Bioresource Technology 101 (2010) 2114–2120

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Biological sulfide oxidation in an airlift bioreactor

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ARTICLE INFO

Article history:
Received 20 July 2009
Received in revised form 29 October 2009
Accepted 30 October 2009
Available online 26 November 2009

Keywords:
Airlift bioreactor
Biological sulfide oxidation
Sulfide production
Elemental sulfur
Dissolved oxygen concentration

ABSTRACT

Biological sulfide oxidation process was investigated in an airlift reactor under oxygen-limited condition (0.2–1.0 mg l^{-1}). Reactor start-up was accomplished using seed sludge from activated sludge process treating domestic wastewater. Synthetic wastewater was used as feed. Gradual increase in volumetric sulfide loading rate resulted in increase of elemental sulfur production. At sulfide loading rate of 2.2 kg S m^{-3} d^{-1}, 50% of influent sulfide was converted to elemental sulfur. At maximum volumetric sulfide loading rate of 4.0 kg S m^{-3} d^{-1}, sulfide consumption of 4.3 kg S kg VSS^{-1} d^{-1} was achieved, and over 93% of sulfide removal was observed. Investigation revealed that up to 90% of sulfide removed was converted to elemental sulfur. Addition of polyaluminium chloride as coagulant was found to be effective for sulfur-particle aggregation.

1. Introduction

Under anaerobic condition, sulfate is converted to sulfide by sulfate-reducing bacteria (SRB). The formation of gaseous and dissolved sulfides from the biological sulfate reduction process causes physical and biological constraints. There is no practical method to prevent sulfate reduction in both anaerobic and aerobic (anoxic microenvironments) wastewater treatment systems. However, by selecting appropriate treatment strategies for sulfate-rich wastewater such as removal of organic matters, removal of sulfate, or removal of both organic matters and sulfate, the problems could be minimized (Lens et al., 1998).

Biological sulfate removal process consists of two serial biological processes, namely: reduction of sulfate to hydrogen sulfide (anaerobic stage); followed by oxidation of hydrogen sulfide to elemental sulfur (aerobic stage) in order to remove the excess sulfide in the treated stream before discharging it to the environment.

In general, the partial oxidation of sulfide changes the reduced ionic sulfur compound to settleable oxidized sulfur cake leading to ease in removal process as per the reaction outlined (Madigan et al., 2003) as below:

$$2HS^- + O_2 \rightarrow 2S^0 + 2OH^- \quad \Delta G^\circ = -210.81 \text{ kJ/mol} \tag{i}$$

$$2HS^- + 4O_2 \rightarrow 2SO_4^{2-} = 2H^+ \quad \Delta G^\circ = -796.48 \text{ kJ/mol} \tag{ii}$$

Mixed-culture studies of sulfide-oxidizing bacteria have shown that the formation of sulfur is dependent on the sulfide loading and the availability of oxygen (Buisman et al., 1989). Fed-batch studies showed that the production of sulfur can be controlled by the amount of oxygen supplied (Janssen et al., 1995). It was also reported that the capacity to produce sulfur was strain dependent on quantitative measurements of sulfur formation under aerobic conditions with pure cultures of several neutrophillic obligatory autophic *Thiobacillus* species (Stefess, 1993; Stefess et al., 1996). *Thiobacillus neapolitanus* can convert only 50% of the incoming sulfide to elemental sulfur while *Thiobacillus* sp. Strain W5 was potential sulfur-producing species with maximum sulfur-producing capacity of 90% (Visser et al., 1997).

In case of highly loaded bioreactors, not all sulfides are converted into sulfur due to the limitation in biological activity. The chemical auto-oxidation of sulfide to thiosulfate becomes relatively important as indicated below (Chen and Morris, 1972):

$$2HS^- + 2O_2 \rightarrow H_2O + S_2O_3^{2-} \quad \Delta G^\circ = -387.34 \text{ kJ/mol} \tag{iii}$$

As previously mentioned, the sulfide oxidation process to be developed must be controlled in such a way that mainly sulfur is produced instead of sulfate. Important criteria for the optimization of the biological sulfide process would then be: (1) minimized production of unwanted sulfate; (2) minimized aeration costs;

Abbreviations: D_i, inner diameter; D_o, outer diameter; DO, dissolved oxygen; HRT, hydraulic retention time; N, normality; NTU, nephelometric turbidity unit; ORP, oxidation reduction potential; S, sulfur; SEM, scanning electron microscopy; SRB, sulfate-reducing bacteria; VSLR, volumetric sulfide loading rate; VSS, volatile suspended solid.

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doi:10.1016/j.biortech.2009.10.093

(3) simple reactor configuration; (4) minimized reactor volume; and (5) minimized chemical usage (Buisman et al., 1990).

Researchers have studied sulfide oxidation with variety of reactor configurations as well as electron donors. Removal of sulfur inorganic compounds by biofilm of sulfate reducing and sulfide oxidation bacteria in a down-flow fluidized bed reactor was recently studied (Celis-García et al., 2008). The researchers successfully transformed sulfate into elemental sulfur under low aeration rate of 2.3 l d^{-1}. This research brought out that it was feasible to obtain elemental sulfur through a coupled anaerobic/aerobic process in one reactor using lactate, sulfate and oxygen from air as substrates. Recent report in sulfide oxidation to elemental sulfur in a bio-membrane reactor brought out that membrane bioreactor can be successfully employed for treating leather tanning industrial waste containing sulfide (Vannini et al., 2008). Several researchers have also reported sulfide oxidation using nitrate as terminal electron acceptor in a natural as well as engineered systems (Kamp et al., 2006; Sher et al., 2008). On the other hand, airlift bioreactors have been employed in several waste treatment application such as treatment of hydrocarbon contaminated waste (Chisti and Moo-Yung, 1994), for nitrification (Shechter et al., 2002). Airlift bioreactor offer several advantages such as better mixing, better contact between microbial floc and substrates. Furthermore, in oxygen limited processes such as sulfide oxidation, application of airlift bioreactor is particularly beneficial due to better and controlled oxygen transfer at low DO.

Recirculation of sulfur particles results in double consumption of the required electron donors (e.g. methanol, ethanol, or hydrogen gas) and increase of sulfide levels in the anaerobic reactor which may cause inhibition of metabolic process. In order to avoid the recirculation of sulfur fraction, the elemental sulfur particles should be removed successively (Buisman et al., 1991). Due to electrostatic force, it is impossible to remove sulfur particles by gravitational settling; except when aggregating with sulfur biomass to form large flocks. Janssen et al. (1996) discussed the possible use of sedimentation, accelerated by addition of flocculants. The findings concluded that the colloidal stability of biologically-produced sulfur greatly depended on the process and environmental conditions prevailing in the bioreactor. In order to improve the sulfur sedimentation capacity, it is necessary to operate the reactor under high loading conditions with minimum of shear forces, so that the large and easily settleable sulfur flocks can be formed (Janssen et al., 1996). Tichy et al. (1998) also found that the immediate oxidation of elemental sulfur particles in an aerated bioreactor is hardly avoidable, unless other measures are applied such as the use of flocculants.

In this study, the airlift bioreactor was developed because of its good mixing property. Air was dispersed into the inner draft tube. The DO concentration increased from the bottom to the top of the draft tube by aeration and decreased in the annulus part from the top to the bottom due to oxygen consumption. Thus, a high recirculation inside the reactor could be achieved and the elemental sulfur, which had a relatively high density, would settle down to the bottom of reactor. The biological sulfide oxidation was investigated during the steady state and the optimal operating conditions for maximizing sulfur production were estimated.

2. Methods

2.1. Process description

The airlift reactor was made of acrylic material with working volume of 4.9 l (excluding settling zone). The 18-mm-inner diameter (D_i) acrylic draft tube with length of 1900 mm was concentrically inserted into the 58-mm-outer diameter (D_o) reactor ($D_i/D_o = 0.31$). Draft tube bottom was 50 mm; sufficient for elemental sulfur settling. The reactor was equipped with pH controller (ProMinent, DULCOMETER D2C). The schematic diagram of the experimental setup is illustrated in Fig. 1. The gas flow was recycled to prevent H_2S escaping from the system. Air was supplied and controlled by a mass-flow controller (Cole-Parmer Flowmeter, type A-32121-22, 0–360 ml min^{-1}) in the range of 60–150 l d^{-1}. The mixed airflow was sparged through air blower inside the draft tube creating air bubble up to top of reactor, and oxygen concentration was maintained. The synthetic sulfide rich wastewater and nutrient solution was continuously supplied via Master Flex (Cole-Parmer) peristaltic pump. The sedimentation tank was

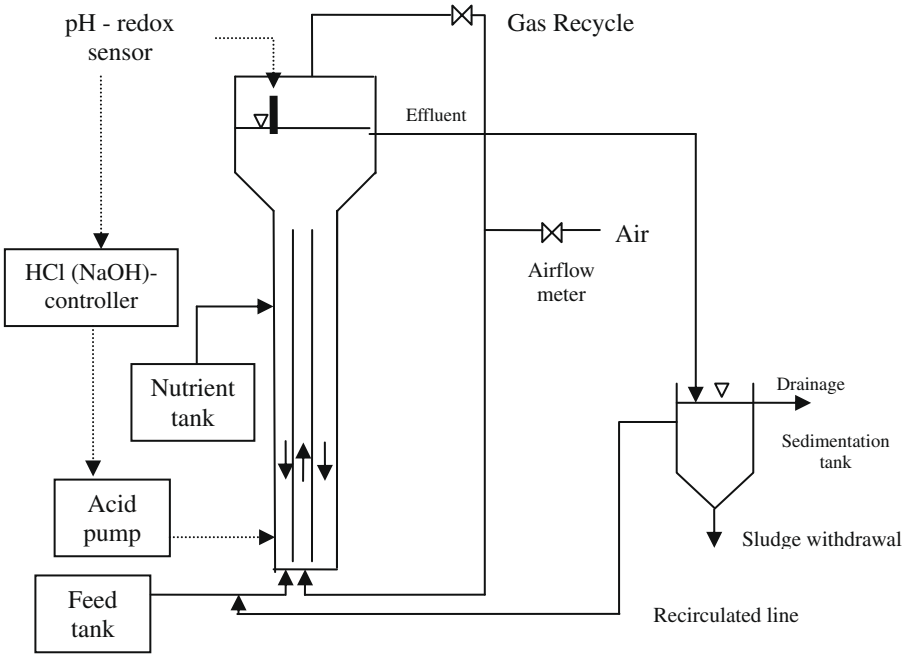

Fig. 1. Detailed schematic flow chart of the biological sulfide oxidation process.