



Research article

Assessment of sulfide production in a full scale wastewater sludge rising main



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ABSTRACT

Production and build-up of sulfide in wastewater systems, especially downstream of rising mains, may lead to severe odour nuisance, toxic environments and high risk of corrosion. Due to increased population migration towards cities and lower area availability for treatment facilities, rising mains for the conveyance of wastewater sludge are becoming more frequent, and research on sulfide build-up in such cases is needed. In this paper the findings of the work carried out in a full scale wastewater sludge rising main, operated during different seasons and under distinct conditions are presented (comprising both the start-up and normal operation stages of the facility). Results showed a sulfide build-up rate of $3.24 \text{ g S}^{-2} \text{ m}^{-2} \text{ d}^{-1}$ in the summer and of $2.30 \text{ g S}^{-2} \text{ m}^{-2} \text{ d}^{-1}$ during the winter. The ratio of sulfate reduction to sulfide production ($\text{SO}_4^{2-}/\text{S}^{-2}$) was of roughly 3 to 1, as expected. Furthermore, obtained results allowed adjusting a second order polynomial empirical equation for the forecasting of sulfide build-up within the sludge rising main. The obtained equation for sludge significantly differs from existing equations obtained for wastewater. Moreover, this work also allowed obtaining new insight into the positive influence of biofilm and hydraulic retention time in the biological sulfide generation, as well as into its variation along the length of the rising main.

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1. Introduction

Build-up of sulfide in wastewater collection and treatment systems has been a major concern for utilities for several decades, due to the production of hydrogen sulfide (H_2S), known to cause extremely negative impacts, such as microbiologically induced infrastructure corrosion, toxic environments and severe odour nuisance (Thistlethwayte, 1972; Matos, 1992; Talaiekhazani et al., 2016). Annual sewer corrosion cost estimates are high, ranging from 5 million euros in Belgium, to about 100 million dollars in Australia and Germany (Gutierrez et al., 2011; Romanova et al., 2014). In addition, minimization and odour abatement strategies are also costly, and usually involve biochemical oxidation or sulfide precipitation (Zhang et al., 2008), through chemical dosage, thus

contributing to large resource consumption.

The sulfur cycle in sewers is complex, involving processes both in the aerobic and anaerobic stages, as well as in the liquid and gas phases. In absence of dissolved oxygen (DO) and nitrate, sulfide is generated by the activity of sulfate reducing bacteria (SRB) mainly present in the biofilm attached to sewer walls, and in sediments to some extent. The respiration process occurs in presence of sulfate (acting as the electron acceptor) and organic carbon, generating carbon dioxide (CO_2) and H_2S (Matos, 1992). Anaerobic conditions are more likely to occur in full-flowing sewers and rising mains. Hvitved-Jacobsen et al. (2013) summarized the main factors affecting the rate of sulfide generation, as: a) the quantity and quality of organic matter available as substrate for biomass growth and as electron donor for SRB; b) the liquid mass temperature (which affects both biological activity and oxygen solubility); c) pH (the optimum range for SRB is from 6 to 9); d) the Area/Volume ratio of the pipe (seeing as sulfide is primarily produced in the biofilm); e) flow velocity, as it impacts the thickness of the biofilm; and f) the anaerobic residence time during transport. Downstream

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of rising mains, under turbulent conditions, the H₂S liquid-gas mass transfer may be affected by phenomena such as airborne droplets, falling wastewater film or air entrainment in the tailwater (Corsi and Quigley, 1996).

Composition of microbial communities in the biofilm and variation in its activity along the length of rising mains also seem to affect the sulfide production rate. For instance, Auguet et al. (2015) studied the colonization of sewer walls by SRB and methanogenic archaea (MA), having observed some sulfide generation from the onset of biofilm development, reaching rather high concentrations after only two weeks of biofilm growth (290.7 ± 72.3 mg S-H₂S l⁻¹ d⁻¹). Mohanakrishnan et al. (2009) have observed higher biofilm activity, in terms of sulfide production, in the upstream section of a rising main, mostly due to its exposure to more abundant substrate and sulfate in the effluent, when compared to the downstream section. In order to address the in-sewer H₂S issue, several empirical equations aiming to predict sulfide build-up in rising mains have been proposed in specialized literature over the past decades. These were obtained using either raw or reclaimed wastewater, as summarized in Table 1. Prediction parameters common to most formulations include several forms of organic matter content, i.e., total or dissolved chemical oxygen demand (COD), biochemical oxygen demand (BOD₅), or volatile fatty acids (VFA), as well as other additional wastewater quality or hydraulic parameters, such as temperature (T), sulfate concentration (C_{S04}), pipe diameter (D) or mean flow velocity (u). Equation (3) includes an empirical parameter, M' (m h⁻¹), which increases with the hydraulic retention time (HRT), although some authors suggest it varies due to the initial presence of DO in the upstream sections of a rising main (Matos, 1992). Typically, it is assumed to be 0.001 m h⁻¹ for design purposes (Pomeroy, 1959). Equations (4) and (6) introduce a dimensionless parameter, ε, to account for different wastewater sources, ranging from 0.001, for typical Danish domestic effluents, to 0.01 for effluents resulting from food processing industries with high concentration of biodegradable organic matter.

Although more complex models, attempting to include all major steps and components of the in-sewer sulfur cycle, have recently been proposed (such as WATS, by Hvitved-Jacobsen et al., 2013 or SeweX, by Sharma et al., 2008), use of empirical equations is also of extreme convenience for utilities wanting an expedite, and inexpensive way to predict sulfide concentrations at its hotspot locations (given their lower demand for calibration parameters), or wanting to adopt model-based Real Time Control strategies.

Despite these efforts, the aforementioned studies and mathematical formulations were obtained using wastewater, regardless of the fact that many authors have identified sludge handling operations as major odour sources (Suffet et al., 2009; Liu et al., 2016), and fewer studies have addressed sulfide related issues, especially during sludge pumping. Due to increased population migration towards cities and lower area availability for treatment facilities,

rising mains for the conveyance of wastewater sludge are becoming more frequent, and research on sulfide build-up in such cases is needed. To illustrate this, numerous examples of sludge rising mains of different lengths and carrying different sludge types can be found in Wang et al. (2008).

Moreover, sulfide generation and H₂S release in sludge treatment operations is also an additional concern, seeing as it compromises the functioning of cogeneration units, generates sulfur dioxide emissions during combustion processes, and at concentrations above 200 mg l⁻¹, sulfide can become toxic to methanogens and is reported to inhibit the anaerobic process of biogas production (ASCE, 1989). Notwithstanding, existing literature mostly focus on predicting H₂S volatilization or odour characterization from individual WWTP components (Suffet et al., 2009; Latos et al., 2011; Lebrero et al., 2013).

There seems to be a lack of knowledge regarding biofilm activity and evaluation of sulfide build-up in sludge rising mains and H₂S release from sludge handling operations, indicating that more data is necessary on this subject, as to accurately calibrate mathematical models and efficiently manage sludge treatment systems with regard to odour, risk and cost minimization strategies.

Given that it is frequently difficult to obtain accurate scaling factors from laboratory experiments to real systems (Zhang et al., 2016), full scale data is essential to obtain a more precise evaluation of the in-sewer processes, such as sulfide generation rates, H₂S release, chemical reagent dosage, and optimization of operational procedures (for instance ventilation and pumping schemes). Some authors also found that important parameters are difficult to accurately reproduce at lab-scale, such as A/V ratios, biofilm thickness or pumping turbulence, usually defined by a Reynolds (Re) number and mimicked through use of magnetic stirrers, and are often only roughly approximated when studying biofilm bioprocesses (Gutierrez et al., 2011; Mohanakrishnan et al., 2009).

To avoid the aforementioned drawbacks, this paper includes the results of extensive full scale field data measurements regarding sulfide processes occurring in different phases of operation of a wastewater sludge rising main. Data was collected during both the start-up stage and the established operation stage of a sludge rising system, with the latter also taking seasonal variation into account. The main purpose of the study was twofold:

- To gain insight into the dynamics of microbiologically induced sulfide formation in a sludge rising system along the conduit, with focus on different operating conditions and biofilm development stages, i.e., young versus mature biofilm;
- To obtain a mathematical formulation able to predict sulfide build-up rates in the studied sludge rising main, preferably related to parameters frequently monitored by utilities, and assess how it compared to existing equations applicable to wastewater.

Table 1
Summary of models to forecast sulfide build-up in wastewater rising mains.

Model for sulfide generation (expressed in g S m ⁻² h ⁻¹ at 20 °C)	Eq.	Reference
$0.5 \times 10^{-3} u BOD^{0.8} C_{S04}^{0.4} \times 1.039^{T-20}$	(1)	Thistlethwayte, 1972
$0.228 \times 10^{-3} COD \times 1.07^{T-20}$	(2)	Boon and Lister, 1975
$M' BOD \times 1.07^{T-20}$	(3)	Pomeroy and Parkhurst, 1977
$\epsilon_1 \times (COD - 50)^{0.5} \times 1.07^{T-20}$	(4)	Hvitved-Jacobsen et al., 1988
$1.52 \times 10^{-2} COD \times \left(\frac{1+0.004D}{D} \right)$	(5)	Boon, 1995
$\epsilon_2 \times (COD - 50)^{0.5} \times 1.03^{T-20}$	(6)	Nielsen et al., 1998
Adjusted ϵ_1 in Eq. (4) for various Danish effluents	(7)	Nielsen et al., 1998
$0.0025 \times 10^{-3} COD_s^{2.1} \times 1.07^{T-20}$	(8)	Elmaleh et al., 1998
Adjusted M' in Eq. (3)	(9)	Hvitved-Jacobsen et al., 2013

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