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THIOBACILLUS IN BIOLOGICAL ODOR CONTROL

Harnessing Sulfur-Oxidizing Bacteria for Hydrogen Sulfide and Nitrate Removal

Educational white paper and website blog resource

TWO BIOLOGICAL PATHWAYS. ONE MANAGED PROCESS.

Aerobic H_2S Oxidation

O_2

Sulfur-oxidizing bacteria convert hydrogen sulfide to sulfate under aerobic conditions.

$H_2S \rightarrow O_2 \rightarrow SO_4^{2-}$

Anoxic Denitrification

N

Denitrifying bacteria convert nitrate to nitrogen gas under anoxic conditions.

$NO_3^- \rightarrow NO_2^- \rightarrow N_2$

Biological Odor Control | System Design | Startup & Optimization | Troubleshooting & Support

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Thiobacillus in Biological Odor Control: Harnessing Sulfur-Oxidizing Bacteria for Hydrogen Sulfide and Nitrate Removal

Meta description: Learn how Thiobacillus and related sulfur-oxidizing bacteria remove hydrogen sulfide, reduce nitrate, and support biological odor-control systems in wastewater treatment plants, pump stations, and industrial facilities.

Hydrogen sulfide is one of the most persistent challenges in wastewater collection and treatment. Even at relatively low concentrations, H_2S can create strong rotten-egg odors. At higher concentrations, it presents worker-safety concerns, accelerates infrastructure corrosion, and can overwhelm conventional odor-control equipment.

Biological odor-control systems take a different approach from chemical scrubbers and disposable adsorbents. Instead of repeatedly purchasing chemicals or replacing saturated media, they cultivate microorganisms that use reduced sulfur compounds as an energy source.

Among the organisms most closely associated with this process are Thiobacillus and related sulfur-oxidizing bacteria.

What Is Thiobacillus?

Thiobacillus is a genus within a broader group of sulfur-oxidizing bacteria capable of obtaining energy from reduced inorganic sulfur compounds such as:

- Hydrogen sulfide, H_2S
- Dissolved sulfide, HS^-
- Elemental sulfur, S^0
- Thiosulfate, $S_2O_3^{2-}$
- Other partially oxidized sulfur compounds

Many of these bacteria are chemolithoautotrophs. Rather than relying primarily on organic carbon for energy, they oxidize inorganic sulfur compounds and use carbon dioxide as a carbon source for cell growth.

The term “Thiobacillus” is still commonly used in wastewater engineering, although microbial taxonomy has changed. Several organisms formerly classified as Thiobacillus have been reassigned to genera such as Acidithiobacillus, Halothiobacillus and Thermithiobacillus. For example, Thiobacillus thiooxidans is now generally classified as Acidithiobacillus thiooxidans.

For practical odor-control discussions, “Thiobacillus” often refers broadly to sulfur-oxidizing bacteria that establish biofilms in biofilters, bioscrubbers and biotrickling filters.

How Thiobacillus Removes Hydrogen Sulfide

A biological odor-control system first transfers gaseous H_2S from the air stream into a moist biofilm. The bacteria living in that biofilm then oxidize the sulfide.

Under oxygen-rich conditions, the overall conversion may be simplified as:

$$H_2S + 2O_2 \rightarrow H_2SO_4$$

In an aqueous system, the sulfuric acid dissociates and ultimately appears primarily as sulfate and hydrogen ions:

$$H_2S + 2O_2 \rightarrow SO_4^{2-} + 2H^+$$

This reaction explains two important operating characteristics:

1. Hydrogen sulfide is converted into a nonvolatile form.
2. Complete oxidation creates acidity and can progressively lower the recirculating-liquid pH.

Depending on oxygen availability, microbial community and reactor conditions, sulfide may also be partially oxidized to elemental sulfur:

$$H_2S + \tfrac{1}{2}O_2 \rightarrow S^0 + H_2O$$

Oxygen-limited systems may intentionally favor elemental sulfur production, while strongly aerobic systems tend to promote more complete oxidation to sulfate. Research has demonstrated near-complete biological H_2S removal while changing oxygen availability to influence whether elemental sulfur or sulfate predominates.

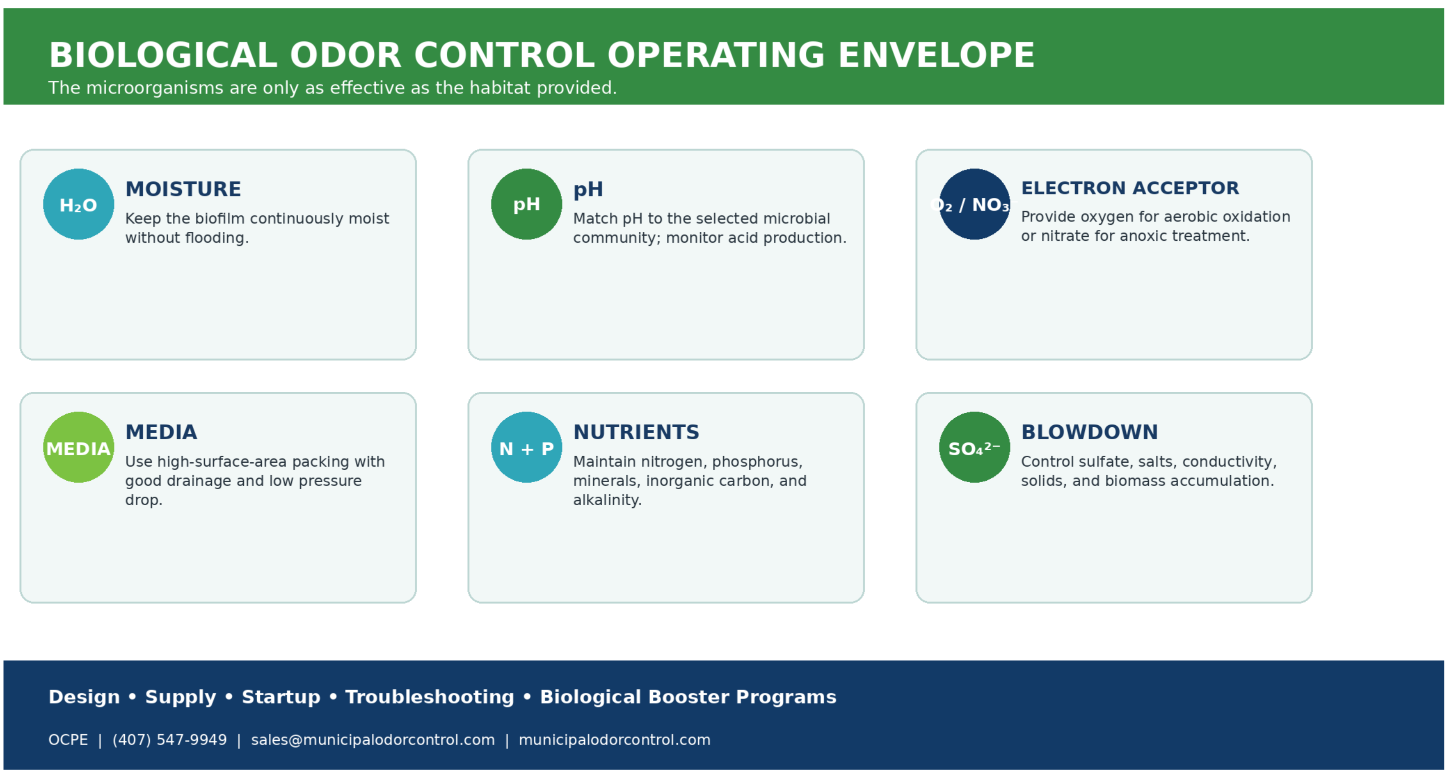

Figure 1. The biological operating envelope must be actively managed to maintain stable H_2S and nitrate-removal performance.

Why the Biofilm Matters

The bacteria do not simply float freely through the odor-control vessel. They generally colonize a moist support surface and form a biofilm.

Common support materials include:

- Structured plastic packing
- Polyurethane foam
- Lava rock or volcanic media
- Ceramic media
- Recycled glass media
- Engineered inorganic media
- Organic biofilter media

A suitable medium provides high surface area, moisture retention, gas distribution and sufficient void space to prevent excessive pressure drop.

Laboratory research using porous lava as a carrier for Thiobacillus thiooxidans demonstrated that water-holding capacity and buffering capacity can materially influence H_2S removal performance. Separate studies have successfully immobilized Thiobacillus thioparus on polyurethane foam in biotrickling filters.

The Important Thiobacillus Groups

Different sulfur-oxidizing organisms perform best under different environmental conditions. A successful biological odor-control system does not merely contain "bacteria." It must cultivate the appropriate microbial community for the expected contaminant load, pH, oxygen level and nutrient conditions.

Thiobacillus thioparus

T. thioparus is a neutrophilic sulfur oxidizer frequently studied for H_2S removal from air. It is commonly associated with systems operated near neutral pH.

A biotrickling-filter study using T. thioparus immobilized on polyurethane foam evaluated operation between approximately pH 6.0 and 8.2, along with sulfate accumulation, liquid recirculation and empty-bed residence time.

Neutrophilic organisms can be useful where the operator wants to maintain moderate pH conditions. However, maintaining that environment may require alkalinity addition because complete sulfide oxidation continually generates acidity.

Acidithiobacillus thiooxidans

Formerly called Thiobacillus thiooxidans, Acidithiobacillus thiooxidans is strongly acidophilic. It can remain active at much lower pH than many neutrophilic organisms.

Acidophilic operation can offer practical advantages:

- Less chemical demand for continuous pH neutralization
- Lower risk of contamination by organisms that cannot tolerate low pH
- Strong activity in sulfate-producing H_2S oxidation
- Potential for treating comparatively high sulfur loads

However, acidic systems require corrosion-resistant materials and careful consideration of effluent handling.

Comparative research has evaluated neutral-pH T. thioparus systems against acidic A. thiooxidans systems, demonstrating that both operating strategies can be effective when the support media and reactor conditions are matched to the organism.

Thiobacillus denitrificans

T. denitrificans is especially important because it can connect the sulfur cycle with the nitrogen cycle.

Under anoxic conditions, it can use reduced sulfur compounds as electron donors and nitrate as an electron acceptor. In simplified terms, it oxidizes sulfide while reducing nitrate toward nitrogen gas.

This makes it relevant to:

- Anoxic biotrickling filters
- Nitrate-driven sulfide control
- Wastewater denitrification
- Sulfide-rich industrial water
- Collection-system odor and corrosion management
- Combined sulfur and nitrogen treatment

Sulfur-driven autotrophic denitrification has been studied for decades and is broadly defined as the coupling of reduced-sulfur oxidation with nitrate reduction.

How Thiobacillus Removes Nitrate

It is important to describe nitrate removal accurately.

Ordinary aerobic H_2S biofiltration does not automatically remove nitrate. Nitrate removal occurs when the system supports sulfur-driven autotrophic denitrification and provides:

- Nitrate or nitrite as an electron acceptor
- An available reduced-sulfur electron donor
- Low-oxygen or anoxic conditions
- Appropriate pH and alkalinity
- Adequate contact time
- A suitable denitrifying microbial population

In that environment, T. denitrificans and related organisms can use sulfide, sulfur or thiosulfate as the electron donor while reducing nitrate.

A simplified sulfide-driven pathway can be represented conceptually as:

Sulfide + nitrate → sulfate + nitrogen gas + water

The actual stoichiometry varies with the sulfur substrate, biomass production and whether nitrate reduction stops at nitrite, continues to nitrogen gas or follows another pathway.

The desired complete pathway is:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The final nitrogen gas leaves the liquid and returns harmlessly to the atmosphere.

Research has shown that nitrate addition can stimulate indigenous nitrate-reducing, sulfide-oxidizing bacteria, including Thiobacillus denitrificans, and reduce sulfide generation or accumulation in wastewater environments.

One Bacterium, Two Treatment Objectives

T. denitrificans is valuable because the same metabolism can address two pollutants simultaneously:

Treatment function	Sulfur compound	Nitrogen compound	Treatment benefit
Electron donor	H_2S, HS^-, S^0 or thiosulfate	—	Provides reducing power
Electron acceptor	—	Nitrate or nitrite	Supports anoxic respiration
Desired conversion	Sulfide to sulfate or sulfur	Nitrate to nitrogen gas	Odor/corrosion and nitrogen control

This process is especially attractive where a water stream contains both nitrate and reduced sulfur. The sulfide becomes part of the treatment mechanism instead of being treated only as a contaminant.

Sulfur-driven autotrophic denitrification also tends to produce less excess biomass than conventional heterotrophic denitrification because the organisms use inorganic carbon rather than requiring a large supplemental organic-carbon feed.

Aerobic Versus Anoxic Biological Sulfide Removal

Aerobic operation

- Oxygen is the primary electron acceptor.
- Sulfide is oxidized to sulfur or sulfate.
- The principal objective is H_2S and odor removal.
- Nitrate is normally a nutrient or minor process constituent, not the main electron acceptor.
- Complete oxidation can lower pH significantly.

This is the most familiar configuration for municipal wastewater odor control.

Anoxic operation

- Nitrate or nitrite replaces oxygen as the principal electron acceptor.
- Sulfide supplies electrons and energy.

- H_2S removal and denitrification can occur together.
- Nitrogen gas is the desired nitrate-reduction product.
- Air addition can be reduced or eliminated in the biological reaction zone.

Anoxic biotrickling filtration has been researched for treating H_2S-containing gas streams, including systems using nitrate-fed T. denitrificans.

However, nitrate dosing must be controlled. Excess nitrate can increase operating cost, create unwanted nitrate residuals, promote nitrite accumulation or shift microbial pathways. In mixed biological systems, high nitrate loading may also interfere with other processes.

Where Thiobacillus-Based Odor Control Is Used

Wastewater treatment plant headworks

Headworks receive turbulent, sulfide-bearing wastewater and frequently release high H_2S loads. Biological systems can treat foul air collected from influent channels, screening rooms, grit chambers, septage receiving areas and influent pump stations.

Lift stations and master pump stations

Long force mains, warm wastewater and extended detention times promote sulfate reduction and sulfide production. Biological treatment can be applied either to the foul air or, with nitrate-based strategies, within the wastewater itself.

Sludge and biosolids processing

Thickening, dewatering and solids handling can release H_2S and other reduced-sulfur compounds. Biological systems are frequently used as a primary stage before polishing media.

Industrial wastewater

Food processing, petroleum operations, rendering, pulp and paper, anaerobic digestion and other industrial processes can produce sulfide-rich gas or water streams.

Biogas treatment

Sulfur-oxidizing bacteria can remove H_2S from digester gas and other energy-gas streams. Oxygen-fed and nitrate-fed biological configurations have both been studied, although biogas applications require careful oxygen control and process-safety review.

Biofilters, Bioscrubbers and Biotrickling Filters

Traditional biofilters

A traditional biofilter passes foul air through moist media colonized by microorganisms.

Advantages include:

- Relatively simple construction
- Low chemical use
- Low energy consumption
- Broad microbial diversity
- Suitability for lower or moderate contaminant loading
- Larger footprint
- Media compaction
- Moisture gradients
- Variable nutrient availability
- Less direct control of pH

Biotrickling filters

A biotrickling filter uses engineered packing with continuously or intermittently recirculated liquid.

The liquid allows operators to control:

- pH
- Nutrients
- Moisture
- Sulfate concentration
- Nitrate concentration
- Conductivity
- Temperature
- Blowdown

Full-scale research has shown that properly operated biotrickling filters can provide stable H_2S removal over extended operating periods, with performance comparable to chemical scrubbing in appropriate applications.

Bioscrubbers

A bioscrubber generally separates gas absorption from biological regeneration. H_2S is first transferred into a liquid and then biologically oxidized in a separate reactor.

This configuration can be advantageous when:

- The gas flow is highly variable.
- The biological reactor requires a longer hydraulic retention time.
- Elemental sulfur recovery is desired.
- Gas absorption and biological oxidation need separate optimization.

Critical Operating Conditions

1. Moisture

The biofilm must remain moist because H_2S must transfer from the gas phase into water before microorganisms can metabolize it.

- Too little moisture causes:
- Biofilm dehydration
- Reduced gas transfer
- Loss of bacterial activity
- Channeling through the media
- Too much liquid can cause:
- Flooding
- Increased pressure drop
- Reduced oxygen transfer
- Media movement
- Biomass sloughing

2. pH

pH determines which organisms dominate.

Neutrophilic Thiobacillus species generally perform near neutral pH.

T. denitrificans has been studied successfully at neutral to moderately alkaline pH.

Acidophilic organisms such as A. thiooxidans tolerate far lower pH.

A study of T. denitrificans in a biotrickling filter reported its strongest H_2S removal performance around pH 7.6–8.5.

There is no universal “best pH” for all biological odor-control systems. The correct setpoint depends on the selected organisms and reactor design.

3. Oxygen or nitrate availability

Aerobic sulfur oxidation requires adequate oxygen transfer. Anoxic sulfide oxidation requires an adequate but controlled nitrate supply.

- When oxygen is insufficient in an aerobic system:
- H_2S breakthrough may occur.
- Elemental sulfur may accumulate.
- Media can plug.
- Odor-removal efficiency can decline.
- When nitrate is insufficient in an anoxic system:
- Sulfide oxidation becomes incomplete.
- Residual H_2S can increase.
- Denitrification performance declines.

4. Sulfate accumulation

Complete sulfide oxidation produces sulfate. If sulfate accumulates in recirculating water, increasing conductivity and ionic strength can inhibit biological performance.

Studies of both T. thioparus and T. denitrificans have evaluated sulfate inhibition as a significant operating parameter.

Blowdown and makeup-water controls are therefore not merely housekeeping functions. They are part of biological-process control.

5. Nutrients

- Although sulfur provides energy, the microorganisms still require nutrients for growth and enzyme production, including:
- Nitrogen
- Phosphorus
- Potassium
- Magnesium
- Trace minerals
- Inorganic carbon

Nutrient limitation may cause slow startup, weak biofilm development or reduced recovery after an upset.

6. Temperature

Most municipal odor-control systems rely on mesophilic organisms. Activity generally improves as temperatures rise within the organisms' preferred range, while cold conditions slow microbial reaction rates.

Seasonal temperature variation should therefore be considered during sizing.

7. Empty-bed residence time

Empty-bed residence time, or EBRT, describes the nominal time the gas occupies the packed reactor volume.

- A shorter EBRT reduces vessel size but increases the required reaction rate per unit of media. Biological systems treating high H_2S loads must balance:
- Gas velocity
- Packing depth
- H_2S concentration
- Mass loading
- Moisture
- Oxygen or nitrate supply
- Target removal efficiency

8. Pressure drop

Excess biomass, mineral deposits and elemental sulfur can obstruct airflow.

- Pressure-drop monitoring provides early warning of:
- Media fouling

- Channeling
- Excess biomass
- Sulfur accumulation
- Flooding
- Distribution problems

Why Biological Systems Sometimes Lose Performance

Sudden increases in H_2S loading: A microbial population acclimated to a moderate load may not immediately oxidize a major peak.

Loss of irrigation: A failed pump, blocked nozzle or empty nutrient tank can dry the biofilm.

Extreme pH change: Insufficient alkalinity can cause rapid acidification in a neutral-pH system. Excessive chemical correction can create the opposite problem.

Sulfate and salt accumulation: Insufficient blowdown allows inhibitory dissolved solids to build up.

Nutrient depletion: The organisms may remain present but become metabolically limited.

Media plugging: Elemental sulfur, solids, scale or excessive biomass can increase pressure drop and reduce effective contact.

Long shutdowns: The biofilm may lose activity when airflow, moisture or nutrient supply stops for an extended period.

Startup and Acclimation

Unlike activated carbon, biological media does not necessarily reach full treatment capacity immediately after installation.

Startup typically includes:

3. Wetting and conditioning the media.
4. Establishing recirculation.
5. Adjusting pH and nutrients.
6. Inoculating the system or relying on natural colonization.
7. Introducing contaminated air gradually.
8. Monitoring H_2S removal and pressure drop.
9. Increasing loading as the biofilm matures.

A bacterial inoculum can shorten the establishment period, but successful startup still depends on maintaining the correct habitat. Adding bacteria without controlling moisture, pH, nutrients and electron acceptors is unlikely to provide sustained treatment.

Thiobacillus Cultures as Biological System Boosters

Existing biological odor-control systems can experience declining performance following:

- Media replacement

- Chemical exposure
- Extended shutdown
- Hydraulic upset
- Nutrient interruption
- Extreme H_2S loading
- Seasonal temperature changes

A concentrated microbial and nutrient booster may help re-establish sulfur-oxidizing activity. Multi-strain formulations can also provide broader metabolic capability than reliance on a single laboratory strain.

A practical booster program may include:

- Sulfur-oxidizing bacteria
- T. denitrificans or related nitrate-reducing sulfur oxidizers
- Supportive Bacillus or Pseudomonas strains
- Enzyme catalysts
- Micronutrients
- Biofilm-support ingredients

The booster should complement, not replace, proper system operation. Persistent breakthrough should trigger evaluation of gas loading, airflow, irrigation, pH, nutrients, sulfate accumulation, pressure drop and media condition.

Advantages of Thiobacillus-Based Odor Control

Properly designed biological systems can provide:

- Continuous H_2S destruction rather than temporary adsorption
- Lower hazardous-chemical usage
- Reduced chemical storage and handling
- Lower secondary-waste production
- Regenerating treatment capacity through microbial growth
- Potential simultaneous sulfide and nitrate removal
- Lower sludge production in autotrophic denitrification
- Compatibility with carbon or multimedia polishing
- Long media life when operating conditions remain stable

Biofiltration and biotrickling filtration have repeatedly demonstrated high H_2S removal efficiencies in laboratory, pilot and full-scale applications.

Limitations and Design Considerations

Biological treatment is not automatically the best solution for every odor source.

Potential limitations include:

- Startup and acclimation time
- Sensitivity to pH, temperature and moisture

- Need for nutrient management
- Sulfate-containing blowdown
- Potential elemental-sulfur accumulation
- Reduced performance during severe loading peaks
- Larger footprint than some adsorption systems
- Limited removal of compounds that are not biodegradable or water-soluble
- Need for polishing when extremely low outlet concentrations are required

A multi-stage design may combine:

10. A biological stage for bulk H_2S removal.
11. A specialized stage for organic sulfur compounds or ammonia.
12. Activated carbon, iron oxide or other media for final polishing.

This approach allows biology to handle the continuous mass load while preserving the polishing media for intermittent peaks and trace residuals.

The Future of Biological Odor Control

Modern biological odor control is moving beyond basic compost biofilters. Emerging and improving designs include:

- Compact biotrickling filters
- Multi-stage biological systems
- Low-profile and underground biofilters
- High-surface-area recycled media
- Automated pH and conductivity control
- Controlled nitrate-fed anoxic reactors
- Selective elemental-sulfur recovery
- Microbial community monitoring
- Targeted biological booster programs
- Hybrid biological and adsorptive systems

The most successful systems treat the microorganisms as a managed process rather than as a passive component inside a vessel.

Conclusion

Thiobacillus and related sulfur-oxidizing bacteria are central to many biological odor-control technologies. In aerobic systems, they transfer hydrogen sulfide from contaminated air into a biofilm and oxidize it to elemental sulfur or sulfate. In carefully designed anoxic systems, organisms such as Thiobacillus denitrificans can couple sulfide oxidation with nitrate reduction, simultaneously addressing sulfur odors and nitrogen contamination.

The biology is powerful, but performance depends on engineering. Media selection, moisture, pH, nutrients, oxygen, nitrate dosing, sulfate control, residence time and loading must all be managed together.

When those conditions are properly controlled, biological odor-control systems can provide an efficient, low-chemical and highly sustainable method for protecting wastewater infrastructure, workers and surrounding communities.

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About OCPE

Odor Control Products & Equipment, LLC (OCPE) supports municipal and industrial clients with biological odor-control system design, equipment and media selection, startup support, troubleshooting, biological booster programs, and hybrid polishing solutions.

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