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Research review paper

Sulfur-oxidizing bacteria in environmental technology

Dana Pokorna *, Jana Zabranska

Department of Water Technology and Environmental Engineering, Faculty of Environmental Technology, University of Chemistry and Technology Prague, Technicka 5, 166 28 Prague 6, Czech Republic

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ABSTRACT

Hydrogen sulfide is widely known as the most undesirable component of biogas that caused not only serious sensoric and toxic problems, but also corrosion of concrete and steel structures. Many agricultural and industrial waste used in biogas production, may contain a large amount of substances that serve as direct precursors to the formation of sulfide sulfur—sources of hydrogen sulfide in the biogas. Biological desulfurization methods are currently promoted to abiotic methods because they are less expensive and do not produce undesirable materials which must be disposed of. The final products of oxidation of sulfides are no longer hazardous. Biological removal of sulfide from a liquid or gaseous phase is based on the activity of sulfur-oxidizing bacteria. They need an oxidizing agent such as an acceptor of electrons released during the oxidation of sulfides—atmospheric oxygen or oxidized forms of nitrogen. Different genera of sulfur-oxidizing bacteria and their technological application are discussed.

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* Corresponding author at: UCT Prague, Technicka 5, CZ 166 28 Prague 6, Czech Republic.

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1. Introduction

Sulfur compounds of anthropogenic origin significantly pollute the environment and their strongly negative impact in many ways is well known—acid rain, odor problems from polluted surface water bodies, wastewater treatment plants, sewerage, landfills, corrosion of steel and concrete structures, leaching and migration of heavy metals and acidic components of sediments etc. Considering sulfur pollution, serious problems are caused mainly by sulfur in reduced form as sulfides due to their odor and toxic characteristics. Unlike the interest and efforts focused to biological elimination of nitrogen and phosphorous, biological treatment of sulfur pollution was devoted relatively little attention. This is being changed recently and many new biotechnologies have been developed based on knowledge and comprehension of the biogeochemical cycle of sulfur in nature. Sulfur-oxidizing bacteria play a key role in these technologies.

1.1. Sources of sulfide sulfur in environment

Sulfur is frequently present in all organisms and occurs in organic compounds such as amino acids, proteins, enzymes, antibiotics and fats. It is present in organic substances with catalytic, structural and regulatory functions. On the contrary, a biological function of inorganic sulfur compounds is limited. These compounds either serve as a source of sulfur for assimilation and synthesis of organic compounds, or they are used as electron acceptors or donors in dissimilation processes. Assimilatory sulfate reduction is common in prokaryotes, plants and fungi. Dissimilation pathways are used mainly by Eubacteria and Archaebacteria.

Hydrogen sulfide and its ionic forms (HS^-, S^{2-}) are rarely present in natural waters with the exception of special sulfurous mineral springs. Its presence in surface waters is caused mainly by a lack of dissolved oxygen and an associated anaerobic biological decomposition of organic substances containing sulfur or by reduction of thiosulfates, polythionates, elemental sulfur, sulfites and sulfates by sulfate-reducing bacteria (SRB). In the natural environment with a low redox potential the most common inorganic sulfur compounds, but also sulfur incorporated in organic substances, may be reduced to sulfides.

Compounds containing sulfur are particularly undesirable components of input to anaerobic fermentation technology of waste organic matter, where biogas is a final product. Sulfur compounds in any oxidized form are under anaerobic conditions inevitably reduced to sulfides, which depending on the fermentation conditions can pass to biogas as gaseous hydrogen sulfide. This biogas component causes then a problem when biogas is used for energy production. Hydrogen sulfide is very corrosive to some parts of gas motors and its combustion produces SO_x emission. Therefore, it is necessary to remove this undesirable component from biogas before its utilization. Currently, this fact is reflected a greater extent at present, because biogas that is the product of anaerobic fermentation of organic wastes is classified as an alternative energy source.

Sulfide pollution, which is to be treated, comes from different sources, e.g. from anaerobic treatment of organic wastes containing sulfur incorporated in proteins (pig manure, …) (Deng et al., 2006), from sulfides directly produced in wastewater and wastes for instance by tanneries or by a production of rayon viscose. In the case of anaerobic treatment of industrial wastewater from textile (Kabdasli et al., 1995), paper (Janssen et al., 2009), breweries or pharmaceutical industry (Rodríguez Martinez et al., 2005), the problem is high concentration of oxidized forms of sulfur, mainly sulfates and sulfites. Mine water also contains a considerable amount of sulfates (Choudhary and Sheoran, 2012). Sulfides can thus be released during anaerobic treatment of these wastes and wastewater either by sulfate-reducing bacteria by direct reduction of sulfates or by activity of other anaerobic bacteria that break down and subsequently decompose the sulfur proteins.

1.1.2. Sulfate-reducing bacteria as producers of sulfide sulfur

SRB need for sulfate reduction a suitable electron donor, whose choice is based on its acquisition costs (van Houten et al., 1994) and its capabilities to reduce sulfates under given conditions without forming secondary pollutants. Thermodynamic and kinetic parameters of reactions are also important in electron donor selection, affecting a relationship between SRB and other anaerobic fermentation bacteria. Organic matter, which is formed as an intermediate product of anaerobic fermentation or which is added to a system as an external substrate, is usually used as electron donor. An energy yield of reduction reactions of SRB is generally more advantageous than the thermodynamics of reactions of other anaerobic bacteria. Therefore SRB thus decrease usable potential of organic substrate for production of biogas in anaerobic fermentation, consuming its significant proportion (Choi and Rim, 1991). Reduction of sulfates is predominant to reduction of carbon dioxide and production of methane. The significance of this competition increases with decline of COD/SO_4^{2-} ratio, i.e. it depends on the concentration of sulfates (Omil et al., 1998).

Since SRB have different affinity to the individual organic substrates (H_2 > propionate > other organic matter), they compete for substrate with different trophic groups of the anaerobic species (Chen et al., 2008b). Competition between SRB and rapidly growing fermentative and acidogenic bacteria practically does not take place because SRB fail to break down more complex organic substances. Only exceptions are a few representatives of SRB, which are capable of metabolizing sugars and amino acids (Hansen, 1993).

A suitable electron donor is hydrogen for which SRB compete with the hydrogenotrophic methanogens and homoacetogens. In the case of a non-limiting concentration of sulfates, hydrogen is entirely consumed by the hydrogenotrophic SRB, whose reaction is energetically more suitable than reaction of hydrogenotrophic methanogens (Omil et al., 1996). Hydrogen concentration decreases below certain useful threshold concentration for hydrogenotrophic methanogens, which explains their high inhibition in the presence of high concentrations of sulfates; hydrogen concentration limit for hydrogenotrophic SRB is higher (Colleran et al., 1995; Oude Elfering et al., 1994; Oude Elferink et al., 1998). Temperature plays an important role in the competition for hydrogen between the hydrogenotrophic methanogens and SRB. While the SRB are dominant under mesophilic conditions, methanogens are dominant under thermophilic conditions (Colleran and Pender, 2002).

Hydrogenotrophic SRB behave similarly in the presence of formic acid (De Smul and Verstraete, 1999). In the presence of methanol, sulfates may be reduced only by several types of SRB of the genus *Desulfotomaculum*, *Desulfoviobrio* or *Desulfobacterium*. However their growth rate is very low at mesophilic temperature in comparison