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ORIGINAL PAPER

Prediction of H_2S Production Rate in Sewer Systems Using the Z Model: A Case Study in Dehloran City, Iran

Rouhollah Shokri[1], Ehsan Derikvand[2], Amir Hossein Mahvi[3], Majid Hashemi[4], Shima Rezaei[5,✉]

1. Department of Environmental Health Engineering, Abadan School of Medical Sciences, Abadan, Iran
2. Department of Water Science, Shoushtar Branch, Islamic Azad University, Shoushtar, Iran
3. Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
4. Ph.D. of environmental Health Engineering, Kerman University of Medical Sciences, Kerman, Iran
5. Department of Environmental Health Engineering, Environmental Health Research Center, Research Institute for Health Development, Kurdistan University of Medical Sciences, Sanandaj, Iran

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ABSTRACT

Modeling of H_2S buildup in sewers is performed due to the health problems associated with the high concentration of H_2S, destruction of non-resistant structures in corrosion processes, and high costs of repairing corroded concrete sewer pipes. This analytical study aimed to predict the risk of H_2S production in the sewage collection network of Dehloran city, Iran using the Z model. In total, 11 main sewage lines with various diameters were selected for wastewater sampling. For each pipeline, two samples per month were collected and processed for the analysis of various parameters in order to determine the H_2S production based on the Z value. Biochemical oxygen demand, chemical oxygen demand, and SO_4^{-2} values in warm seasons were 117, 291, and 251 mg/l, while they were 101, 247, and 234 mg/l in cold seasons, respectively. In all the samples, the Z value was >13,000. In addition, the Z level was higher in warm seasons (Z value in guaranteed H_2S production category) compared to cold seasons (Z value in a large possibility of H_2S production category), which could be due to the high temperature and anaerobic decomposition of organic matter in summer. A significant correlation was also observed between the Z value in different seasons and various diameters of the sewers. Considering the high risk of H_2S production, it is recommended that proper scheming and planning be performed to eliminate this gas and prevent corrosion.

Keywords: Sewage Collection Network, Hydrogen Sulfide, Z Model

Introduction

In sewerage, total sulfide is present in three forms, including dissolved sulfide, metal sulfide, and elemental sulfur. Due to their precipitate form, metal sulfide and elemental sulfur are not involved in H_2S production, while dissolved sulfide participates in H_2S production. Total dissolved sulfide is the composition of sulfide, mono-hydrogen sulfide, and hydrogen sulfide.[1]

H_2S is a putrid gas with the characteristic odor of rotten eggs.[2, 3] This colorless, water-soluble gas is detrimental and generally exists in wastewater collection lines and sediment deposits, possessing various deteriorating properties, such as toxicity, corrosivity, flammability, and explosivity.[4] The threshold odor limit of H_2S is extremely low (0.011 mg/m^3), so that it causes bronchial constriction in asthmatic patients at the concentration 2.8 mg/m^3 and expanded eye complaints at 5 ppm. H_2S level of more than 140 mg/m^3 could cause olfactory paralysis, while an increased concentration of 560 mg/m^3 leads to respiratory distress. Furthermore, exposure to H_2S concentrations of greater than 700 mg/m^3 may be fatal.[5]

In sewerage mechanism, the transformation process links with sulfide levels include the generation, oxidation, emission, and precipitation of sulphide.[1] In partially filled gravity sewer pipelines, the generated H_2S is

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✉ *Shima Rezaei*
sh_rezaey@yahoo.com

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emitted to the gas phase by diffusion into the thin liquid film and absorption in the condensation layer of the exposed pipe surface.[2, 6, 7] In the next stage, the generation of H_2SO_4 occurs through biological and chemical oxidation, thereby subjecting pipeline structures to attacks by the interactions with corrodible compounds.[6, 7]

Hydrogen sulfide fate is defined as the precipitation of metal sulfides in wastewater due to the presence of metals such as copper, lead, and iron.[7] Several factors control the sewer process, including the wastewater flow, hydraulic retention times, turbulence, type of sewer pipes (pressurized/gravity), temperature, sewerage structure (shape and slope),wastewater quality, and properties of the biochemical processes occurring in wastewater.[1, 6]

In gravity lines, sulfides are generated under anaerobic conditions in *large-diameter pipes* through slow-*moving processes* at high temperatures and high residence times.[4, 6, 8-10] Evidence suggests that H_2S concentrations have increased to approximately 300 mg/m in gravity sewers.[3, 7]

Corrosion in the sewer network is considered to be a notorious challenge in sewer management across the world, which is associated with the great costs of sewage network repair. [11, 12] In a study, Nadafi et al. stated that corrosion effects were minimal at the H_2S concentrations of less than 0.005 ppm,[13] and total sulfide concentration of 0.1-0.5 mg/l led to the slight corrosion of concrete.[2, 7] Reports have indicated that the hydrogen sulfide level of >2 ppm is needed for severe concrete corrosion in the presence of high dissolved oxygen and relative humidity.[6, 14] Additionally, the powerful corrosion rates in the H_2S concentrations of 5-10 ppm have a great potential to occur.[15] Repair and maintenance of corroded pipes account for 10% of the costs of wastewater treatment.[7]

Sewer gas seeping is potentially toxic to the environment and causes health hazards to the community, especially sewer workers, who could be affected by breathing difficulties, eye and skin irritation, and even death.[1, 9] Exposure to H_2S in concentrations range of 100-200 ppm causes problems in the eyesight, coughing, and sense of smell within 2-15 minutes, as well as dizziness after 14-30 minutes.[10] Moreover, sewage effluent containing extreme sulfide contents is toxic to aquatic organisms, such as the fish.[4] Using chemical additives to limit H_2S production is one of the main sulfide control strategies, which is a costly technology.[11, 16]

Accurate and reliable predictions of sulfide generation is of paramount importance in the proper management of sewers, which affects the estimation of the dosages of chemicals, adoption of appropriate control strategies, design of gas treatment units, and evaluation of the overall service life of sewer pipes; therefore, such predictions are essential to the recognition of H_2S production routes.[9, 12, 14] Estimation of H_2S buildup in wastewater networks was first carried out in the 1950s.

Several empirical predictive models have been proposed for sulfide formation by various researchers, including Boon and Lister (1975), Pomeroy (1959),Pomeroy and Parkhurst (1977), and Thistlethwaite (1971).[14, 10] The mentioned empirical models have limitations in describing sulfide production. Among these models, the Z formula is considered to be more applicable and has been developed to analyze the variations during diurnal equilibrium. The testing of this model has yielded promising results about the concentration of hydrogen sulfide.[10]

The Z model for H_2S formation is affected by several parameters, such as wastewater discharge, concentrations of organic matters, and temperature. The present study aimed to apply the Z formula to investigate the risk of hydrogen sulfide production from municipal sewage conveyance systems in Dehloran city, located in Ilam, Iran.[3].

Materials and Methods

Overview of Study Region

Dehloran city is located in the southwest of Iran in Ilam province, covering an area of 6,674 square kilometers. This city is situated in a warm and dry climate.

The maximum and minimum temperatures are recorded to be 1 and 50.6°*C*, respectively. Gravity lines are used in the sewer systems of

Dehloran to collect and transport wastewater.

The city has only one hospital, the sewage of which is treated in a private wastewater treatment plant, and the effluent is discharged into the urban sewerage transfer network. In addition, Dehloran has a slaughterhouse located outside the city, and the slaughterhouse wastewater does not enter the sewer system. It is notable that Dehloran has no other industrial activities, and there are no industrial effluents in the gravity lines that carry wastewater.

The Z Formula

One of the objectives of the present study was to predict the risk of H_2S production based on the Z formula (as described in Equation 1) in the gravity sanitary sewer pipes designed with a different slope.

$$Z=\frac{3\cdot BOD_5\cdot 1.07^{(T-20)}}{\sqrt{S\cdot Q}}\cdot\frac{P}{b} \tag{1}$$

In Equation 1, BOD_5 is the five-day biochemical oxygen demand (g O_2/m^3), Q represents the wastewater discharge (l/s), T denotes the temperature (ºC), B is the width of the water surface (m), P shows the wetted perimeter (m), and S represents the pipe slope (o/oo). Arrangement of the production risk of H_2S in various lower and upper limits for the Z value is presented in Table 1.[10]

Table 1. Risk of H_2S Production in Gravity Sewers Based on Z Formula

Lower Limit< Z< Upper Limit	Risk Assessment
$0<Z<5000$	No risk
$5000<Z<10000$	Possible H_2S production
$10000<Z<25000$	The large possibility of $_2S$ production
$25000<Z<\infty$	Guaranteed H_2S production

Random sampling was performed twice per month for each pipeline. In total, 132 wastewater samples were collected from 11 sewer pipelines with various diameters, including 400 millimeters (three pipelines), 500 millimeters (three pipelines), 600 millimeters (three pipelines), and 800 millimeters (two pipelines). Sample collection was performed in warm and cold seasons, and the samples were transferred to the laboratory under standard conditions.

Various parameters were measured, such as the biochemical oxygen demand (BOD), chemical oxygen demand (COD), sulfate, sewage quantity, temperature, sewage height, and pH. Diameters and slopes of the sewers were obtained from the water and wastewater company. With the availability of the sewage height (h) and diameter of the pipes (D), wetted perimeter and surface width could be calculated in millimetres and filling percentage (h/D), respectively.

Data analysis was performed in SPSS using univariate analysis of variance for the basic data. After obtaining the historical data and various parameters from the field sites over a six-month monitoring period, the risk of H_2S production was specified based on the Z levels.

Results and Discussion

The H_2S emission resulting from very complex physical, biological, and chemical processes leads to problems such as bad odor, corrosion, and adverse health consequences.[1] Table 2 shows the data on the mean values of the measured variables, including wastewater discharge flow rate (Q) (l/s), pipe slope, filling percentage, wetted pipe perimeter, width of the water surface (b), and Z value. Furthermore, Table 2 presents the estimated mean values of all the parameters during the measurement period in the pipes with various diameters.

Reliable modeling of sulfide production in sewer systems provides valuable data for the managers of urban sewer systems.[9] As is shown in Table 1, the Z levels in warm and cold seasons were higher than 13,000 in the pipes with variable diameters (Figure 1). Therefore, it could be inferred that the risk of H_2S production is higher in warm seasons compared to cold seasons. The risk of H_2S production was under the ‘guaranteed H_2S production’ category in warm seasons, while it was under the ‘large possibility of H_2S production’ category in cold seasons.

Table 2. Estimated Mean Values of Different Parameters, Z Value, and Prediction of H_2S Production

	Season	Q (l/s)	S (0.00)	h/D	h (mm)	P (m)	b (m)	P/b	Z	H_2S production risk
D= 400 mm										
Pipeline No. 1	*Hot*	٨٥	٠,٠٠٦	٠,١٥	٦٠	٠,١٨٨	٠,١٨١	١,٠٣٨	٣٢٢٨٤	Guaranteed H_2S production
	Cold	٨٨	٠,٠٠٦	٠,١٦	٦٤	٠,٢	٠,١٩٢	١,٠٤٢	١٣٧٥١	Large possibility of H_2S production
Pipeline No. 2	*Hot*	٩٣	٠,٠٠٥٨	٠,١٧	٦٨	٠,٢١٣	٠,٢٠٣	١,٠٤	٣١٦٤٣	Guaranteed H_2S production
	Cold	٩١	٠,٠٠٥٨	٠,١٧	٦٨	٠,٢١٣	٠,٢٠٣	١,٠٤٨	١٣٨٣٠	Large possibility of H_2S production
Pipeline No. 3	*Hot*	٨٩	٠,٠٠٥٦	٠,١٦	٦٤	٠,٢	٠,١٩٢	١,٠٤١	٣٣١١٣	Guaranteed H_2S production
	Cold	٩٥	٠,٠٠٥٦	٠,١٨	٧٢	٠,٢٢٦	٠,٢١٤	١,٠٥٤	١٣٨٥٦	Large possibility of H_2S production
D= 500 mm										
Pipeline No. 4	*Hot*	٨٥	٠,٠٠٥	٠,١٤	٧٠	٠,٢١٩	٠,٢١٢	١,٠٣	٣٤٩٨٩	Guaranteed H_2S production
	Cold	٩٠	٠,٠٠٥	٠,١٧	٨٥	٠,٢٦٦	٠,٢٥٤	١,٠٤٨	١٤٩٧٨	Large possibility of H_2S production
Pipeline No. 5	*Hot*	٩١	٠,٠٠٤٨	٠,١٧	٨٥	٠,٢٦٦	٠,٢٥٤	١,٠٥	٣٦٧٣٩	Guaranteed H_2S production
	Cold	٨٨	٠,٠٠٤٨	٠,١٦	٨٠	٠,٢٥١	٠,٢٤	١,٠٤٢	١٥٣٧٤	Large possibility of H_2S production
Pipeline No. 6	*Hot*	٨٨	٠,٠٠٤٧	٠,١٦	٨٠	٠,٢٥١	٠,٢٤	١,٠٤٢	٣٦٤٥٩	Guaranteed H_2S production
	Cold	٩٠	٠,٠٠٤٧	٠,١٨	٩٠	٠,٢٨٢	٠,٢٦٧	١,٠٥٤	١٥٥٣٩	Large possibility of H_2S production
D= 600 mm										
Pipeline No. 7	*Hot*	٩٤	٠,٠٠٤	٠,١٧	١٠٢	٠,٣٢	٠,٣	١,٠٤٩	٣٨٠٣٥	Guaranteed H_2S production
	Cold	٩٧	٠,٠٠٤	٠,١٨	١٠٨	٠,٣٣٩	٠,٣٢١	١,٠٥٤	١٦٢٢٥	Large possibility of H_2S production
Pipeline No. 8	*Hot*	٩٨,٥	٠,٠٠٣٨	٠,١٩	١١٤	٠,٣٥٧	٠,٣٣٧	١,٠٦١	٣٨٤٧٠	Guaranteed H_2S production
	Cold	٩٩	٠,٠٠٣٨	٠,١٩	١١٤	٠,٣٥٧	٠,٣٣٧	١,٠٦١	١٦٥٨١	Large possibility of H_2S production
Pipeline No. 9	*Hot*	٨٨,٦	٠,٠٠٣٧	٠,١٦	٩٦	٠,٣٠١	٠,٢٨٩	١,٠٤١	٤٠٤٧١	Guaranteed H_2S production
	Cold	٩٠	٠,٠٠٣٧	٠,١٧	١٠٢	٠,٣٢	٠,٣٠٥	١,٠٤٨	١٧٤١١	Large possibility of H_2S production
D= 800 mm										
Pipeline No. 10	*Hot*	١٥٥	٠,٠٠٣	٠,١٨	١٤٤	٠,٤٥٢	٠,٤٢٨	١,٠٥٦	٣٤٣٧١	Guaranteed H_2S production
	Cold	١٦٢	٠,٠٠٣	٠,٢	١٦٠	٠,٥٠٢	٠,٤٧	١,٠٦٨	١٤٧٠٩	Large possibility of H_2S production
Pipeline No. 11	*Hot*	١٥٦,١	٠,٠٠٢٧	٠,١٩	١٥٢	٠,٤٧٧	٠,٤٤٩	١,٠٦٢	٣٦٢٥٣	Guaranteed H_2S production
	Cold	١٥٧	٠,٠٠٢٧	٠,١٩	١٥٢	٠,٤٧٧	٠,٤٤٩	١,٠٦٢	١٦٠٨٩	Large possibility of H_2S production

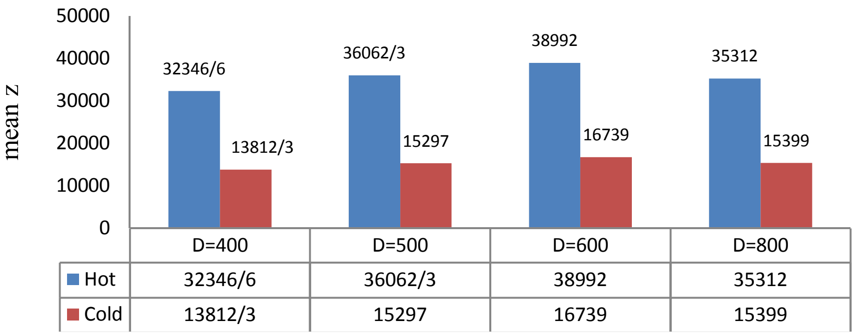

Fig. 1. Mean Z Value in Warm and Cold Seasons in Different Diameters of Pipes (D)

Due to the aforementioned changes in the wastewater composition, sulfide production kinetics is often affected by the presence of electron acceptors (oxygen) and soluble electron donors (organic matters), sulfate concentrations, temperature, and velocity of wastewater flow.[14, 17] In addition, the conditions that promote biofilm growth, solid settling, and septicity are of great importance for the total generation of sulfide.[14]

Field investigations have yielded clear evidence that BOD and COD values are undoubtedly the key influential factors in H_2S production in sewers. According to the current research, BOD, COD, and SO_4^{-2} values in warm seasons were 117, 291, and 251 mg/l, while they were 101, 247, and 234 mg/l in cold seasons, respectively.

In the present study, wastewater contained small quantities of BOD, which was an indicator of the low levels of organic materials. In addition, lack of manufacturing and industrial processes in Dehloran city was associated with the absence of industrial wastewater in sewage collection pipes. In a study in this regard, Pomeroy et al. confirmed that BOD_5, wastewater temperature, slope of sewage pipes, h/D, and flow rate affected the buildup of H_2S and corrosion.[10] Moreover, the main source of sulfur was reported to be sulfate (SO_4^{2-}) in domestic wastewater.[7]

In the present study, the highest rate of H_2S production in wastewater was attributed to food industries, while the wastewater from mixed municipal and industrial (food) sources had an average rank, and typical domestic wastewater with slight/no contents of industrial sewage had the lowest production rate.[10] Figure 2 depicts the variations in the Z level due to the changes in various parameters in different seasons and pipelines.

The results of the present study indicated that the risk of H_2S production increased with increasing temperature and organic loading (BOD_5). Additionally, increased filling percentage and discharge flow rate (l/s) in the sewage pipelines was associated with the decreased possibility of H_2S production in warm and cold seasons. Therefore, it could be concluded that the possibility of hydrogen sulfide production was inversely proportional to the filling percentage and quantity of the sewage and directly proportional to temperature and BOD_5. Moreover, a significant difference was observed in the Z value in different seasons ($P<0.001$) and different sewer diameters ($P<0.001$). Since the value obtained for the adjusted R-squared was higher than 0.7 and close to one. Therefore, it could be concluded that more than 90% of the variations in the Z value depended on the season and D (adjusted R-squared=0.994).

Temperature plays a pivotal role in the emission rate of H_2S from the liquid to the gas phase. In the current research, the temperature in two seasons in Dehroran city was 30.2 and 20 ºC, respectively. In this regard, Joseph et al. have confirmed the specific influence of temperature and relative humidity.[12] In addition, Sharma et al. have reported that high organic and sulfate concentrations increase the temperature and sewage age conducive to sulfide generation.[14] At high temperatures, the biological activity in the sediment rises in sewer networks.[7] Baumgartner et al. have suggested that sulfide production is discontinued at the temperatures below 7ºC, and the highest sulfide production rate occurs at the temperature of 30ºC. High temperature increases H_2S solubility, so that the H_2S emissions increase by 7% per each 1ºC of temperature increment.[18]

Fig. 1. Variations in Z Level Due to Changes in Several Parameters in Warm and Cold Seasons and Various Pipelines (*a:* different Q [l/s], *b:* different S, *c:* different h/D, *d:* different P/b)

Pipe diameter is another key factor to control H_2S generation. Principally, the sulfide generation in small diameters appears in the biofilm on the pipe walls, while the anaerobic activity in the bulk liquid in large-diameter sewers greatly influences H_2S production.[10] In a study, Alani et al. proposed a model using a novel data-driven technique, known as evolutionary polynomial regression, which encompasses the most effective parameters in the sulfide formation problem. In the mentioned research, the effects of each contributing parameter to sulfide formation were evaluated using the extended sensitivity analysis. The results demonstrated that while sulfide formation grows by increasing COD, temperature, retention time and/or flow velocity, sewer diameter has an inverse impact on sulfide buildup.[19]

In the current research, mean pH was 7.34 in the warm and cold seasons. In wastewater, pH is normally within the range of 6.6-7.2, where the chemical equilibrium between H_2S and HS^- is extremely sensitive. In other words, acidity (pH) plays a key role in the concentrations of H_2S and HS^- in sewage collection networks. At the pH of 7, the amount of sulfide ions and dissolved H_2S are equal, while at lower pH, the H_2S production rate and H_2S transfer rate to the gas phase increase.

Conclusion

Investigation of the *H_2S production risk* in the sewage collection network of Dehloran city (Iran) indicated the high level of Z. The Z level in all the samples was more than 13,000, while the Z value was higher in warm seasons compared to cold seasons. Therefore, the corrosion potential was relatively high in the studied sewage pipe network. According to the findings, quantitative and qualitative parameters, such as the concentrations of sulfate and organic matters, temperature, sewage pH, flow velocity, and surface area of the pipe, had significant effects on the buildup of H_2S based on the Z formula. Furthermore, the rate of H_2S production in the wastewater of food industries had the highest rate. Due to the high costs of the rehabilitation and replacement of damaged sewers, management practices based on the estimation of H_2S concentration are essential.

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