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Optimization of Hydrogen Sulfide Bio Filter Performance, a Systematic Review

David Dnaroma
Mechanical, Chemical and Electrical Engineering Departments, Houston university, Texas, USA

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ABSTRACT

The study of biological removal of volatile inorganic compounds has been widely conducted. Most studies have focused on H_2S and other sulfur or nitrogen-containing compounds such as sulfides, mercaptans, methane thiol, or ammonia. The removal of H_2S from wastewater treatment plants was investigated in 1923, and the oldest recorded article is from 1934. In various studies that have been conducted so far to remove pollutants including H_2S, different biological systems have been used. As mentioned earlier, these biological systems include bio filters, trickling bio filters, and biological scrubbers. The use of bio filters with organic substrates is more commonly used for biological treatment of volatile inorganic compounds. Since microorganisms grow as biofilms on packing materials and absorb, decompose, and convert pollutants into non-harmful substances. Therefore, the selection of the appropriate microorganism in biological treatment will play an important role. For the removal of sulfur-containing compounds in bio filters, microbial species of the genera Thiobacillus and Hyphomicrobium are often considered very desirable decomposers. Volatile organic compounds can also be treated by specialized microorganisms. These compounds include halogenated aliphatic and other halogenated and aromatic pollutants. The dominant microorganisms in VOC-purifying bio filters are heterotrophs that require an organic carbon source and are unable to use carbon dioxide as the sole carbon source. Removal capacity, which indicates the rate of pollutant removal at a given mass load and is defined as the mass of pollutant removed per unit bed volume per unit time, is an important parameter in biological removal processes. This parameter for different pollutants in the biological treatment of VIC can vary from a few grams to more than 200 grams per cubic meter per hour of inlet gas with a removal efficiency of over 90%, and this parameter has been reported as one of the main parameters in various articles.

Introduction

Hydrogen sulfide (H_2S) is a toxic, corrosive, and foul-smelling gas produced in many industries such as oil and gas, petrochemicals, wastewater treatment, and more. In addition to posing a threat to human health, this gas also corrodes equipment and damages the environment byy Eze et al., (2025) [1]. Therefore, it is essential to eliminate or reduce its concentration. Hydrogen sulfide adsorbents are materials that can physically or chemically absorb this gas and remove it from the environment. These adsorbents are produced in various types such as solid, liquid, and mixed adsorbents, each of which has its own advantages and disadvantages. For example, the main adsorbents for the desulfurization process can be listed as follows.

- ✓ Hydrogen sulfide adsorbent based on (1, 3, 5) MEA thiazine.
- ✓ Hydrogen sulfide adsorbent based on glyoxal.
- ✓ Hydrogen sulfide adsorbent based on aldehyde.

Corresponding Author: **David Dnaroma (donaroma2036@gmail.com)*

- ✓Hydrogen sulfide adsorbent based on polymer by Imanzadeh et al., (2024) [2].

Mechanism of action of (1, 3, 5) MEA thiazine as a sulfur and hydrogen sulfide scavenger

The amine moiety in (1, 3, 5) MEA thiazine acts as a nucleophile in the sulfur scavenging process, meaning it readily donates electrons. This allows it to react with H_2S, which acts as an electrophile (electron acceptor). The reaction proceeds via nucleophilic substitution, in which the nitrogen atoms attack the sulfur atom in H_2S. This results in the formation of stable, non-toxic byproducts that effectively remove H_2S from the system. This works by a chemical reaction called nucleophilic substitution. The mechanism is explained in detail below by Darwish et al., (2024) [3].

Nucleophilic amine: Mono-ethanolamine thiazine has nitrogen atoms with lone pairs of electrons. These electron-rich nitrogen atoms act as nucleophiles, meaning they are attracted to positively charged or electron-deficient species. Electrophilic hydrogen sulfide: It has a partially positive sulfur atom due to the difference in electronegativity between sulfur and hydrogen. This makes the sulfur atom an electrophile, meaning it attracts electrons by Barot et al., (2024) [4].

Attack of the nucleophilic nitrogen atoms in (1, 3, and 5) MEA thiazine: The thiazine attacks the electrophilic sulfur atom in H_2S. This creates a new bond between the nitrogen and sulfur. The hydrogen atoms are displaced from H_2S, forming a stable, non-toxic byproduct called Thiazine. Two molecules of mono-ethanolamine (MEA) are also produced as byproducts. Theoretically, although (1, 3, 5) MEA thiazine can react with three molecules of H_2S, it mainly reacts with two molecules:

MEA thiazine + 2H_2S –> Dithiazine + 2MEA

Think of the (1, 3, 5) MEA thiazine ring as a triangle with nitrogen atoms at each corner. Each nitrogen has “arms” (hydroxyethyl groups) coming out of them. These nitrogen “arms” grab onto the sulfur in the H_2S and separate it from the hydrogens, forming a new ring structure.

Zare et al., (2024) [5], this study applied Response Surface Methodology (RSM) to optimize the operational parameters of a bio filter for hydrogen sulfide (H_2S) removal. It identified optimal conditions of pH, empty bed residence time (EBRT), and inlet concentration for maximum removal efficiency. The results of the studies showed that the bed mixing operation is suitable to prevent the formation of flow channels and to obtain a constant moisture content for the bed, granulation, porosity, and overall homogeneity of the compost bed. Bed mixing also provides practical conditions for controlling sulfate accumulation by better washing the bed. However, the investment and operating costs required to implement bed mixing in full-scale bio filters must be considered and evaluated before its application.

Methodology

In this study, more than 60 articles on topics such as: Thiobacillus, Hyphomicrobium, H_2S, Microorganism, Biological Treatment in knowledge bases such as Elsevier, Science Direct, Ichemica, and Civilica were reviewed between 2009 and 2025.

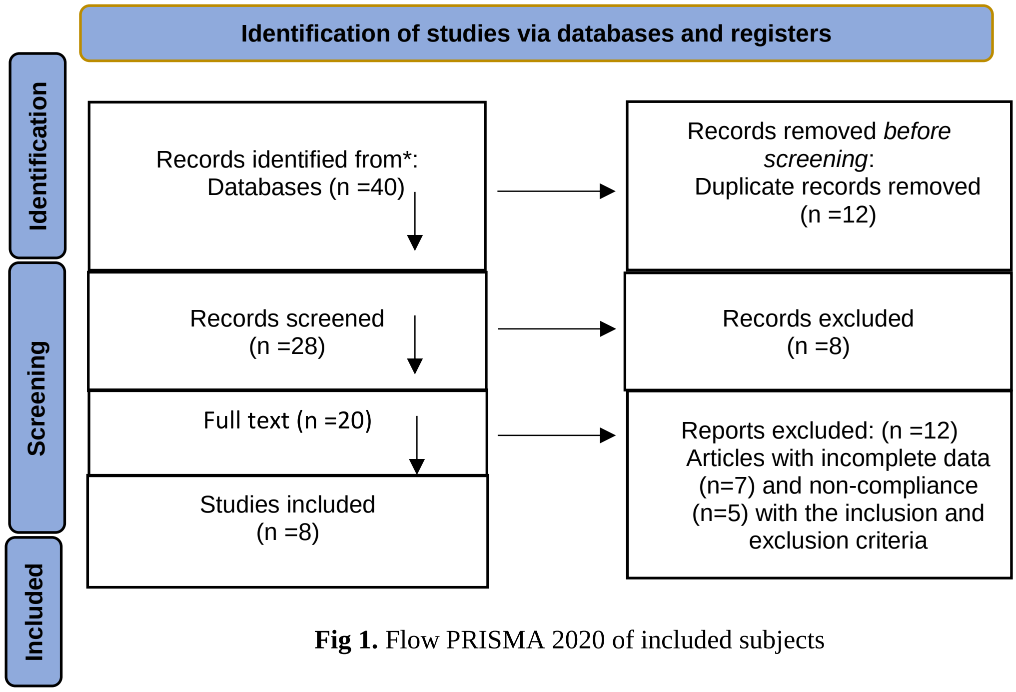

Fig 1. Flow PRISMA 2020 of included subjects

Omotayo et al. (2025) [6], this foundational book on bio filtration provides detailed design principles, operational challenges, and microbial considerations for controlling air pollution, including H_2S. It serves as a standard reference in the field. Since biological oxidation occurs immediately after physical adsorption on the bio filter bed, the selection of a suitable carrier for immobilization of bacteria on it in the bioreactor system is of great importance. Therefore, they used four different packings for biological removal of high concentrations of H_2S using immobilization of the bacteria Thiobacillus denitrificans. Their experiments were conducted on the physical adsorption capacity, residence time and pressure drop of four packings: moss compost, wood chips, ceramic and granular activated carbon. The results of the research showed that the granular activated carbon bioreactor has a better ability to remove H_2S from the gas stream. This packing provides a more uniform surface area and has good resistance to crushing and provides better operational control over the gas adsorption capacity and pressure drop. In addition, granular activated carbon provides a higher adsorption capacity for bacteria than the other packings tested. In table 1, Omotayo et al. (2025) the same data and analysis presented in English, suitable for inclusion in a report or research paper on Optimization of Hydrogen Sulfide Bio Filter Performance is illustrated.

Table 1. The same data and analysis presented in English, suitable for inclusion in a report or research paper on "Optimization of Hydrogen Sulfide Bio Filter Performance

Day	Inlet Flowrate (L/min)	Inlet H_2S Concentration (ppm)	Outlet H_2S Concentration (ppm)	Ambient Temp (°C)	Removal Efficiency (%)
1	2.5	50	12	25	76.0
3	2.5	50	8	26	84.0
5	2.5	50	5	26	90.0
7	3.0	60	9	27	85.0
9	3.5	60	12	28	80.0
11	3.5	65	13	30	80.0
13	4.0	70	15	31	78.6
15	4.0	70	18	32	74.3

Deokar et al., (2025) [7], this book covers the biotechnological applications in air and odor control, with several chapters focusing on the optimization of bio filters for volatile sulfur compounds like H_2S. It also discusses practical case studies. They used the bio filter constructed in his previous work to determine the effect of mixing and stirring the bio filter bed on the H_2S removal efficiency and evaluated the performance of important operating factors such as bio filter bed moisture, pressure drop, and sulfate accumulation with respect to the mixing of the bed.

Hasanpour et al., (2025) [8], the authors used artificial neural networks (ANN) to model and optimize the performance of H_2S bio filters. The ANN model accurately predicted removal efficiency based on various input variables, aiding real-time control. They proposed a technique for analyzing and estimating the changes in the physical structure of a bio filter medium over time. The system used in this study consisted of four workshop-scale bio filter columns that removed H_2S from a humid air stream. Each column, made of polyvinyl chloride and 0.1 m in diameter and 1.2 m in height, was filled to 1 m with compost medium. The columns operated in an up flow mode, with the air flow rate kept constant at 10 l/min, and the residence time in each column was 50 s. Under these operating conditions, the H_2S removal efficiency decreased from 100% to 90% after 206 days of bio filtration, which was due to changes in moisture content and specific surface area over time.

Purnami et al. (2025) [9], this study examined VOC emissions during bio-waste composting and discussed the role of bio filtration in controlling odorous compounds like H_2S. The findings highlighted the need for continuous monitoring of emission loads. The granular activated carbon bioreactor produced an average removal efficiency of 96.8% of hydrogen sulfide at an inlet concentration of 110–120 mg/l over a 160-day operation period. As previously mentioned, trickling bio filters are another system used in bio filtration, which is similar in principle to bio filters, with the only difference being that the aqueous phase of the nutrient solution is continuously dripped onto the compressed bed. Among the researchers who have used trickling bio filters to remove H_2S from air streams is Sercu et al., who in 2005 investigated the removal of dimethyl sulfide (DMS) and hydrogen sulfide from air streams using a two-stage trickling bio filter. In figure (2), two graphs showing the relationship between H_2S removal efficiency and two key operational variables is illustrated.

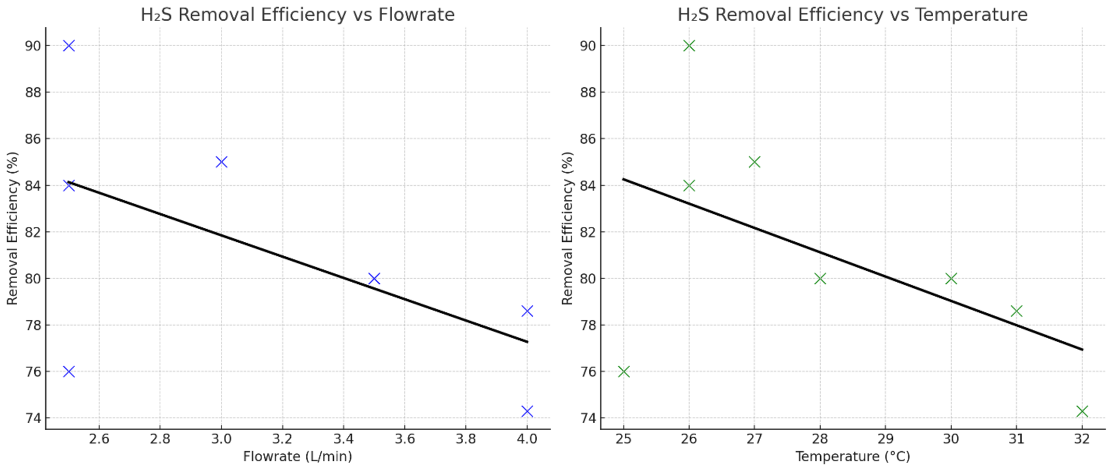

Figure 2. The relationship between H_2S removal efficiency and two key operational variables

According to figure 2:

1. Flowrate (L/min): As flowrate increases beyond 3.0 L/min, removal efficiency shows a decreasing trend, indicating potential system overload or reduced contact time.
2. Temperature (^{oC}): Optimal efficiency is observed between 25^{oC} and 28^{oC}. Performance begins to decline as temperature exceeds 30^{oC}, possibly due to microbial stress.

Factors Affecting the Desulfurization Process

The performance of (1, 3, 5) MEA thiazine can be significantly affected by several factors. Understanding these factors is critical to optimizing its use and ensuring effective H_2S removal. (1, 3, 5) MEA thiazine more thiazine means faster and more efficient reaction. As the concentration of MEA thiazine increases, the rate of H_2S removal increases. This is because more MEA thiazine molecules are available to react with H_2S, resulting in faster and more efficient removal. However, simply using the highest possible concentration is not always practical or cost-effective. The optimal concentration depends on factors such as the H_2S concentration, the desired removal level, and the specific application.

Three main stages are observed in the bio filter process: attachment of microorganisms to porous bio carbon surfaces and formation of biofilm, consumption of substrate H_2S and growth of biomass, washing (Filter Backwashing). To prevent excessive accumulation of microorganisms, the filter is washed with 32oEC water every 100-200h. A direct relationship is observed between the porosity of bio carbon and the biofilm formed on the one hand and the rate of H_2S removal on the other. The main product of microbial oxidation of H_2S is sulfuric acid. Adjustment of pH, temperature, humidity and aeration is essential. Evaluation of the bio filter performance is estimated by the Elimination Capacity=EC factor. Bio carbon absorbs high concentrations of H_2S and gradually makes it available to the filter microorganisms and maintains humidity. Therefore, Bio carbon is a suitable option for removing hydrogen sulfide from wastewater [10].

Almajidi et al., (2024) [11] modified the Ottengraf model in a way that it is more consistent with reality. In this model, methanol and oxygen were considered as substrates affecting the reaction rate, and the model results were compared with laboratory results related to methanol removal. Also developed a laboratory-scale trickling bio filter system for the removal of H_2S from biogas under anaerobic conditions. In these experiments, polyethylene balls inoculated with anaerobically adsorbed sludge were used as packing material in the bioreactor, and nitrate was used as an electron acceptor in the absence of oxygen. The removal efficiency in this study was reported to be more than 85% for an inlet concentration of 500 ppm hydrogen sulfide and a gas flow rate of 50 L/h.

Zbuzant (2022) [12] presented a model to simulate biofilters in toluene purification. In this model, calculations were performed according to the dimensions of the activated carbon pores and the porous medium, and changes in the biofilm thickness over time were included in the model.

Sadawarte et al., (2024) [13] investigated a new medium for bio filtration in a municipal pumping station in the United Arab Emirates for H_2S removal. The system built in this work consists of a mobile bio filter, a humidifier, a membrane pump, a gas compressor and a rotameter, and the air stream containing H_2S is humidified before entering the bio filter system. The new medium used for the bio filter bed is an artificial medium in the form of hollow cylindrical particles whose base material is covered with nutrients and microbes. Using this new medium, more than 99% hydrogen sulfide removal efficiency was achieved, which indicates that the new system was effective in removing hydrogen sulfide.

Atlas et al., (2025) [14], investigated the removal of H_2S and NH_3 using a bio filter loaded with cells immobilized with Pseudomonas putida and Arthrobacter oxydans for H_2S and NH_3 removal, respectively, and tested different gas mixtures containing different ratios of H_2S and NH_3. Removal efficiencies of more than 95% and 90% were observed for NH_3 and H_2S, respectively. In the range of 5–65 ppm, the removal efficiencies of H_2S and NH_3 were more than 96%, although at higher concentrations, the simultaneous presence of H_2S and NH_3 had inhibitory effects on H2S removal. In this study, the kinetics of the process were also investigated and its relevant parameters were obtained. In figure (3) four additional visualizations for deeper analysis of bio filter data is illustrated.

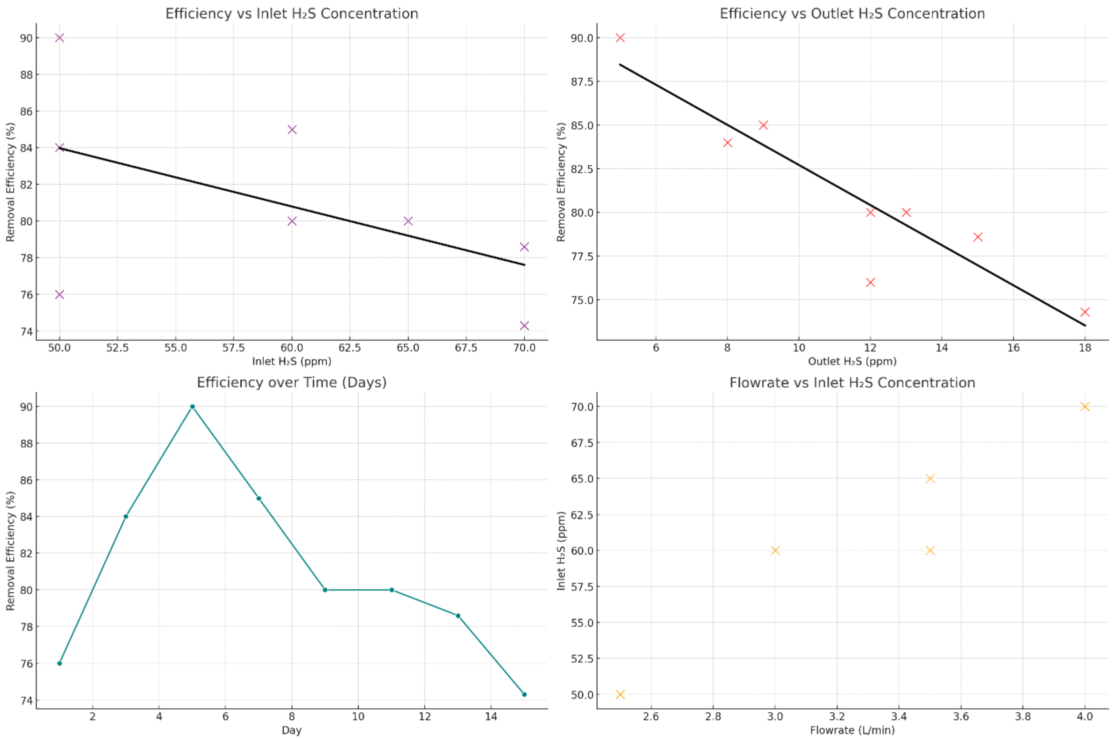

Figure 3. Four additional visualizations for deeper analysis of bio filter data

Here are four additional visualizations for deeper analysis of bio filter data:

1. **Efficiency vs Inlet H_2S Concentration**: Shows a slight negative trend higher inlet concentrations may challenge removal efficiency.
2. **Efficiency vs Outlet H_2S**: As expected, higher outlet concentrations correspond with lower efficiency.
3. **Efficiency over Time**: Performance initially improves, peaks, and then gradually declines possibly due to bio filter saturation or microbial fatigue.
4. **Flowrate vs Inlet H_2S**: Helps visualize if higher inlet concentrations are correlated with higher flowrates (often true in real setups).

In 2025, Asadian et al., [15] used a bio filter to remove hydrogen sulfide from a bed of scallops using the bacterium Thiobacillus thioparus. The bio filter column was made of Plexiglas and had 4 sections, each section 40 cm high, and small scallops were also used as the bed. The results of the experiments showed that, considering the dimensions of the column and the porosity of the bed, the actual residence time of 0.4 min was the best residence time in the above column. A trickling bio filter was investigated for the removal of hydrogen sulfide from an air stream with a bed of porous volcanic lava as a carrier of the bacterium Thiobacillus thioparus. In this trickling bio filter, the airflow and the culture medium liquid were in opposite directions. In this study, the effect of operating parameters on the performance of the trickling bio filter was investigated and complete removal of H_2S was achieved in 85% of the initial bed.

In 2025, Kumar Reddy et al., [16] at Shiraz University of technology investigated a bio filter for removing hydrogen sulfide from landfill gas at the laboratory level using a capsule containing biogas. Previous research shows that in various studies conducted so far to remove pollutants, including H_2S, different biological systems have been used.

Morah et al., (2024) [17] also tested the bio filter constructed with another bacterium, Thiobacillus novellus, which is a facultative chemoautotroph, for H_2S removal from air. As in the previous two studies, the effect of various parameters on hydrogen sulfide removal was investigated and it was found that the H_2S removal capacity of Thiobacillus novellus in the mixotrophic bio filter was superior to that of the autotrophic bio filter. Also, pH control in the autotrophic bio filter is of great importance. In this study, H_2S removal efficiency of up to 99.6% was also achieved, and the products produced were sulfate (83.6%) and sulfite (12.6%) and a small amount of sulfide was converted to elemental sulfur. A comprehensive review of H_2S removal using bio filters, this article details microbial pathways, packing materials, and the influence of operational parameters like temperature, pH, and moisture content on system performance.

Shahraki et al., (2025) [18], this book explores gas-phase pollutant treatment via bioreactors, particularly focusing on design and optimization techniques for H_2S removal. It integrates microbial kinetics and process modeling. They described the purification of air contaminated with volatile organic compounds in a bio filter under transient and steady-state operating conditions with a mathematical model and investigated the effect of various parameters such as Peclet number, biofilm thickness, gas-solid adsorption coefficient, specific surface area of the bed, etc. on the system.

Mummadi et al., (2025) [19], the paper demonstrates the co-treatment of H_2S and toluene in a bio trickling filter, showcasing synergies and challenges in multi-pollutant treatment. It discusses mass transfer limitations and microbial competition. Another result obtained at two different concentrations of 5 ppm and 60 ppm was that at low concentration (5 ppm) the main product was elemental sulfur, while at high concentration (60 ppm) the main product was sulfate. The effect of residence time in the bio filter was also investigated by injecting 60 ppm hydrogen sulfide at different flow rates, which showed that Thiobacillus thioparus bacteria are less sensitive to changes in residence time compared to the previous bio filter that worked with Pseudomonas putida bacteria. Finally, this study showed that with Thiobacillus thioparus bacteria, more than 98.5% H_2S removal efficiency was achieved.

Samimi et al. (2025) presented a dynamic model for ammonia removal by bio filtration, which was developed based on mass balance equations for four phases: gas, liquid, biofilm, and solid. The liquid phase is actually used to model the periodic dewatering in the system and the liquid collection exiting the bio filter. In this work, they used complex bio removal kinetics including inhibition and oxygen limitation. Due to the complexity of the various mechanisms in the bio filter, its modeling is difficult and most models are presented by considering simplifying assumptions. Different models differ in assumptions such as the degree and type of kinetics and the shape of the biofilm. In this study, in order to reduce the problems related to the distribution of pollutants such as hydrogen sulfide and to better understand bio filtration systems, modeling of the bio filtration process for removing hydrogen sulfide pollutant from gas flow has been studied. In this modeling, in addition to considering the non-uniformity in the biofilm, changes in biofilm thickness with time have also been considered. The authors investigated the microbial ecology of VOC-degrading bio filters. While focused on VOCs, the insights on microbial community structure are applicable to H_2S bio filtration optimization.

Hasanpour et al., (2025): This experimental study used peat as a bio filter packing material to treat BTEX pollutants. Though not specific to H_2S, it demonstrates how media choice and residence time impact performance, useful for H_2S systems (Table 2).

Table 2. Combining thiazine MEA with other H_2S scavengers

Possible methods	Hydrogen sulfide level	Volume of treated water
Disinfecting well water by chlorine shock	---	Total treatment of incoming water or well water treatment
Disinfecting and removing unpleasant odors Example: Activated carbon filter + ultraviolet ray device	Less than 1 ppm	
Oxidizing filter Example: Green sand filter	Between 5 and 7 ppm	
Injection of oxidizing chemical + physical removal of oxidized hydrogen sulfide Example: Chlorine injection + particle separator filter + activated carbon filter Potassium permanganate injection + Green sand filter	Between 7 and 10 ppm	
Distillation	---	Treatment at the point of use
Reverse osmosis	---	

Process Conditions

PH: The reaction works best under alkaline conditions. Thiazine works best in alkaline environments (pH above 7). This is because the reaction mechanism involves nucleophilic attack, which is favored under alkaline conditions. Low pH can significantly reduce the reaction rate and inhibition efficiency. Maintaining the proper pH is critical for optimal performance.

Costa et al., (2011): Higher temperatures generally speed up the reaction. Like most chemical reactions, the reaction between (1, 3, 5) MEA thiazine and H_2S is faster at higher temperatures. Increasing temperature provides more energy for the molecules to collide and react, increasing the rate of inhibition. However, excessively high temperatures can lead to the degradation of (1, 3, 5) MEA thiazine and reduce its effectiveness. It is essential to operate within the recommended temperature range for the specific formulation.

Competition and Interference with Other Chemicals: Other chemicals in the system can interfere with the performance of MEA thiazine. Some chemicals may compete with the thiazine MEA for the reaction with H_2S, while others may inhibit the reaction or form by-products that prevent collection [23]. It is therefore important to consider the chemical composition of the system in which the thiazine MEA will be used. Compatibility testing may be necessary to ensure that other chemicals do not adversely affect its performance (Figure 4).

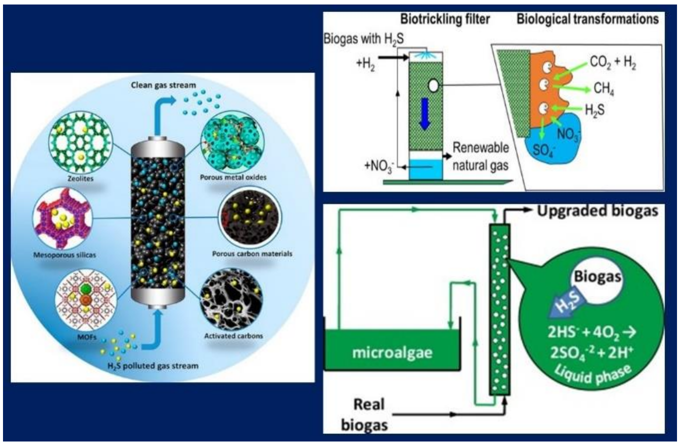

Figure 4. Competition and Interference Hydrogen Sulfide Bio Filter Performance

Advantages of using MEA in processes High efficiency

Delborty et al., (2022), this study evaluated a novel bio filter for VOC removal under varying temperature and inlet concentrations. Although it focused on VOCs, the work provides valuable insights into how temperature fluctuations affect microbial performance critical in H_2S bio filtration. This unit is highly flexible, measures the necessary parameters in time, and works well with polluting and corrosive gases. In this study, wastewater produced in leather industries was used as a source of microorganisms, and since the purpose of the experiments was to use them in the industry, the costs of microorganism growth were eliminated in their pure form. In addition, since the purpose was to purify the air, the presence of a mixture of microorganisms in the substrate was not problematic. In the experiments, the polluting gas injected into the air for removal was hydrogen sulfide, and the substrate used was compost used for mushroom growth, which can be obtained from mushroom production factories.

Chmielowiec-Korzeniowska et al. (2012) the article reviews various odor treatment technologies in wastewater treatment plants, including bio filtration. It assesses performance, cost, and environmental impact, emphasizing bio filters' effectiveness in reducing H_2S concentrations. They used a packing material with the trade name ABONLIR to perform the bio filtration process for removing H_2S from air. This material was composed of pig manure and sawdust, and its grains were made by mechanical compaction without the addition of chemicals. The bio filter made in this work had a volume of 7 liters, a length of 1 m and an internal diameter of 10 cm. This bio filter, which was made of PVC, was divided into 3 replaceable parts and the gas entered the bio filter from the top. The H_2S input mass load, defined as the amount of H_2S injected into the system per unit time and per unit volume of packing material, varied from 10 to 45 g/m3/h, and the by-product obtained in the biological degradation process was elemental sulfur.

Yang et al., (1994): This research demonstrated the feasibility of using perlite media in bio filters for gas-phase VOCs. It highlighted media-specific microbial support characteristics relevant to optimizing H_2S bio filter design.

Kurniadewi et al. (2025), the study examined trickle-bed bio filter performance for removing volatile organic compounds (VOCs). Findings on flow dynamics and media properties are directly applicable to bio filters targeting H_2S. The bio filter was constructed as a cylindrical column of acrylic with 4 sections, with air entering from the bottom and water entering the bio filter from the top to provide moisture to the bed. This semi-industrial unit was tested for 1.5 months and the flow rate of contaminated air entering the bed was 12 liters per minute under laboratory conditions, and the hydrogen sulfide removal efficiency in this study was reported to be about 99%. The semi-industrial unit was again used in 1998 to remove hydrogen sulfide from the air with a natural bed containing compost and mussels.

Shareefdeen (2012) Utilizing statistical experimental design, this work optimized the removal of H_2S and VOCs from air using biofiltration. It showed that inlet load, pH, and nutrient dosing significantly affect performance.

Ahmadpour et al. (2023): This paper presents a detailed model of a bio filter used for ammonia removal, including parameter analysis and model validation. Although focused on ammonia, the modeling framework is applicable to H_2S bio filters, particularly for simulation-based optimization.

Chung et al., (1996), the authors evaluated the long-term performance of a polyurethane-based bio filter treating complex odorous gases, including H_2S. They observed that consistent humidity and biofilm stability are crucial for sustained removal efficiency. The efficiency of the bio filter was investigated for 4 months with different volumetric velocities and concentrations at ambient temperature. The results of this study showed that the efficiency of this method was more than 95% for a concentration of about 150 ppm at an average temperature of 26.9°C and at volumetric velocities of 6 and 12 liters per minute.

Chen et al., (2014), this study examined how a pre-loaded sorptive medium influences the performance of a trickle-bed bio filter for VOCs. The results imply that initial media conditioning may enhance H_2S removal by improving microbial colonization and pollutant absorption.

Prasath et al., (2025): The researchers investigated the long-term operational stability of a bio filter treating dimethyl sulfide. Their findings on microbial adaptation and media saturation dynamics are highly relevant for optimizing H_2S bio filters.

Parsa et al. (2024): The authors conducted a detailed assessment of how operational parameters such as EBRT, nutrient availability, and inlet load influence H_2S removal efficiency in bio filters. The study offered practical design recommendations. In figure (5), 3D Plot, Efficiency vs flowrate and temperature and in figure (6), Correlation Matrix of this article are illustrated

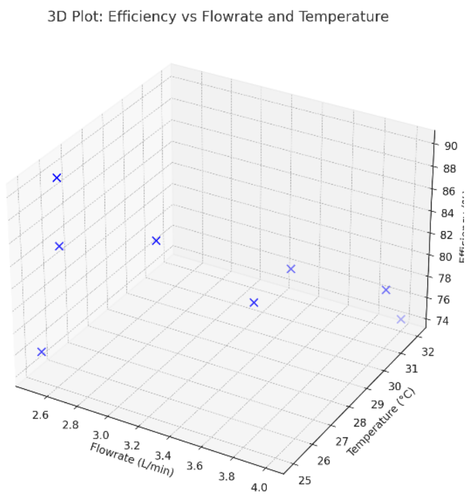

Figure 5. 3D Plot, Efficiency vs flowrate and temperature

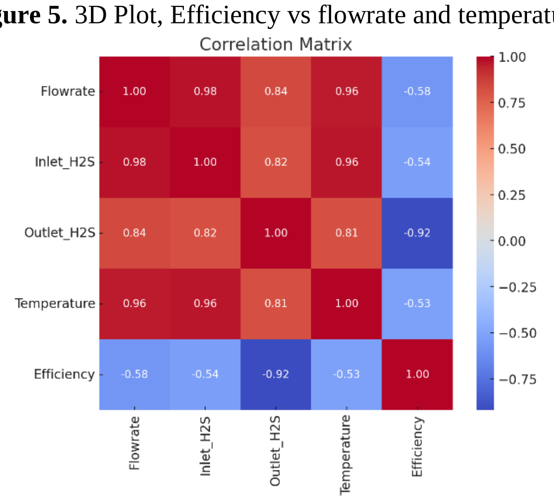

Figure 6. Correlation Matrix

Kautsar et al. (2025), A comprehensive review of biological processes for H_2S removal from gas streams. It compares bio filters, bio scrubbers, and bio trickling filters, offering key insights into operational optimization, advantages, and limitations of each system. Since the bacterium Thiobacillus denitrificans is a strictly autotrophic and facultative anaerobic bacterium and uses thiosulfate, elemental sulfur, and sulfide as an energy source, it is considered a suitable microorganism for the biological removal of hydrogen sulfide, which was used by Sublette in 1987 to study the anaerobic oxidation of H_2S under constant growth conditions. In this study, the organism in question was cultivated in a stirred reactor, and due to the anaerobic conditions, potassium nitrate and ammonium chloride were used to provide nitrate as the electron acceptor of the bacteria at high concentrations in the reactor. The H_2S-containing feed stream entering the reactor varied from 1.45 mmol H_2S per hour to 3.22 mmol H_2S per hour, and ultimately the efficiency of hydrogen sulfide removal from the feed was reported to be more than 97%. This paper analyzed the behavior of bio filters under transient loading conditions. The results showed how bio filters adapt-or deteriorate under fluctuating H_2S loads, offering insight for optimizing dynamic operation.

Wiyono et al., (2025): Focusing on municipal wastewater treatment plant emissions, this study tested the odor removal efficiency of a bio filter for H_2S. It demonstrated how media type and humidity control can optimize performance.

Turkia et al., (2024): This research separated biotic and abiotic removal mechanisms for H_2S in bio filters. It emphasized the dominance of microbial degradation under optimal moisture and pH, helping to fine-tune design parameters.

Samimi (2021), a field-scale evaluation of H_2S bio filtration performance in a real wastewater plant was conducted. The findings emphasized the importance of maintaining optimal operational conditions and media replacement for long-term performance. They also conducted a study on the aerobic oxidation of H2S with the bacterium Thiobacillus denitrificans to expand the application of microbial desulfurization technology. Of course, under aerobic conditions, oxygen may contaminate the desulfurized gas. If the treated gas has no fuel value, this contamination by oxygen can be ignored and aerobic oxidation of H_2S can be used under these conditions. In this study, which initially had aerobic growth of bacteria in a batch mode, a thiosulfate-free nitrate-free culture medium at $30^{\circ C}$ and pH 7 was used for bacterial growth.

Musheer et al. (2024), this early study demonstrated the effective use of immobilized Thiobacillus species on porous ceramics for degrading H_2S. It introduced the concept of carrier-based microbial systems, which remains key to modern bio filter design. The proprietary media of this bio filter was wood-based and designed to provide a suitable biological environment in terms of pH buffering capacity, low pressure drop, and resistance to compaction. A commercially available bio filter is open-air and removes hydrogen sulfide and ammonia with efficiencies greater than 96%. A year later, Shareefdeen reviewed the progress of bio filtration for removing H_2S from polluted air using an artificial bed environment.

Zhang et al., (2009), Focused on design and operational considerations, this work offers practical guidance for bio filtration of H_2S, including reactor sizing, gas flow rates, and microbial inoculation strategies to improve reliability and efficiency. In this study, the results obtained from a bio filter installed in a municipal sewage pumping station in Canada were examined, which showed that for inlet concentrations above 40 ppm, only 30 seconds of residence time was required, but for lower concentrations (>12 ppm), 20 seconds of residence time was sufficient to completely remove H_2S from the air stream. In addition, the results showed that the bio filter under study could perform well under low and neutral pH conditions without adding buffer chemicals to the bed medium.

Wiyono et al., (2025) investigated the performance of two trickling bio filters inoculated with two different bacterial strains for hydrogen sulfide removal.

Ismael et al., (2025), the authors proposed using biologically activated carbon for H_2S removal. The hybrid system showed promising results by combining microbial degradation with physical adsorption, enhancing both removal capacity and start-up speed. They removal of hydrogen sulfide in a laboratory-scale bio filter using porous volcanic lava as a carrier for Thiobacillus thiooxidans. Three different volcanic lava samples were investigated. The three types of carriers differed in water holding capacity, pH, density, and buffering capacity, defined as the amount of sulfate added to reduce the pH to 4. Based on the values obtained for the H_2S removal capacity of volcanic lava in this study, it was concluded that this material is suitable for carrying microorganisms in bio filtration. In 2002, Shareefdeen and colleagues reported results from a commercial bio filter operated in Ontario, Canada. This bio filter treated an air stream contaminated with several odorous compounds, including dimethyl sulfide, ammonia, methane thiol, hydrogen sulfide, and ethylamine.

Shareefdeen et al., (2009), this foundational study introduced the concept of substrate uptake rates in microbial film systems, forming the basis for modern kinetic models used in bio filter optimization, including for H_2S degradation. They tested the bio filter made with Thiobacillus thioparus bacteria for hydrogen sulfide removal. In this study, conditions of sudden changes in the H_2S inlet concentration were investigated and the results showed that by changing the concentration from 5 ppm to 60 ppm, a period of time equivalent to 5 days was required for the microorganisms to regain their oxidation ability.

Parsa et al., (2024): This article reviewed bio filtration technologies for VOCs, providing insights into filter media selection, microbial inocula, and operational controls that are also crucial for H_2S treatment. The conditions of the two bio filters were exactly the same, except that the pH was set to acidic for Acidithiobacillus thiooxidans and neutral for Thiobacillus thioparus. The maximum removal capacity for the bio filter inoculated with T. thioparus was 14 g of sulfur per cubic meter of packing per hour in the pH range 5.5-7, and the value obtained for the trickling bio filter inoculated with A. thiooxidans was 370 g of sulfur per cubic meter of packing per hour. Aroca therefore concluded that the acidic trickling bio filter inoculated with A. thiooxidans was a better method for removing H_2S and had the additional advantage of not requiring pH control of the liquid medium.

Discussion

Samimi et al., (2020) investigated the effect of factors such as inlet concentration and velocity on the efficiency of H_2S removal by a strain of bacteria that can tolerate high sulfate concentrations and acidic pH conditions. They studied three strains of the species Acidithiobacillus thiooxidans and found that a strain of this bacterium coded AZ11 had the highest tolerance to sulfate. A. thiooxidans AZ11 could grow at a pH of 0.2 and in the presence of 74 g/L sulfate. The final oxidation product was elemental sulfur. To test the effect of various factors on bio filtration by AZ11, A. thiooxidans was also inoculated into a bio filter with a porous ceramic bed. Initially, a maximum input load of 670 g sulfur per m3/hr of gas was applied at a filling rate of 1200 h-1, and the inlet H_2S concentration was increased from 200 ppm to 2200 ppm. Under these conditions, less than 0.1 ppm hydrogen sulfide was observed at the bio filter outlet. When the inlet H_2S concentration was kept constant at 200 ppm and the filling rate was increased from 1200 to 1400 h-1, 99% H_2S removal was achieved. However, with increasing the filling rate to 1500 and 1600 h-1, the H_2S removal efficiency decreased to 98% and 94%, respectively

Sajjadnejad et al., (2024), this comparative study evaluated different packing materials for H_2S biofilters, such as activated carbon, compost, and synthetic media. It concluded that media porosity and microbial compatibility are critical for system performance. The first trickling bio filter was inoculated with Acidithiobacillus thiooxidans bacteria and operated without pH control, while the second trickling bio filter was inoculated with Hyphomicrobium bacteria and operated at neutral pH. The reactors used were made of Plexiglas with an internal diameter of 0.045 m and filled with polyethylene rings as bacterial carriers. The maximum removal capacity observed with this system was 83 g H_2S per cubic meter of packing per hour, equivalent to 100% removal efficiency, and 58 g DMS per cubic meter of packing per hour, equivalent to 88% removal efficiency. The paper presented successful biological deodorization of H_2S using Thiobacillus thiooxidans immobilized on lava rock. It highlighted the importance of carrier texture and microbial adherence in achieving stable removal. They used a laboratory-scale bio filtration system using peat as a medium for Thiobacillus thioparus bacteria to treat gas streams containing high concentrations of H_2S. The system consisted of an acrylic tube with a diameter of 0.055 m and a height of 0.6 m, with a working volume of 1 liter. The inoculation systems used resulted in a good bacterial colony formation on the compost, and the number of Thiobacillus thioparus bacteria reached 2.7×108 cells per gram of dry compost. With a H_2S inlet concentration of 355 ppm and an air flow rate of 30 liters per hour, a removal efficiency of 100% was achieved, and the maximum removal capacity was 55 grams per cubic meter of packing per hour.

Musheer et al., (2024) [45], Using modeling and experimental validation, this study optimized a modular bio filter for VOCs. Its modular approach, scalability, and media changeability are directly applicable to designing flexible H_2S bio filtration units. He performed anaerobic biological desulfurization of natural gas using Thiobacillus denitrificans in a three-phase fluidized bed bioreactor and optimized the operating parameters such as time, pH, temperature, and gas flow rate for maximum bacterial growth to maximize H_2S removal efficiency from natural gas. The results showed that the maximum H_2S removal achieved under the optimal conditions of feed temperature of $45^{\circ C}$ and pH of 7 was 89.90%. Several different studies on bio filtration have been conducted in Iran. The bacteria were then easily grown aerobically in a stirred reactor with a continuous feed of H_2S, and various feed rates ranging from 1.73 mmol H_2S/h to 2.28 mmol H_2S/h were tested. At a flow rate of 36 liters per hour with different concentrations of 5, 10, 20, and 60 parts per million (ppm) of hydrogen sulfide, the average removal efficiency was 93.5 percent, which increased to 92.5 percent with an increase in flow rate to 72 liters per hour. The effect of temperature on H_2S removal efficiency was also investigated in the range of $20\text{-}50^{\circ C}$, and the results showed that high removal efficiency was achieved with negligible changes (95-97%) in the temperature range of $25\text{-}37^{\circ C}$. However, the removal efficiency decreased with increasing temperature in the higher temperature ranges ($50\text{-}42^{\circ C}$). For example, when the temperature increased from 37^{oC} to 50^{oC}, the H_2S removal efficiency decreased from 97.5% to 82.5%. The effect of gas residence time in the bio filter was tested by injecting 60 ppm hydrogen sulfide at different gas flow rates into the bio filter, and the highest removal efficiency (more than 97%) was achieved when the residence time was in the range of 40-140 seconds. When the residence time is reduced to 14 seconds, the removal efficiency drops significantly to 25%, since studies show that microorganisms decompose hydrogen sulfide in 1-2 seconds. Therefore, the reduction in removal efficiency at short residence times is due to the slow diffusion from the gas phase to the liquid phase. Because, as mentioned earlier, the gas removal mechanism in the bio filter is such that H_2S is transferred from the gas phase to the liquid film by diffusion and then decomposed.

Conclusion

The results show that the hydrogen sulfide removal efficiency increases with increasing the diffusion coefficient, increasing the specific surface area of the fillers, and decreasing the inlet gas velocity. Also, the hydrogen sulfide removal efficiency increases with increasing the biofilm thickness for low biofilm thickness values. This indicates that at low biofilm thicknesses, the reaction rate is the controlling factor and the biofilm resistance does not have much effect on the separation rate. A further increase in the biofilm thickness reduces the hydrogen sulfide removal efficiency. It seems that the reason for this is the increase in the effect of diffusion on the mass transfer rate. Also, a direct relationship is observed between the porosity of the bio carbon and the biofilm formed on the one hand and the rate of H_2S removal on the other hand. The main product of microbial oxidation of H_2S is sulfuric acid. Adjusting pH, temperature, humidity, and aeration is essential. The evaluation of the bio filter performance is estimated with the Elimination Capacity=EC factor. bio carbon absorbs high concentrations of H_2S and gradually makes it available to filter microorganisms and retains moisture. Therefore, bio carbon is a suitable option for removing hydrogen sulfide from wastewater.

The results of the mathematical model showed that the hydrogen sulfide removal efficiency increases with increasing diffusion coefficient, increasing the specific surface area of the fillers and decreasing the inlet gas velocity. Also, the hydrogen sulfide removal efficiency increases with increasing biofilm thickness, for low biofilm thickness values (5-20 μm). This indicates that at low biofilm thicknesses, the reaction rate is the controller and the biofilm resistance does not have much effect on the separation rate. A further increase in biofilm thickness (20-100 μm) causes a decrease in the hydrogen sulfide removal efficiency. It seems that the reason for this is the increase in the effect of diffusion on the mass transfer rate.

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Authors' Contributions

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