



Sulfide and methane production in sewer sediments: Field survey and model evaluation



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ABSTRACT

Sewer sediment processes have been reported to significantly contribute to overall sulfide and methane production in sewers, at a scale comparable to that of sewer biofilms. The physiochemical and biological characteristics of sewer sediments are heterogeneous; however, the variability of in-sediments sulfide and methane production rates among sewers has not been assessed to date. In this study, five sewer sediment samples were collected from two cities in Australia with different climatic conditions. Batch assays were conducted to determine the rates of sulfate reduction and methane production under different flow velocity (shear stress) conditions as well as under completely mixed conditions. The tests showed substantial and variable sulfate reduction and methane production activities among different sediments. Sulfate reduction and methane production from sewer sediments were confirmed to be areal processes, and were dependent on flow velocity/shear stress. Despite of the varying characteristics and reactions kinetics, the sulfate reduction and methane production processes in all sediments could be well described by a one-dimensional sewer sediment model recently developed based on results obtained from a laboratory sewer sediment reactor. Model simulations indicated that the in-situ contribution of sewer sediment emissions could be estimated without the requirement of measuring the specific sediment characteristics or the sediment depths.

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1. Introduction

Operation of sewer systems and downstream wastewater treatment plants is considerably influenced by the physical, chemical, and biological processes occurring in sewers (Hvitved-Jacobsen et al., 2013). One of the major concerns when designing and operating a sewer system is the process of sulfate reduction which is mainly due to slow-growing, sulfate-reducing bacteria (SRB), and which causes the build-up of odorous hydrogen sulfide ($H_2S_{(g)}$) in sewer networks (Hvitved-Jacobsen et al., 2013). This anaerobic process occurs in both the sediments and biofilms covering the wetted inner surfaces of sewer pipes. Sulfate reduction and H_2S emission underpin microbially induced concrete corrosion in sewers, resulting in significant, detrimental economic impact

throughout the world (Nielsen et al., 2008; Pikaar et al., 2014; Sharma et al., 2008). Another microbially mediated process, which also causes problems in sewer systems, is the production of methane gas by methanogenic archaea (MA) through methanogenesis (Guisasola et al., 2008; Liu et al., 2015c, 2014). Methane production in sewer systems also requires control as; (a) at concentrations greater than 5%, methane forms an explosive mixture with air, (b) methane is a greenhouse gas with a global warming potential of approximately 34 times that of carbon dioxide, and (c) methanogenesis depletes carbon sources in sewage, which in turn affects downstream nutrient removal processes at the wastewater treatment plant (Guisasola et al., 2009; Liu et al., 2015b).

To date, many studies have focused on methane and sulfide production by biofilms covering the wetted surface of sewer walls (Guisasola et al., 2008; Hvitved-Jacobsen et al., 2013; Nielsen et al., 2005; Sharma et al., 2008; Sun et al., 2014, 2015). However, in contrast to sewer biofilms, which typically have a depth of several hundred micrometers, sewer sediments exhibit a biologically active bacterial layer of several centimeters or more, which could contribute significantly to sulfide and methane production

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(Schmitt and Seyfried, 1992). Considering that the sediment deposition rates range from 30 to 500 g per meter length of sewer every day (Ashley et al., 2003, 2005), it is likely that methane and sulfide production from sediments is significant. Recently, Liu et al. (2015d) demonstrated that sewer sediment collected from a sewer in Australia produced significant amounts of sulfide and methane, with a rate higher than, or comparable to, those of rising main sewer biofilms, proving that the contribution of sediments to sulfide and methane production in sewer systems cannot be ignored. However, sediment deposition rates and characteristics are highly variable both temporally and spatially (Ashley et al., 2005; Ashley and Verbanck, 1996), which is expected to result in heterogeneity of sulfide and methane production from different sewer sediments under varied operational conditions (flow or static). Therefore, detailed studies are required to evaluate the variability of sulfide and methane production from sewer sediments.

Mathematical modeling of in-sewer processes is of great importance for a holistic understanding of the sewer system and optimization of practical mitigation strategies for sewer emissions. The established WATS (Hvitved-Jacobsen et al., 1998) and SeweX models (Guisasola et al., 2009; Sharma et al., 2008) have been widely applied to simulate in-sewer biological reactions as biofilm processes, without consideration of the contribution from sewer sediments. Recently, a detailed one-dimensional sediment model was built to predict sulfide and methane production as well as microbial distribution in sewer sediment (Liu et al., 2015a). However, this model was validated by a single sediment sample incubated in a laboratory sediment reactor, with applicability to other sediments remaining unknown.

The objective of this study was to assess the variability of sulfide and methane production activities of sewer sediments collected from different systems, and their dependency on the sewage flow conditions. The second objective is to assess the applicability of a previously proposed one-dimensional in-sediments reaction model for describing sulfide and methane production in sewer sediments with different characteristics. These results, when coupled to models predicting the in-sewer sedimentation processes, will enable more accurate prediction of sulfide and methane production in sewer networks.

2. Materials and methods

2.1. Sediment characteristics

Sediment selection was based on the sewer location and age, and characteristics of wastewater discharged to the sewer. A total of five sewer sediment samples were collected from Sydney (Sediments A, B and E) and the City of Gold Coast (Sediments C and D), Australia (Table 1). Sediments A, C, D and E were collected from sewers receiving domestic wastewater only (Table 1). Sediment A was collected from a relatively young sewer while Sediments C, D, and E from relatively old sewers. Sediment B was collected from a sewer, which received wastewater from both domestic and industrial sources. Industrial wastewater discharge to sewer B was

composed of 49.7% food/beverage, 30.4% cooling tower, 10.6% metal processing, 5% transport services, and 4.3% pharmaceutical industries. Sediment collection was conducted using a shovel, with maximum care taken to have the sediments as intact as possible. Sampled sediments were then carefully placed into the plastic containers to avoid disturbance before topping up the container with sewage collected from the same system. After transportation, the samples were stored at 4 °C in the laboratory. Sediments were analyzed for total solids (TS), volatile solids (VS) and bulk density (Table 1).

2.2. Batch tests

In order to investigate the variability of sulfide and methane production by sewer sediments, four types of batch assays were carried out to determine: (i) the exogenous sulfate reduction and methane production rates of suspended sediments with sewage being present in excess, (ii) the endogenous sulfate reduction and methane production rates of suspended sediments in the absence of sewage, (iii) the sulfate reduction and methane production activity under stagnant conditions mimicking sewer conditions between pumping events (no sewage flow over the sediments), and (iv) the effect of flow velocity (shear stress) on the sulfate reduction and methane production activity of the sediments.

2.2.1. Exogenous rate of sulfate reduction and methane production of suspended sediments supplemented with sewage

Batch assays to investigate the maximum sulfate reduction and methane production capacity of suspended sediments (Sediments A – E) in the presence of exogenous carbon sources (raw sewage) were carried out in 120 mL serum bottles. Serum bottles were filled with 60 mL sediment, sealed with rubber butyl stoppers and aluminum crimps, and flushed with N₂ gas to create an O₂-free environment. Sediments were weighed to determine the bulk density. The serum bottles were then completely filled with 60 mL of fresh sewage, which typically contained 15–25 mg SO₄²⁻-S/L, <1 mg H₂S-S/L, 50–100 mg VFA-COD/L and <1 mg CH₄/L. The ‘control’ bottle contained oven-dried sediment (105 °C) (which inactivated sediment biomass) to determine the methane production and sulfate reduction potential of suspended biomass in sewage.

Serum bottles were then continuously and vigorously mixed using an orbital shaker (Bioline, Edwards Ins. Co. Australia) to cause complete suspension of sediment. The aim of complete suspension was to increase the surface area of the sediment so that the maximum achievable rates could be determined. It should be noted that all the experiments were conducted in closed systems without headspace, and in the absence of oxygen to prevent oxidation of sulfide. Batch experiments were carried out in triplicate over a 2 h duration. Sampling was done at time 0, 40, 90, and 120 min, and the samples were analyzed for sulfur species and methane content. The TS and VS contents in each serum bottle were measured subsequent to completion of the batch test.

Table 1
Sampling locations and characteristics of sediments.^a

Sediment	Catchment	Sewage type	Location	TS content (% wet weight)	VS content (% wet weight)	Bulk density (g/cm ³)
A	Liverpool/Moorebank	Domestic	Pumping Station	79.7 ± 0.59	1.58 ± 0.05	1.66
B	Moorebank/Wattle Groove	Domestic/industrial	Pumping Station	25.0 ± 3.86	3.73 ± 0.25	1.35
C	Burleigh Heads	Domestic	Manhole	74.0 ± 0.44	0.71 ± 0.03	2.02
D	Elanora WWTP	Domestic	Grit Chamber	17.7 ± 0.78	12.1 ± 0.27	1.12
E	Coogee	Domestic	Grit Pit	74.0 ± 0.98	3.40 ± 0.26	1.37

^a Mean ± standard error (*n* = 6).

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