Conversion of Biological Sulfate in Waste Water Treatment: A Review

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ABSTRACT: Diagnosis of bodies of water polluted with sulfur-containing compounds (S) as a result of seawater intrusion, as well as the the use seawater (e.g. seawater flushing, cooling) and manufacturing processes, became a difficult problem, given that nearly two-thirds of the world's population lives within 150 kilometers of the coast. Using sulfate-reducing bacteria, researchers have already developed a variety of bioartificial systems for the treatment of industrial sulfate-containing sewage and sulfur-contaminated groundwater (SRB). The bulk of these research are focused on SRB alone or on microbiological rather than engineering applications. Existing sulfate-based biochar application and novel methods for treating sulfate-contaminated waterways are addressed in this study. Because the sulfur cycle is linked to the carbon, nitrogen, and phosphorus cycles, a new framework of sulfur-based biotechnologies capable of removing sulfate and other pollutants (such as carbon, nitrogen, phosphorus, and metal) from wastewaters may be created. For a greater understanding of S associated modern biotechnology, all potential electrons donors for sulfate reduction are outlined, giving rates and advantages of each electron donor. The improvement of sulfur conversion-based biotechnologies was aided by a study of known SRB and their environmental preferences with respect to bioreactor operating parameters (e.g. pH, temperature, salinity, etc.). This study not only summarizes information from existing sulfur transformation biotechnologies for further improvement and comprehension, but it also proposes new sulfur-related biotechnology research paths.

KEYWORDS: Pollutants, Sulfur Conversion Biotechnology, Sulfate reduction, Wastewater treatment, Water.

1. INTRODUCTION

Sulfur is mostly found in the natural surroundings in the stable forms of reduced pyrite (FeS2) and oxidized gypsum ($CaSO_4$) in sediment, as well as the sulfate ion in seawater, where it may have been produced photolysis from volcanic SO_2 and H_2S. With impacts from both natural and human processes, polluting groundwater supplies and agricultural output by sulfate and salts, seawater intrusion has become a significant problem in many coastal regions. According to the Intergovernmental Panel on Climate Change (IPCC 2001), global warming will cause a sea-level increase of 110 to 880 mm by 2100. Such a rise would significantly increase saltwater intrusion, worsening water shortages in coastal areas (100 km from shore), where 40 percent of the world's population lives and roughly a third of total freshwater use is dependent on groundwater (UN Atlas of the Oceans). As a result, there will always be a demand for expense and practical purification methods for saltwater polluted groundwater[1].

Seawater, on either hand, offers a variety of alternate water resources, including saltwater desalination, cooling water, and toilet flush with seawater. In comparison to desalination, replacing freshwater with saltwater for toilet flushing offers a cost-effective and long-term solution for water-scarce coastal towns. For example, Hong Kong has been flushing toilets with saltwater for almost 50 years, with a daily supply of 750,000 cubic meters of seawater serving 80 percent of the city's 7 million residents (WSD, 2010). This accounts for 20% of the city's overall water consumption. The use of large-scale saltwater toilets produces salty sewage with an average of 550 mg sulphate and 5000 mg chloride[2].

Different sulfate-laden effluents are generated by manufacturing applications such as pulp, fermentation, pharmaceutical manufacturing, food production, tannery operations, petrochemical and mining activities, in additional to brackish and salty water Mining and metal sectors, on the other hand, produce the most waste having significant levels of sulfate and/or dissolved metals. Acid mine drainage (AMD) is presently one of the world's largest most severe causes of water and soil contamination. Mine effluents, for example, severely contaminated about 19,300 km of streams and rivers, as well as over 72,000 hectares of lakes and reservoirs in 1989. Sulfur-derived garbage is also widely dispersed in the air. Sulfur-containing fossil fuels are responsible for about 90% of anthropogenic SO_2 emissions. Even though wet flue gas desulfurization (FGD) has been effectively used as one of the massive control metrics for atmospheric S groundwater pollution in industrialised countries, cost-effective disposal of FGD by-products/wastes, which include calcium sulfate and resultant wastewater high in chlorides, heavy metals, and dissolved solids, continues to be a problem in developing countries, including India[3].

Due to its multiphase nature under common environmental conditions (i.e. solid, liquid, and gaseous state) as well as a broad range of redox states (from —2 to +6) about which existing chemical and/or biocontrol procedures are built, the underlying cause of these troubles is complex and interconnected sulfur conversions and transitions.

In microbe-mediated physiological sulfur conversions/transports, for example, three processes are usually used: Sulfur (S) assimilation, desulfurization/ dissimilation of organic S, and oxidation / reduction of S molecules, during which complex molecular organic S molecules are desulfurized/decomposed to simple inorganic S compounds such as sulfate, sulfide, and thiosulfate, among others Inorganic S is taken up as a nutrient by a wide range of microorganisms in order to manufacture important S-containing organic molecules, such as cystein. Inorganic sulfur compounds (such as sulfide, elemental sulfur, and thiosulfate) function as electron acceptors in photoautotrophic sulfur bacteria's carbon dioxide fixation. Frigaard and Dahl examined the processes of these bacteria, which are classified into purple and green sulfur bacteria. The research of phototrophic sulfur bacteria has mostly concentrated on microbiology rather than bioprocess innovation due to a lack of understanding of their metabolism and limited environmental biomonitoring applicability. S-reducing bacteria (SRB) play an important part in a variety of waste management and biotransformation methods that have been researched extensively over the years[4].

Due to its multi stage essence under prevalent climate factors (i.e. solid, liquid, and gaseous state) and a broad range of redox states (from 2 to 6) on which current chemical and/or biocontrol processes are built, the underlying cause of these problems is interrelated hydrogen sulfide converters and transitions, as summarized[5].

In microbiota biological sulfur conversions/transports, for example, three processes are usually used: Sulfur (S) assimilation, desulfurization/ dissimilation of organic S, and oxidation / reduction of S compounds, during which complex molecular organic S molecules are desulfurized/ decomposed to simple inorganic S molecules such as sulfate, sulfide, and thiosulfate, among others. Inorganic S is taken up as a food by a wide variety of microbes in order to manufacture important S-containing organic molecules, such as cysteine. Inorganic sulfur compounds (such as sulfide, elemental sulfur, and thiosulfate) function as electron acceptors in photoautotrophic sulfur bacteria's carbon dioxide fixation. Frigaard and Dahl examined the processes of these bacteria, which are classified into purple and green sulfur bacteria (2008). The research of phototrophic sulfur bacterium has mostly concentrated on microbiological rather than bioprocess innovation due to an inadequate knowledge of their metabolic and limited environmental biomonitoring applicability. S-reducing bacteria (SRB) play an important part in a variety of waste management and biotransformation methods that have been researched extensively over the years.

The biological sulfur transformation treatment methods were developed primarily for: a) sulfide formation control, b) hydrogen sulfide volatilization, c) chemical and biological sulfide oxidation, and d) metal sulfide precipitation. To remove the sulfide danger or recover elemental sulfur as a resource, most of these methods combine a single biological step (i.e. sulfate reduction) with a chemical step (i.e. sulfide chemical oxidation) as a treatment period. Rather than controlling or removing other contaminants, the method is often utilized for metal precipitation[6].

2. DISCUSSION

1. *Biological sulfur conversion on different electron donors and acceptor:*

SRB metabolic has been found to include a variety of carbon sources and electron donors, depending on the kind of growth (autotrophic, heterotrophic). Many SRB that can thrive on hydrogen using sulfate as just an electron acceptor may use hydrogen as an effective source of energy (electron donor). High sulfate reduction rates may be obtained in both mesophilic and thermophilic bioreactors within 10 days when H_2 and CO_2 are used as substrates). In fluidized bed bioreactors, synthetic gas combinations of H_2, CO_2, and CO have been investigated for potential reducing costs and optimization. Desulfotomaculum carboxydivorans was effectively isolated by Parshina et al. while Du Preez and Maree (1994) demonstrated a sulfate reduction rate of 2.4 g SO_2 on pure CO. The use of syngas, on the other hand, has two drawbacks: a low CO fraction (5 to over 50%) and CO toxicity towards SRB with a range of concentrations of 2e70 percent vol. Methane may also be burned with an equal quantity of sulfate to produce bicarbonate and sulfide. Anaerobic oxidation of methane (AOM) with sulfide formation is apparent in marine gas hydrate regions or even hypersaline seep sediments. With different culturing of SRB, methane-dependent specific reduction rates of sulfate ranging from SO_2 for day 1 g cell dry mass 1 were found. According to Nauhaus et al., the optimal temperature for sulfate reduction is between 4 and 16 degrees Celsius at 0.1 MPa methane pressure, with methane pressure having a favorable effect on the sulfate reduction (e.g. increasing the methane pressure to 1.1 MPa results in a four to fivefold increase in the sulfide production rate). The mechanism of AOM, on the other hand, is yet unknown. Hoehler et al. hypothesized that archaea and SRB work together to conduct AOM, with the former producing a free, external intermediate that the latter scavenges. The kind of intermediary shuttling between the methane-using archaea and the SRB, however, is unclear[7].

2. *Key Organisms:*

The main organisms in biological S reduction are SRBs. Beijerinck found that anaerobic respiration could convert sulfate to sulfide in sediments in 1895, which was the first indication of SRB activity. The universally dispersed SRB has been identified and counted using a variety of methods. There are two types of counting techniques: 1) direct detection methods and 2) culture approaches. Cultivation is an ancient method that undervalues actual number of bacteria. The direct detection methods are newly invented molecular-based techniques, such as polymerase chain reaction (PCR), fluorescence in situ hybridization (FISH), denaturing gradient gel electrophoresis (DGGE), terminal restriction fragment length polymorphism (T-RFLP), GeneChip®, and pyrosequencing, which are all based on 16S rRNA. Over a century of research has yielded more than 120 species and 40 genera belonging to three bacterial phyla and one prokaryote phylum. These 40 genera were reorganized into two categories based on their biological and metabolic functions, i.e. full and incomplete organic oxidizers, and updated with all possible electron acceptors and morphology, as described by Barton and Hamilton[8].

3. *Sulfur conversion Biotechnologies:*

SRB can grow in a broad variety of conditions, including temperatures ranging from 0 to 100 degrees Celsius, salinity ranging from freshwater to halite saturated solutions, and a pH range of 3 to 9.8. Despite their need for anaerobic metabolism, SRB have been discovered in aerobic environments. This opens up a lot of possibilities for developing SRB-based or similar treatment methods, with anaerobic sulfate reductions being a crucial stage in all sulfur-related waste therapeutic approaches. Sulfide, produced by sulfate reduction of organic matter, may be used as an electron donor for nitrogen removal through autotrophic denitrification or as a catalyst for heavy metal precipitation. Sulfide is converted chemically/biologically to hydrogen sulfide and recovered in more instances, which may be utilized as a raw material for sulfuric acid production or a substrate for metal-polluted soil and sediment bioleaching. However, certain problems associated with the synthesis of elemental sulfur, such as local corrosion, clogging of pipelines and valves, and so on, needed to be solved. The main sulfur reduction biotechnologies developed for industrial and municipal wastewater treatment during the last several decades are analyzed and summarized in this paper. The supplemental material contains the relevant process schematics/principles. The majority of sulfur conversion wastewater treatment biotechnologies are being used in industry. Sulfate-laden wastewaters result from two major factors: 1) sulfuric acid is one of the world's largest chemical products in terms of quantity, and it is widely used in many industrial processes; and 2) mining and metallurgy, as well as the application of sulfur-containing minerals, all result in sulfate-laden wastewaters. In-sewer sulfide control trials via chemical inhibition (e.g. ferrous salt, nitrite), electrochemical oxidation and biological denitrifying sulfide removal (DSR) process have all been used in household wastewater treatments[9].

4. *Factors affecting the efficiency of sulfate reducing bioprocesses:*

Improving and improving bioreactor performance is a major goal in terms of engineering design and operations. Apart from the substrates (carbon and sulfur) and microbial community, which have already been addressed, there are a number of additional variables that may influence the effectiveness of the biopharmaceutical operation. One example is the SANI biological phosphorus removal investigation. where, despite the discovery of a sulfur linked phosphate release and absorption cycle, the advancement of this process was hampered by the lengthy operating time needed (48 h). The sensitivity of most known SRB to even moderate acidity (pH 5) and their slow growth rate are two of the aforementioned characteristics that limit the design and use of salts systems. While raising the pH with lime or using side stream SRB reactors to avoid direct contact of SRB with acidic wastewater are common solutions for low pH applications, there is little writings on low pH SRB reactor operation, apart from John's report on a lab-scale (pH: 3-4) sulfidogenic system using glycerol, acetic acid, and hydrogen as sources of energy. In low pH sulfidogenic systems, information on scale-up problems, substrate restriction, temperature, and seeding sludge impacts is limited. Systematic investigation of SRB bioreactor growth, development, and operation at low pH (pH 5) is required[10].

3. CONCLUSION

Despite numerous lab-scale experiments with selective inhibition of SRB by molybdate, transition elements, or antibiotics, a generally recognized conclusion emerged from years of research and research (Lens et al., 1998) that no practical ways to prevent sulfate - reducing exist. Rather, improving and designing SRB (Table 6) for beneficial S bioconversion applications could be a cost-effective way to improve existing industrial and municipal wastewater treatment systems. Sulfur sources, for example, may be readily integrated into urban sewage disposal by flushing toilets with saltwater or bringing highly sulfate-laden wastes like distillation brine straight into the wastewater treatment plant. Recent advancements in SANI, DS-EBPR, and sulfate reduction de ammonification processes have paved the way for S bioconversion systems to be used in wastewater treatment processes for effective removal of carbon and nutrients with minimum biological sludge formation and greenhouse gas emissions. These benefits are not achievable with traditional carbon loop methods of treatment.

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