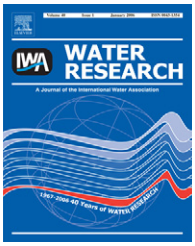
WATER RESEARCH 42 (2008) 1–12

Available at www.sciencedirect.com

ScienceDirect

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



Review

# Chemical and biological technologies for hydrogen sulfide emission control in sewer systems: A review

*Lehua Zhang, Peter De Schryver, Bart De Gusseme, Willem De Muynck, Nico Boon, Willy Verstraete**

*Laboratory of Microbial Ecology and Technology (LabMET), Ghent University, Coupure Links 653, B-9000 Ghent, Belgium*

ARTICLE INFO

*Article history:*
Received 19 March 2007
Received in revised form
10 July 2007
Accepted 12 July 2007
Available online 19 July 2007

*Keywords:*
Concrete corrosion
*Thiobacillus*
Sulfate attack
Sewage
Iron salts
Nitrate
Microbial fuel cells

ABSTRACT

Biogenic corrosion of sewers represents a cost of about 10% of total sewage treatment cost in Flanders (Belgium) and is further increasing. In the past, research has resulted in a number of prevention methods, such as injection of air, oxygen, $H_2O_2$, NaClO, $FeCl_3$ and $FeSO_4$. The possibility of biological oxidation of sulfide using nitrate as the electron acceptor has also been explored in sewer systems. However, all of these methods have a problem with the high cost (€1.9–7.2 $kg^{-1}$ S removal). In this review, new approaches for hydrogen sulfide emission control in sewer systems are discussed. The control of hydrogen sulfide emission by using a microbial fuel cell (MFC) can be cost-effective while the BOD is removed partially. The use of phages that target sulfate-reducing bacteria (SRB) can possibly inhibit sulfide formation. Novel inhibitors, such as slow release solid-phase oxygen ($MgO_2/CaO_2$) and formaldehyde, warrant further study to control hydrogen sulfide emission in sewer systems.

## Contents

---

**Corresponding author.* Tel.: +32 9 264 59 76; fax: +32 9 264 62 48.
E-mail address: Willy.Verstraete@UGent.be (W. Verstraete).

0043-1354/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.watres.2007.07.013

## 1. Introduction

Hydrogen sulfide emission in sewer systems is associated with several problems, including biogenic corrosion of concrete, release of obnoxious odors to the urban atmosphere and toxicity of sulfide gas to sewer workers (ASCE, 1989; Nielsen and Keiding, 1998; Nielsen et al., 1998; US Environment Protection Agency (US EPA), 1974). Minor problems of concrete corrosion have been reported when the concentration of total sulfide in the wastewater is within the range of 0.1–0.5 $mg\,S\,L^{-1}$. Severe concrete corrosion may occur at sulfide concentrations from 2.0 $mg\,S\,L^{-1}$ on (Hvitved-Jacobsen et al., 2002). In Los Angeles County, approximately 10% of the sewer pipes are subject to significant sulfide corrosion, and the costs for the rehabilitation of these pipelines are roughly estimated at €400 million (Sydney et al., 1996). The restoration of the overall damaged sewer systems in Germany is estimated to cost about €100 billion per year (Kaempfer and Berndt, 1998). In Flanders (Belgium), biogenic sulfuric acid corrosion of sewers is approximated at €5 million per year, representing about 10% of total cost for wastewater collection and treatment (Vincke, 2002).

To solve the biogenic corrosion problem, several methods have been investigated, i.e. (1) optimizing the sewer hydraulic design to minimize sulfide generation, (2) sulfate source control technologies such as urine separation or pretreatment, (3) improving the resistance of sewer pipes to biogenic corrosion and (4) decreasing hydrogen sulfide emission from sewage (De Belie et al., 2004; Monteny et al., 2000, 2001; Nielsen et al., 2006a; Scrivener et al., 1999; Yamanaka et al., 2002; US EPA, 1991). This review focuses on chemical and biological technologies that prevent or decrease hydrogen sulfide emission in sewer systems (Fig. 1).

One category involves increasing redox potential, thus decreasing sulfide production. Increasing redox conditions involves addition of thermodynamically favorable electron acceptor compounds such as oxygen, nitrate or nitrite (Bentzen et al., 1995; Hobson and Yang, 2000; Londry and Suflita, 1999). Alternatively, SRB activity can also be inhibited by pH elevation or inhibitors such as biocides and molybdate (Jayaraman et al., 1999; Nemati et al., 2001c; Reinsel et al., 1996).

Another category is chemical and biological removal of sulfide (e.g. addition of iron salts, $H_2O_2$, chlorines or nitrate) that may be considered as ultimate treatments to remove sulfide (Cadena and Peters, 1988; US EPA, 1991). Addition of iron salts or precipitation of ferrous sulfide removes dissolved sulfide from the sewage (Nielsen et al., 2005c; Padival et al., 1995; Tomar and Abdullah, 1994). Addition of $H_2O_2$ or chlorines chemically oxidizes sulfide, thereby decreasing the amount of dissolved sulfide (Tomar and Abdullah, 1994; Waltrip and Snyder, 1985). Addition of nitrate and nitrite may also favor biological oxidation of sulfide by means of nitrate-reducing, sulfide-oxidizing bacteria (NR-SOB) (Garcia De Lomas et al., 2005; McInerney et al., 1996; Nemati et al., 2001a, b; Shelley et al., 2005).

In recent years, significant increase in the knowledge on biological and chemical technologies for hydrogen sulfide emission control in existing sewer systems has been made. This paper summarizes the current state and explores future research possibilities.

## 2. Biogenic corrosion of sewer systems

### 2.1. *Sulfur cycle in sewers and the environmental parameters*

Several processes are associated with the sulfur cycle in sewer networks (Sand, 1997; Lens and Kuenen, 2001). The conceptual models for simulation of the sulfur cycle process and prediction of sulfide buildup in sewers have been developed recently (Lahav et al., 2004, 2006; Hvitved-Jacobsen et al., 1998; Matos and Aires, 1995; Nielsen et al., 2005a–c; Yongsiri et al., 2003, 2004b). Fig. 2 outlines the major processes and environmental parameters associated with the sulfide cycle in sewer systems, including the bulk wastewater, biofilms, sediments, atmosphere and surface exposed to the atmosphere. These processes are (1) formation of sulfide, (2) volatilization of hydrogen sulfide, (3) chemical and biological oxidation of sulfide and (4) precipitation of metal sulfides.

For domestic wastewater, the main source of sulfur is sulfate ($SO_4^{2-}$) in a concentration range of 40–200 $mg\,L^{-1}$ (Araùjo et al., 2000; Kalogo and Verstraete, 1999; Paing et al., 2000). Sulfate can be reduced to sulfide by sulfate-reducing bacteria (SRB) (Fig. 2). This biological process mainly occurs in biofilms and sediments under anaerobic conditions in the submerged part of sewers (Beardslay et al., 1956; Carpenter, 1932; Parande et al., 2006). It is readily observed in areas with