nomenclatures

C_{BT}	Boattail factor
D	Body diameter, m
x_{cp}	Centre-of-pressure location measured from the nose apex, m

Greek Symbols

α	Angle of attack, deg.
β	Mach number parameter, $\sqrt{M^2-1}$
θ	Semi-vertex angle of the conical nose (Fig. 1), rad.

Abbreviations

ISA	International Standard Atmosphere
JESTEC	Journal of Engineering Science and Technology
NACA	National Advisory Committee for Aeronautics
WHO	World Health Organization

References

[1] Habeeb, O. A., Kanthasamy, R., Ali, G. A. M., Sethupathi, S., & Yunus, R. B. M. (2017). Hydrogen sulfide emission sources, regulations, and removal techniques: a review. Reviews in Chemical Engineering, 34(6), 837–854. https://doi.org/10.1515/revce-2017-0004

[2] Zamani, M., Shafaghat, R., & Alizadeh Kharkeshi, B. (2023). Ex

[3] perimental Investigation on the Effect of Flow Rate and Load on the Hydrodynamic Behavior and Performance of an Archimedes Screw Turbine. International Journal of Engineering, 36(4), 733–745. https://doi.org/10.5829/ije.2023.36.04a.12

[4] Grengg, C., Mittermayr, F., Ukrainczyk, N., Koraimann, G., Kienesberger, S., & Dietzel, M. (2018). Advances in concrete materials for sewer systems affected by microbial induced concrete corrosion: A review. Water Research, 134, 341–352. https://doi.org/10.1016/j.watres.2018.01.043

[5] "Numerical Study of Water-air Ejector using Mixture and Two-phase Models," International Journal of Engineering, vol. 35, no. 2, pp. 307-318, 2022, doi: 10.5829/ije.2022.35.02b.06

[6] Hassan, W. H., Nile, B. K., & Al-Masody, B. A. (2017). Climate change effect on storm drainage networks by storm water management model. Environmental Engineering Research, 22(4), 393–400. https://doi.org/10.4491/eer.2017.036
[7] Salehi, R., & Chaiprapat, S. (2021). Predicting H2S emission from gravity sewer using an adaptive neuro-fuzzy inference system. Water Quality Research Journal, 57(1), 20–39. https://doi.org/10.2166/wqrj.2021.018
[8] Zuo, Z., Chang, J., Lu, Z., Wang, M., Lin, Y., Zheng, M., Zhu, D. Z., Yu, T., Huang, X., & Liu, Y. (2019). Hydrogen sulfide generation and emission in urban sanitary sewer in China: what factor plays the critical role? Environmental Science: Water Research & Technology, 5(5), 839–848. https://doi.org/10.1039/c8ew00617b
[9] Hamoda, M. F., & Alshalahi, S. F. (2021). Assessment of hydrogen sulfide emission in a wastewater pumping station. Environmental Monitoring and Assessment, 193(6). https://doi.org/10.1007/s10661-021-09116-9
[10] Guo, S., Qian, Y., Zhu, D. Z., Zhang, W., & Edwini-Bonsu, S. (2018). Effects of Drop Structures and Pump Station on Sewer Air Pressure and Hydrogen Sulfide: Field Investigation. Journal of Environmental Engineering, 144(3). https://doi.org/10.1061/(asce)ee.1943-7870.0001336
[11] Yang, Z., Zhu, D. Z., Yu, T., Edwini-Bonsu, S., Shypanski, A., & Liu, Y. (2020). Case study of H2S release and transport in a trunk sewer with drops. Water Science and Technology, 82(11), 2271–2281. https://doi.org/10.2166/wst.2020.475
[12] Zwain, H. M., Nile, B. K., Faris, A. M., Vakili, M., & Dahlan, I. (2020). Modelling of hydrogen sulfide fate and emissions in extended aeration sewage treatment plant using TOXCHEM simulations. Scientific Reports, 10(1). https://doi.org/10.1038/s41598-020-79395-8
[13] Hussein, A. O., Shahid, S., Basim, K. N., & Chelliapan, S. (2015). Modelling Stormwater Quality of an Arid Urban Catchment. Applied Mechanics and Materials, 735, 215–219. https://doi.org/10.4028/www.scientific.net/amm.735.215
[14] Chang, J. C., & Hanna, S. R. (2004). Air quality model performance evaluation. Meteorology and Atmospheric Physics, 87(1–3). https://doi.org/10.1007/s00703-003-0070-7
[15] Yang, Z., Zhu, D. Z., Yu, T., Edwini-Bonsu, S., & Liu, Y. (2019). Case study of sulfide generation and emission in sanitary sewer with drop structures and pump station. Water Science and Technology, 79(9), 1685–1694. https://doi.org/10.2166/wst.2019.164
[16] Behnami, A., Zoroufchi Benis, K., Shakerkhatibi, M., Derafshi, S., & Chavoshbashi, M. M. (2018). A systematic approach for selecting an optimal strategy for controlling VOCs emissions in a petrochemical wastewater treatment plant. Stochastic Environmental Research and Risk Assessment, 33(1), 13–29. https://doi.org/10.1007/s00477-018-1623-0