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Sulfide elimination by intermittent nitrate dosing in sewer sediments

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ABSTRACT

The formation of hydrogen sulfide in biofilms and sediments in sewer systems can cause severe pipe corrosions and health hazards, and requires expensive programs for its prevention. The aim of this study is to propose a new control strategy and the optimal condition for sulfide elimination by intermittent nitrate dosing in sewer sediments. The study was carried out based on lab-scale experiments and batch tests using real sewer sediments. The intermittent nitrate dosing mode and the optimal control condition were investigated. The results indicated that the sulfide-intermittent-elimination strategy by nitrate dosing is advantageous for controlling sulfide accumulation in sewer sediment. The oxidation–reduction potential is a sensitive indicator parameter that can reflect the control effect and the minimum N/S (nitrate/sulfide) ratio with slight excess nitrate is necessary for optimal conditions of efficient sulfide control with lower carbon source loss. The optimal control condition is feasible for the sulfide elimination in sewer systems.

Introduction

The production and the emission of hydrogen sulfide by anaerobic microorganisms in sewer systems are a well-documented problem. The emission of hydrogen sulfide produced in anaerobic zones within the biofilm and in sediments that cover the submerged sewer wall to the sewer atmosphere induces the biological production of sulfuric acid, which causes serious corrosion and health problems (Pomeroy, 1990; Hvitved, 2002; Aysen, 2003). In severe cases, hydrogen sulfide can cause a corrosion rate of around 5 mm/year in a concrete surface (Roberts et al., 2002). In Los Angeles, about 10% of the sewer pipes are prone to sulfide corrosion, and the rehabilitation costs of these corroded pipelines are estimated at $400 million (Sydney et al., 1996). These problems further cause a high working load and expensive rehabilitation and maintenance costs of sewer systems (Sydney et al., 1996; Vincke, 2002).

The control of the production and emission of hydrogen sulfide, which are the leading causes of pipe corrosion and sewer odor, was investigated to solve this biogenic problem. Studies on different control methods, such as injecting oxygen or adding nitrate/nitrite, iron salts, or H_2O_2, have been carried out (Zhang et al., 2008). These studies generally involve (1) the prevention of anaerobic conditions by the addition of oxidants (*e.g.*, nitrate, nitrite, and oxygen), (2) the precipitation of formed sulfide with metal salts (*e.g.*, iron, zinc, lead), (3) the elimination of sulfate reduction bacteria (SRB) populations with biocides (*e.g.*, ozone, hydrogen peroxide, and chlorine), (4) increasing the pH by alkali dosing and minimizing sulfide transfer from liquid to gas phase, and (5) improving sewer design (Zhang et al., 2008; Boon et al., 1998; Hobson and Yang, 2000; Gardner and Stewart, 2002; Charron et al., 2004; Gutierrez et al., 2008). For these methods to be effective, chemical or biological continuous dosing by flow-paced and profiled dosing rates was mostly adopted through trial and error methods (Ramon et al., 2011). Thus, the costs of all of these methods are high (0.19–7.2 €/kg S removal) (Zhang et al., 2008). The industry must find a different chemical dosing strategy. And a new chemical dosing method that takes into account the long persistent inhibition effect, such as those of free nitrous acid, was investigated (Ramon et al., 2011; Jiang et al., 2011;

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Jiang et al., 2013a; Jiang et al., 2013b). Thus, a feasible, cost-effective, and efficient control strategy and the optimal conditions of different control methods must be established to rehabilitate and maintain sewer systems.

Control methods such as nitrate dosing with both chemical and biological effects have been favored and are widely used for controlling sulfide formation in sewer networks (Hvitved, 2002; Myhr et al., 2002). The effect of nitrate dosing on sulfide control in laboratory sewer has been mentioned in previous studies (Einarsen et al., 2000; Rodriguez et al., 2005). The sulfur transformation pathways by using important intermediate S^0 in anoxic and anaerobic conditions was reported in the previous studies (Jiang et al., 2009). The influence of nitrate concentration and exposure time on the inhibition levels of SRB and *Methanogenic Archaea* was studied, both in laboratory simulated biofilm reactors of sewers (Jiang et al., 2013a). The effect of nitrate dosing on SRB community change and on nitrate denitrification-sulfide oxidation bacteria (NR-SOB) simulations in biofilms was investigated in previous studies by using laboratory simulated sewer biofilm reactor (Juan et al., 2007; Mohanakrishnan et al., 2009). Furthermore, continuous nitrate dosing at a concentration range of 10 to 40 mg N/L was shown to reduce the sulfide concentration to 0.2–3 mg S/L in main sewers with lengths from 2.4 to 5 km (Bentzen et al., 1995; Saracevic et al., 2006).

However, in practice the build-up of hydrogen sulfide produced in the sediment environment of the gravity sewer system is significant when the sediment was accumulated for a long-term operation of the sewer pipe, especially in the absence of the maintenance and at low flow condition. Moreover, complex carbon, nitrogen, and sulfur cycles simultaneously occur with nitrate dosing in the sewer. Thus, the optimal cost-effective and efficient conditions for sulfide control must include the minimum nitrate dosing amount, the maximum sulfide removal rate, and the minimum carbon source loss in sewer sediments. The minimized loss of organic carbon source will decrease the consumption of easy biodegradable carbon source in wastewater during the transfer process and provide higher biodegradable carbon source for denitrification process in wastewater treatment plants. Although the effectiveness of sulfide control by nitrate dosing has been investigated in many studies, most of which were carried out by using laboratory cultures in biofilm conditions, but the overall demonstration of real sewer sediment conditions and carbon source loss needs to pay more attention. Furthermore, sulfide accumulation concentration and flow dynamics of gas phase and liquid phase have a dynamic behavior, and the dynamics are different and complex in real sewer systems. The optimal control condition for sulfide elimination in the sewer sediment needs to be developed.

This study aims to develop a new, optimal, and effective control strategy and to determine the optimal control condition by intermittent nitrate dosing for sulfide elimination in sewer sediments. The study was carried out by lab-scale experiments with real sewer sediments and by using real domestic wastewater from sewers. Different dynamic intermittent nitrate dosing modes and optimal dosing conditions were investigated. The effects of efficient sulfide control, minimal nitrate dosing, and low carbon source loss were both considered.

1. Material and methods

1.1. Lab-scale sewer reactors and operation conditions

The reactors were made of Perspex and designed in the laboratory to simulate real sewer conditions (Fig. 1). The laboratory reactor system consisted of two parallel lines, with one being named as the implement control reactor (ICR) that conducted different following nitrate dosing strategies (listed as ICR1 and ICR2), another was named as the without control reactor (WCR) and served as the background reference (listed correspondingly as WCR1 and WCR2) during experiments. Each reactor had a volume of 5 L with a diameter of 150 mm and a height of 300 mm. Plastic cylinder vessels with a diameter of 100 mm and a height of 80 mm were fixed on three plastic rods inside each reactor as sediment carriers. The sediments were collected from the downstream of full-scale sewer pipes that contain abundant microbial community to simulate the actual sediment environment of sewer systems. The reactor operated for several weeks to reestablish the original configuration of sediment environment of real sewers. There is a head space in the reactor. The reactors were completely covered with aluminum foil to avoid exposing the sewage and sediment to light. Each reactor had a separate sewage feed, discharge, and control as the experiment schemes.

Domestic wastewater was collected from the end of the drainage network near the wastewater treatment plant and was used as the feed. The sewage had weekly variations in sulfate, volatile fatty acids (VFAs), and chemical oxygen demand (COD) concentration. The typical physicochemical parameters of the fresh sewage are: sulfide 0.20 ± 0.01 mg-S/L, sulfate 65–80 mg-SO_4^{2-}/L, VFA 10.8 ± 0.5 mg-COD/L, total COD 210 ± 5 mg-COD/L and soluble COD 154 ± 5 mg-COD/L, ammonia 45.0 ± 0.5 mg-N/L, pH 7.15–7.60, and oxidation–reduction potential (ORP) from −70 to −100 mV. Nitrate was not present in the fresh sewage. Sulfite and thiosulfate were presented in negligible amounts (<1 mg-S/L). The sewage was stored at 4°C and heated up to 20°C (temperature of experiment) before it was pumped into the reactors. The system was intermittently fed with sewage through a peristaltic pump in the initial phase of the experiment. Every feed transferred 4.5 L of sewage into the reactor system. The nitrate solution was dosed into ICR to obtain final nitrate concentrations of 10 and 30 mg-N/L. The sample was taken once every 8 hr with the experiment tests. The rate of nitrate (r_{NO_3}) and sulfate reduction ($r_{sulfate}$), the consumption rate of COD and VFA (r_{COD}, r_{VFA}), and the rate of sulfide oxidation ($r_{sulfide}$) were tested during the experiment. A similar hydraulic condition with the real sewer system was obtained by the magnetic stirrers (200 r/min) to simulate the sediment environment of the real sewer system. There is no obvious biofilm with rich sulfate reducing bacteria growth attached in the sewer inside wall because of the periodically cleaning during the experiments.

1.2. Design of nitrate dosing schemes

Two strategies of intermittent nitrate dosing mode were developed. The first strategy involves the use of sulfide full elimination (SFE). The nitrate (30 mg-N/L) was dosed into the reactor at once when the sulfide disappeared in bulk water. The second strategy involves the use of sulfide intermittent elimination (SIE). The nitrate (10 mg-N/L) was dosed into reaction when the sulfide accumulated and reached a particular concentration (10 mg-S/L). The two strategies of sulfide control were carried out by intermittent nitrate dosing. The carbon, nitrogen, and sulfur cycles in the process were investigated during the experiments.

The optimal dosing control condition was determined by short-term batch tests. The consistent sediment environment and the same initial condition were kept for serial test