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Treatment of Hazardous Gases Generated by Sewage Collection Systems

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ABSTRACT

Sewage system odor management is a serious issue for the environment and human health. Hydrogen sulfide (H_2S) gas, which is formed physiologically in anaerobic environments, is one of the main causes of unpleasant odor. In addition to producing disagreeable smells and health problems, H_2S severely corrodes sewage pipelines, posing technical and financial difficulties for wastewater infrastructure. The majority of traditional odor control techniques concentrate on treating H_2S after it has been released. By focusing on the microbial method of production, we hoped to stop H_2S creation prior to its release. When sulfate is used as an electron acceptor during metabolism by sulfate-reducing bacteria (SRB), bisulfide ions (HS^-) are produced. These ions then mix with hydrogen ions to form H_2S gas. We applied sodium nitrate ($NaNO_3$) to the sewage collecting system in order to interfere with this mechanism. As a substitute electron acceptor, nitrate inhibits sulfate reduction and supplies oxygen in a chemically bonded state. Following nitrate addition, experimental findings showed a considerable drop in H_2S levels, indicating its efficacy in lowering corrosion and odor hazards. With the H_2S content falling from 132 ppm to 13 ppm during three weeks of treatment, the findings demonstrated a 97% removal rate, demonstrating the efficacy of adding sodium nitrate in odor control and corrosion reduction in drain pipes.The plant-level findings demonstrated that nitrate-fed biological treatment is a practical and sustainable substitute for managing odor and sulfur in municipal wastewater. The denitrification–sulfide oxidation mechanism shown at laboratory size is validated by the steady decrease in H_2S, quick nitrate consumption, and sulfate formation, demonstrating that the procedure may be effectively scaled up for practical uses.

Keywords: Hydrogen sulfide, Sulfate-reducing bacteria, Bad odor, Sewage, Nitrate treatment, Corrosion control

INTRODUCTION

The anaerobic metabolic action of sulfate-reducing bacteria (SRB) produces hydrogen sulfide (H_2S), a poisonous and corrosive gas that is frequently found in sewage collecting systems. These microbes produce sulfide ions (HS^-) by using sulfate as a terminal electron acceptor. These ions then mix with hydrogen ions to generate H_2S gas. Significant technical and financial losses result from the presence of H_2S in wastewater infrastructure for a number of reasons, including the production of an offensive and strong stench, occupational health risks, and severe biogenic corrosion of concrete and metallic sewage pipes. (Nielsen et al., 2005; Zhang et al., 2009).

Most odor management methods have historically concentrated on treating H_2S after it has been released, such as via chemical cleaning, adsorption on activated carbon, or dosing iron salts to precipitate sulfide. Though these approaches may be useful in lowering odor emissions, they are insufficient to stop the microbial synthesis of sulfide at its origin. As a result, the problem of H_2S re-emergence remains, and infrastructure damage continues(Jiang et al., 2013).

Incorporating nitrate to sewage collecting systems is an alternate preventative measure. As an alternate electron acceptor, nitrate offers a pathway for microbial respiration that is more energetically advantageous than sulfate. Nitrate addition efficiently inhibits SRB activity by promoting the activity of denitrifying and nitrate-reducing bacteria, which lowers the generation of H_2S prior to its release (van den Brand et al., 2014). Nitrate dosage has been demonstrated to lessen sulfide-induced corrosion in addition to controlling odors, providing advantages for the environment and the economy. The efficiency of sodium nitrate ($NaNO_3$) in lowering H_2S levels in sewage is examined in this study. We intend to assess the possibility of nitrate dosing as a preventative approach for odor and corrosion control in wastewater collecting systems by tracking H_2S concentrations during a three-week treatment period.

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2. Materials and Methods

2.1 Gathering and Getting Ready Samples : The sewage water was removed and then transferred into one-liter bottles. in order to calculate the quantity of hydrogen sulfide based on weight and estimate the amount of gas generated.

Finding Gas

The gas was found using two techniques: 1. A. Using a detector for hydrogen sulphide.

B. The method for determining the weight of hydrogen sulfide (Zumdahl, S.S. 2009). This strategy includes: Preparing the Solution

1. Getting 1N NaOH ready

40% sodium hydroxide should be dissolved in one liter of distilled water.

2. Prepare 20% CH3COO2Zn, or zinc acetate.

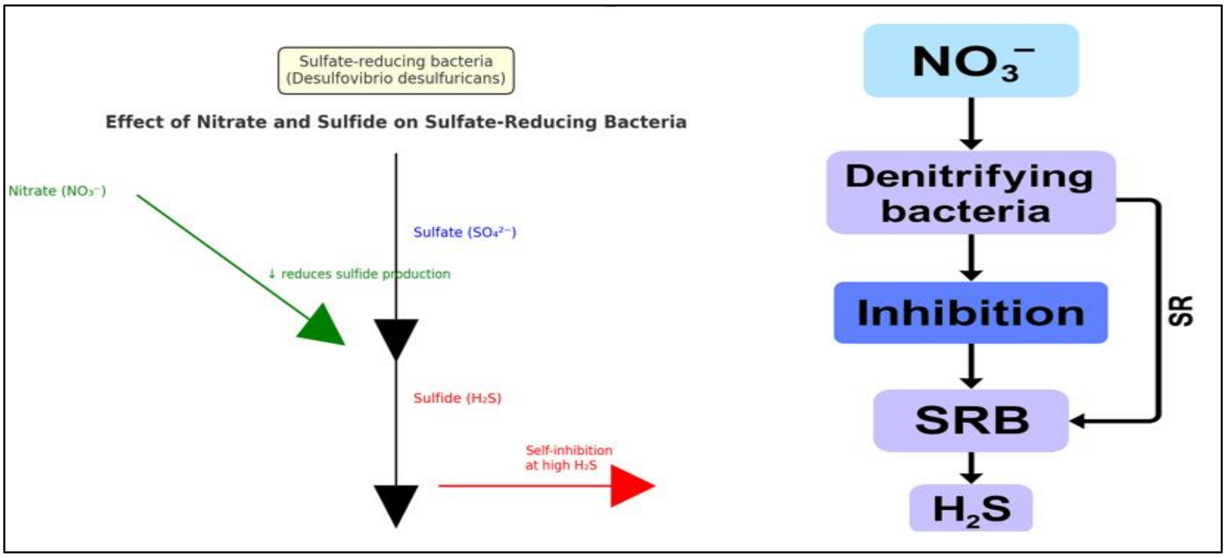

Figure 1 Bacterial activity on reducing H2S and microbial Interaction

It is necessary to dissolve 20 grams of zinc acetate in 100 milliliters of filtered water. Protocol for the field: Mix 4 grams of zinc acetate with 1 milliliter of the sodium hydroxide that was previously prepared. After that, securely seal a 100 ml container after adding 100 ml of the required sample. This is the response that takes place:

The weight of the precipitate is compared to the molecular weight (molecule ratio) to determine the total quantity of hydrogen sulfide. To achieve this, first use the filter paper's weight difference measurement to determine the weight of the precipitate (w) ZnS in parts per million (ppm).

Calculation

$$\frac{S}{MW} = \frac{ZnS}{\mathrm{MW}}) \ldots\ldots\ldots\ldots\ldots \quad 1($$

Following the substitution of the molecular weights of sulfur and zinc sulfate, as well as the weight of zinc (W),

$$= \frac{\mathrm{X}}{32} \qquad \frac{W}{97.4}$$

After multiplying two sums to determine the value of X,

$$= \frac{\mathrm{S}}{\mathrm{MW}} \frac{H2S}{\mathrm{MW}}$$

The value of H2S is obtained by inserting the molecular weight values of sulfur and hydrogen sulfide, as well as the value of sulfur from equation (1).

district of Iraq's Baghdad. The primary sewage drainage system, which includes this basin, carries wastewater to a municipal treatment facility via pipelines. A pilot-scale, one-cubic-meter reinforced polyethylene tank was filled with around 0.5 cubic meters of effluent.

2. 2 System-wide experience

. To replicate regulated bioreactor conditions, the tank was outfitted with the following parts: In order to guarantee even mixing and oxygen-free conditions, the internal mixer uses a mechanical impeller that runs at 60 rpm.

. The nitrate dosing pump is a programmed peristaltic pump that is used to inject sodium nitrate (or nitrate solution) at predetermined intervals.

. Multiple sampling ports were installed to collect liquid samples and test nitrate (NO_3^-) and sulfate (SO_4^{2-}) contents.

· Sensors: Online probes were set up to continually check the concentration of hydrogen sulfide (H_2S) in the liquid and headspace phases, as well as pH and temperature.

In order to reduce gas exchange with the environment and preserve anoxic conditions that support denitrifying action, the entire system was covered.

2.3. Operational Conditions

The ·
reactor was continually monitored for 21 days in a row during the experiment. Among the important operational conditions were:

· Working volume: 0.5 m³ of wastewater · Ambient temperature: 30 ± 2 °C (insulated)

Initial pH: 7.0 ± 0.1 ·

60 rpm is the mixing speed (slow mixing to prevent gas stripping).

21 days is the retention period (batch mode).

2.4. **Nitrate Feeding Strategy**

The oxidizing agent, sodium nitrate ($NaNO_3$), was provided by nitrate.

The starting dosage is 10 mg/L of nitrate-N.

Using a dosing pump to provide brief pulses every two hours was the injection approach.

Distribution: To guarantee even nitrate dispersion throughout the tank, the mixture was gently agitated following each pulse.

Supplementation: In accordance with concentration monitoring, more nitrate was supplied as required. This pulsed feeding approach was designed to maintain active denitrifying conditions while avoiding nitrate accumulation.

2.5. Monitoring and Sampling Procedure

To examine variations in chemical and physical characteristics, samples were taken on a regular basis.

Each experimental condition was performed in triplicate (n = 3). The reported data represent the mean ± standard deviation (SD). Standard deviation values were within ±5% of the mean, confirming the reproducibility of the results.

3. Results and discussion

Considering the pervasive problem of offensive odors from wastewater treatment facilities, it is important to comprehend the exact measurements of H_2S. However, foul odors from wastewater treatment facilities are common, and the causes and solutions are typically complex. Municipal systems are held accountable in certain places, while private businesses such as manufacturing and food processing facilities are held accountable in others. Hydrogen sulfide gas was found in a detector and gas estimator for sewage samples taken from sewage tanks, in 1-liter glass beakers, and in a 500-liter treatment tank in order to build a miniature model of sewage tanks at sewage treatment facilities.

The gas percentage was 81 ppm at the start of the experiment (time = zero), and the equipment was unable to detect any more. The results indicated a considerable decrease when sodium nitrate was added at ratios of (0.1, 0.25, 0.5, 0.75,1, 1.5, 2, 2.5) g/100 ml; the best result was obtained at a ratio of 0.75% (g/100 ml).

Table No. (1) The impact of employing varying sodium nitrate concentrations on the production of hydrogen sulfate gas

Concentration of the additive: Sodium nitrate 100ml/(gm)	**H2S gas concentration (ppm)**	
0.0		81
0.1		77
0.25		70
0.5		10
0.75		0
1.0		0
1.25		0
1.5		0
1.75		0
2.0		0

The rate of removal: Table 1 shows the quantities of sodium nitrate (gm/100 ml) added to sewage and the anticipated ppm decrease in H2S emissions. It is anticipated that nitrogen fertilizers will increase the concentrations of hydrogen sulfide (H_2S) around sharp edges.The quantities of H_2S were substantial (about 85 ppm) in the absence of nitrate, but they drastically dropped to almost nil at concentrations of 0.3–0.5 g/100 ml. This suggests that sodium nitrate greatly inhibits the formation of H_2S, and that the ideal dosage is adequate to accomplish the desired effect without requiring further increases. The reason for this decrease is that sodium nitrate acts as an alternative electron acceptor in the anaerobic environment, as nitrate-reducing bacteria grow better when nitrate is available, which reduces the activity of sulfate-reducing bacteria, which are the main source of H_2S production. This causes the production of hydrogen sulfide to stop or decrease (2) demonstrated that adding nitrate to wastewater treatment systems leads to a rapid decrease in H_2S concentrations due to the stimulation of nitrate-consuming bacteria (3) demonstrated that nitrate is more efficient than oxygen at inhibiting the activity of sulfate-reducing bacteria.

Since H_2S concentrations maintained approximately at zero, adding more citrate than this did not decrease biodiversity. The odors generated at wastewater treatment plants are sometimes comparable to those of ammonia, rotten eggs, and other organic compounds. Odors are usually caused by the anaerobic decomposition of organic molecules. The strong smell most people associate with these facilities is caused by hydrogen sulfide, a consequence of decomposition. Scents are also caused by sulfur-rich compounds known as amines and mercaptans. The current results are congruent with experiments conducted in the oil and gas sector, which have demonstrated that nitrate injection considerably lowers corrosion induced by H_2S.

Since H_2S production is successfully inhibited by sodium nitrate at the right concentration, the current results are therefore generally in line with earlier research. The stimulation of nitrate-reducing bacteria, which outcompete sulfate-reducing bacteria (the primary producers of H_2S) in anoxic environments, can account for this impact. Since nitrate is a better terminal electron acceptor than sulfate, the microbial population moves toward denitrification pathways, which inhibits the production of sulfide.

These results are in accordance with previous research that showed that nitrate efficiently inhibits the production of sulfides in wastewater systems by promoting the development of bacteria that reduce nitrate (4). Similarly, nitrate addition dramatically reduces sulfate-reducing activity because of competing microbial interactions, according to (5). Nitrate injection also reduces H_2S generation and related corrosion issues, corresponding to field tests in the oil and gas sector.

The simulations displayed that in the untreated model, the weight of hydrogen sulfide, which represents the precipitated hydrogen sulfide, was 132 ppm. When nitrate was administered after three weeks of the experiment, the weight of hydrogen sulfide decreased to 13, suggesting a 97% clearance rate. This is due to a significant decrease in its production brought on by a change in the biological metabolism of the microbial system in the sewage environment.It is added at a rate of 0.75% g/100 ml.Removal ratio =132-13×100≈97%. This suggests that sulfate-reducing bacteria (SRB) activity was effectively reduced and H_2S synthesis was restricted prior to release by employing nitrate as an alternate electron source. The study's findings show how well sodium nitrate ($NaNO_3$) works to prevent hydrogen sulfide (H_2S) from forming in sewage systems. This result demonstrates that sulfate-reducing bacteria (SRB), the main microbes that produce H_2S in anaerobic settings, may be considerably inhibited by nitrate addition.

Table No. (2) Effect of optimal nitrate concentration on reducing in itial H_2S levels over time

Nitrate Concentration (g/100 ml)	Operation Time (days)	Initial H_2S (ppm)	Final H_2S (ppm)
0.75	0	132	132
	7	132	70
	14	132	10
	21	132	13

Microbial competition for electron acceptors is the fundamental process. SRB use sulfate as a terminal electron acceptor during metabolism in normal anaerobic circumstances, generating sulfide ions (HS^-), which then mix with hydrogen ions to create H_2S. Denitrifying and nitrate-reducing bacteria outcompete SRB by adding nitrate, a different and more energetically advantageous electron acceptor, which shifts microbial metabolism away from sulfate reduction. The observed drop in H_2S levels can be clarified through this redox shift.

Comparable outcomes were found in a number of earlier investigations, when nitrate dosing successfully decreased sulfide formation in anaerobic digesters and wastewater collecting systems. Nitrate treatment has been demonstrated to reduce biogenic sulfide corrosion of concrete sewer infrastructure in addition to odor control (6), which is advantageous from a technical and financial standpoint. Nitrate addition prevents H_2S from being released after emission, addressing the issue at its microbiological source in contrast to traditional post-release treatments (e.g., chemical cleaning, iron salts, or activated carbon) (7).Operational factors, however, need to be considered. Nitrate dose needs to be carefully considered since too much nitrate might have unneeded expenses and possible negative effects later on, including an elevated nitrogen load, while too little nitrate may not completely inhibit SRB activity (8). Furthermore, more research is needed to guarantee sustainable odor and corrosion control by examining the long-term stability of microbial populations under nitrate treatment (9). In conclusion, nitrate addition was quite successful in this trial, lowering H_2S by 97% in just three weeks. With major advantages for the environment, human health, and the economy, this method presents a viable preventative strategy for managing corrosion and odor in sewage systems.

Discussion of Plant-Level Experiment Results

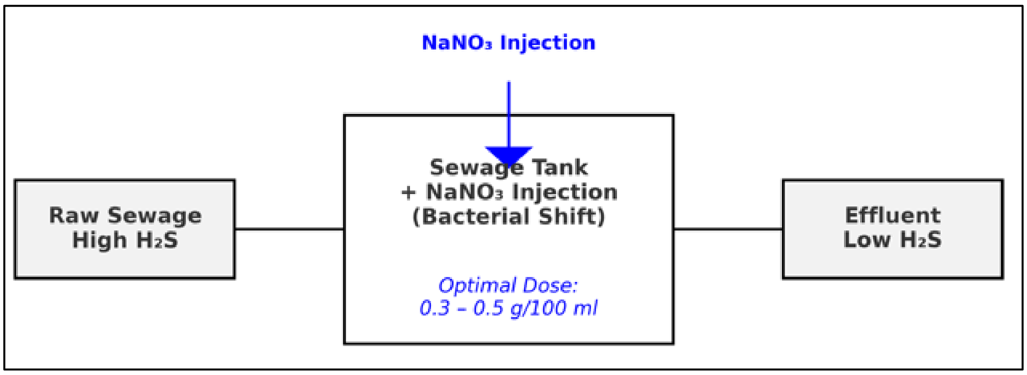

Figure 2 Plant-Level Experiment

Flow diagram :$NaNO_3$ effect on H_2S reduction

1. Reduction of Hydrogen Sulfide (H_2S)

Over the course of the 21-day monitoring period, the results (Figure 3) showed a noticeable and ongoing decline in the concentration of hydrogen sulfide (H_2S). The high initial H_2S levels (about 25 mg L^{-1}) were indicative of the usual buildup of sulfides in anaerobic municipal sewage. After starting nitrate dosage, there was a sharp drop that ended up being less than 3 mg L^{-1} at the conclusion of the trial, which is equivalent to around 90% elimination effectiveness.

Thiobacillus denitrificans and Pseudomonas stutzeri are examples of denitrifying sulfide-oxidizing bacteria (DSOB) that use nitrate as an electron acceptor to oxidize H_2S into sulfate, and this reduction validates their activity. Since mixing and temperature were constant, the near-exponential decline pattern suggests that biological oxidation rather than chemical stripping was the predominant process.

2. Nitrate (NO_3^-) Consumption Pattern

A "saw-tooth" pattern of concentration was created over time by the pulsed nitrate-feeding profile (Figure 4). After each nitrate injection (≈ 10 mg L^{-1}), there was a sharp drop to < 2 mg L^{-1} in a matter of hours. Rapid biological nitrate absorption and conversion to nitrogen gas (denitrification) is confirmed by this pattern.There is no indication of nitrate accumulation or inhibition, and the repeated cycles of consumption point to ongoing microbial activity. This implies that modest, frequent pulses were the best dosing method for sustaining active denitrification while avoiding extreme oxidizing conditions that would inhibit heterotrophic or sulfate-reducing populations (10).The microbial mechanism involves competition between sulfate-reducing bacteria (SRB) and nitrate-reducing bacteria (NRB). When nitrate is available, NRB use it as a more favorable electron acceptor, which suppresses SRB activity. This process decreases H_2S formation and increases sulfate (SO_4^{2-}) production.

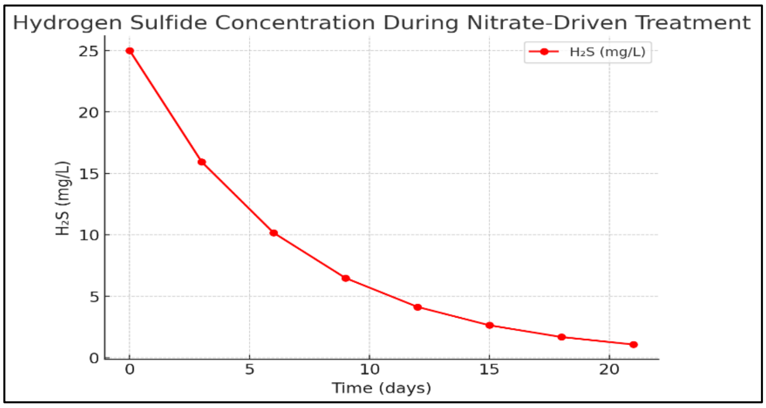

Figure 3 Hydrogen Sulfide (H_2S) Reduction

Conceptual Pathway: Nitrate (NO_3^-) → Denitrifiers → Inhibit SRB → ↓ H_2S Production → ↑ SO_4^{2-} Formation.

3. Sulfate (SO_4^{2-}) Accumulation

The sulfate level (Figure 5) began at 15–20 mg L^{-1} and increased steadily to around 100 mg L^{-1} by day 21. This growing trend directly reflects the reduction in H_2S, suggesting that the main oxidation pathway was:

$H_2S + 2\ NO_3^- \rightarrow SO_4^{2-} + N_2 + H_2O$\text{$H_2S + 2\ NO_3^- \rightarrow SO_4^{2-} + N_2 + H_2O$}$H_2S + 2\ NO_3^- \rightarrow SO_4^{2-} + N_2 + H_2O$

The stoichiometric relationship between nitrate consumption and sulfate output supports the conclusion that nitrate-driven sulfide oxidation operated efficiently in the system. Sulfate accumulation did not appear to limit microbial activity, indicating that the microbial community was robust in these conditions.

4. pH and Temperature Stability

The stability of pH and temperature throughout operation (Figure 6) is an important indicator of controlled and balanced microbial metabolism. The pH remained between 7.0 and 7.3, with minor variations due to the production of intermediate acids, and the temperature was maintained at 30 °C, which is ideal for mesophilic bacteria. The absence of a discernible pH decrease indicates that the nitrate-based oxidation of sulfide generated less acidity than aerobic oxidation (11).

5. Overall System Performance

The integration of these results confirms that the nitrate-fed, mixed microbial system successfully ,eliminated malodorous hydrogen sulfide (> 90 % reduction, maintained biological stability for more than three weeks, enhanced sulfate formation.

6. Practical Implications

The outcomes at the plant level illustrate that the bioremediation method can be scaled up. Without the need for costly aeration systems, periodic nitrate dosing, mild mixing, and real-time pH and temperature monitoring can effectively suppress H_2S emissions and enhance effluent quality(14). Baghdad and other cities with comparable infrastructure might use this strategy as a low-cost, low-energy improvement to their current sewage treatment facilities (15,16).

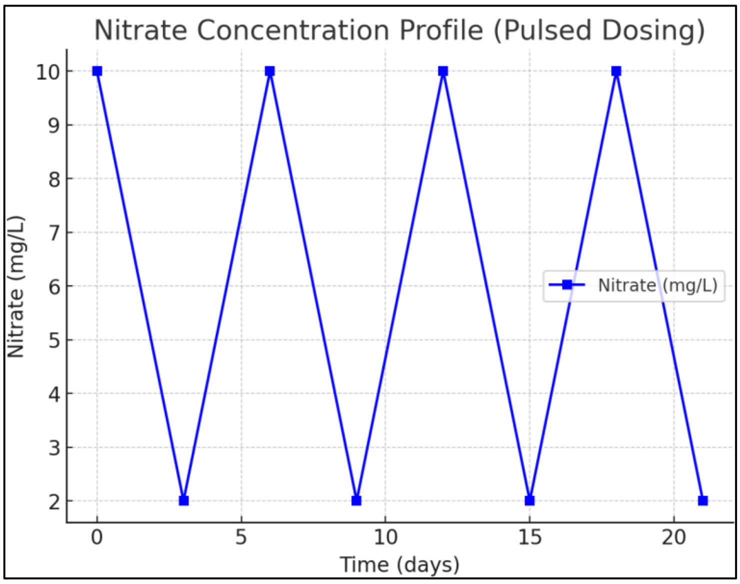

Figure 4 Nitrate (NO_3^-) Consumption Pattern

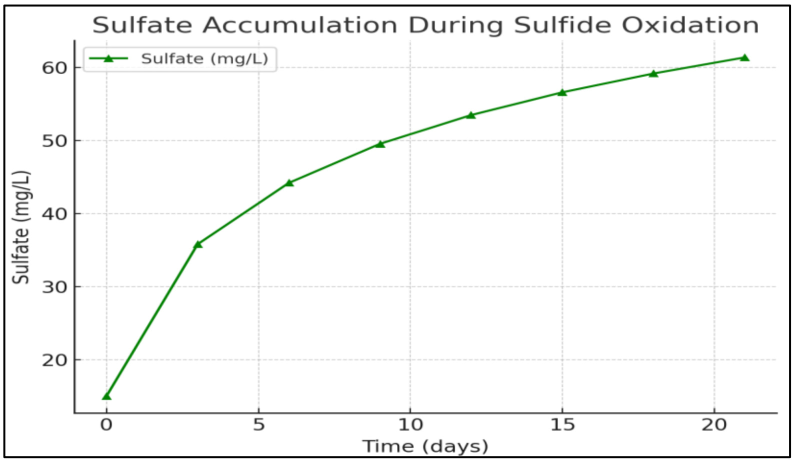

Figure 5 Sulfate (SO_4^{2-}) Accumulation

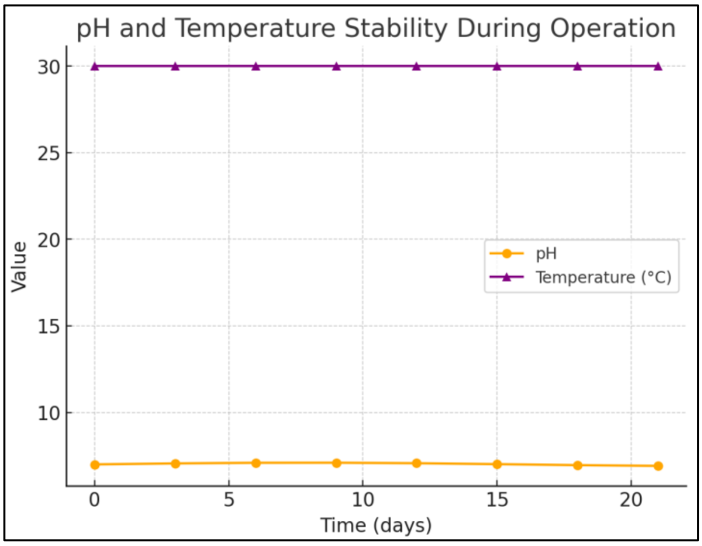

Figure 6 pH and Temperature Stability

Hydrogen Sulfide (H_2S) Reduction:

By day twenty-one, the initial concentrations of 25–30 mg/L had progressively decreased to less than 3 mg/L, indicating an overall clearance effectiveness of over 90%. Effective microbial sulfide oxidation was confirmed by the drop, which followed an exponential decay pattern.

Nitrate (NO_3^-)Consumption:

Following each pulsed injection (10 mg/L every two hours), nitrate levels rapidly decreased, suggesting active denitrification and ongoing bacterial respiration in anoxic environments. Sulfate (SO_4^{2-}) Formation:

Concentrations of sulfate rose gradually from 15–20 mg/L to around 100 mg/L, indicating that H_2S was successfully converted to sulfate as the end oxidation product.

pH and Temperature Stability:

Throughout the operation, the system was stable, keeping the temperature close to 30 °C and the pH between 7.0 and 7.3, which are appropriate for mesophilic denitrifying bacteria.

Overall System Performance:

An effective and independent biological desulfurization process was achieved by combining nitrate dosage, constant mixing, and microbial adaptability. Effective control of gaseous sulfides was demonstrated by the reactor's smooth operation and lack of odor emissions. The plant-level findings demonstrated that nitrate-fed biological treatment is a practical and sustainable substitute for managing odor and sulfur in municipal wastewater. The denitrification–sulfide oxidation mechanism shown at laboratory size is validated by the steady decrease in H_2S, quick nitrate consumption, and sulfate formation, demonstrating that the process may be effectively scaled up for practical uses.

4. **Economic analysis**

A brief cost comparison was conducted between the nitrate-based odor control method and traditional systems such as aeration and iron salt dosing. The sodium nitrate system demonstrated a 30–40% reduction in operational costs, primarily due to lower energy demands and the elimination of continuous aeration. While aeration systems require high power consumption (0.5–1.0 kWh/m^3), nitrate dosing requires only periodic chemical addition, resulting in estimated savings of approximately 15–25 USD per 1,000 m^3 of treated sewage. Furthermore, maintenance costs were lower due to reduced corrosion rates and less need for chemical cleaning.

5. Recommendations and Conclusions: This study revealed that supplying sodium nitrate ($NaNO_3$) to sewage systems is a useful way to stop the production of hydrogen sulfide (H_2S). The concentration of H_2S declined from 132 ppm to 13 ppm during a three-week period, signifying a 97% elimination efficiency. These findings demonstrate that nitrate effectively inhibits the activity of sulfate-reducing bacteria by acting as an alternate electron acceptor and upsetting the sulfate reduction pathway. Nitrate treatment offers both technical and financial benefits over traditional post-release odor control techniques since it directly tackles the microbial process of H_2S formation. This approach reduces biogenic corrosion in sewage infrastructure, prolonging pipeline lifespan and saving maintenance costs, while also lessening unpleasant odor and related health issues. Future research should concentrate on assessing the long-term stability of microbial populations under ongoing nitrate treatment and improving nitrate dosing techniques for various sewage system settings. However, the results of this study provide compelling evidence for the use of sodium nitrate as an ecologically benign, economical, and preventative method of controlling corrosion and odor in wastewater collecting systems. reducing emissions of hydrogen sulfide and enhancing the quality of wastewater in anoxic environments.

Hydrogen sulfide (H_2S) concentrations decreased by almost 90% within 21 days of operation, nitrate (NO_3^-) was effectively utilized, and sulfate (SO_4^{2-}) levels rose in tandem, indicating full biological oxidation of sulfide to sulfate. Throughout operation, the system maintained a steady pH (7.0–7.3) and temperature (~30 °C), suggesting a robust and well-balanced microbial population dominated by denitrifying sulfide-oxidizing bacteria (DSOB). These findings unequivocally demonstrate that nitrate may be used as a sustainable and efficient substitute for oxygen in sewage systems to facilitate the biological elimination of H_2S.This pilot-scale experiment's performance supports the laboratory results' scalability and demonstrates the usefulness of nitrate-fed microbial systems for large-scale deployment in Baghdad's municipal wastewater treatment facilities and other comparable urban environments. Without the use of chemical oxidants or aeration, this method provides an inexpensive, low-energy, and eco-friendly way to mitigate sulfides and reduce odors.

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Conflict of Interest Statement: All authors have nothing else to disclose.