WATER RESEARCH 68 (2015) 522–532

Available online at www.sciencedirect.com

ScienceDirect

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

Implications of Downstream Nitrate Dosage in anaerobic sewers to control sulfide and methane emissions

Olga Auguet [a], *Maite Pijuan* [a], *Helena Guasch-Balcells* [a], *Carles M. Borrego* [a,b], *Oriol Gutierrez* [a,*]

[a] *Catalan Institute for Water Research (ICRA), Scientific and Technological Park UdG, Girona, Spain*
[b] *Group of Molecular Microbial Ecology, Institute of Aquatic Ecology, University of Girona, Girona, Spain*

ARTICLE INFO

Article history:
Received 19 June 2014
Received in revised form
18 September 2014
Accepted 24 September 2014
Available online 18 October 2014

Keywords:
Sewer
Nitrate
Sulfide
Methane oxidation
Microbial biofilms

ABSTRACT

Nitrate (NO_3^-) is commonly dosed in sewer systems to reduce sulfide (H_2S) and methane (CH_4) produced in anaerobic rising main pipes. However, anoxic conditions along the whole rising pipes are difficult and costly to maintain since nitrate is added at the upstream sections of the sewer. In this study we tested the effects of the Downstream Nitrate Dosage strategy (DND) in anaerobic pipes in a specially designed laboratory-scale systems that mimics a real rising main. Effectiveness of the strategy was assessed on H_2S and CH_4 abatement on the effluent of the lab sewer system. A combination of process (Normal Functioning monitoring and batch tests) and molecular (by 454-pyrosequencing) methods were used to investigate the impacts and microbial activities related to the nitrate addition. Results showed a complete abatement of H_2S generated, with a fraction transformed to elemental sulfur (S^0). Methane discharged was reduced to 50% while nitrate was added, due to the CH_4 oxidation in the anoxic conditions established at the end of the pipe. Both sulfidogenic and methanogenic activities resumed upon cessation of NO_3^- dosage. An increase of microorganisms of the genera *Simplicispira*, *Comamonas*, *Azonexus* and *Thauera* was detected during nitrate addition. Regarding anoxic methane oxidation, only one Operational Taxonomic Unit (OTU) was identified, which is likely related with this metabolism. Obtained results are relevant for the optimal management of nitrate dosage strategies in sewer systems.

1. Introduction

Sewer networks are important infrastructures aimed to collect and transport wastewater to wastewater treatment plants (WWTP). Wastewater is transported either through aerobic (gravity) or anaerobic (rising-pressured) sewer pipes where biofilms are usually developed. The activity of microorganisms that are part of these biofilms produces changes in wastewater characteristics during its transport. These

* *Corresponding author*. Tel.: +34 972183380; fax: +34 972183248.
E-mail addresses: oauguet@icra.cat (O. Auguet), mpijuan@icra.cat (M. Pijuan), cborrego@icra.cat, carles.borrego@udg.cat (C.M. Borrego), ogutierrez@icra.cat (O. Gutierrez).
http://dx.doi.org/10.1016/j.watres.2014.09.034
0043-1354/

Abbreviations

CH_4	Methane
COD	Chemical oxygen demand
DND	Downstream Nitrate Dosage
H_2S	Sulfide
hNRB	Heterotrophic, nitrate reducing bacteria
HRT	Hydraulic retention time
IC	Ion chromatography
MA	Methanogenic archaea
MOR	Methane oxidation rate
N_2O	Nitrous oxide
NF	Normal functioning
NO_2^-	Nitrite
NO_3^-	Nitrate
NRR	Nitrate reduction rate
OTU	Operational taxonomic unit
S^0	Elemental sulfur
SBR	Sulfate reducing bacteria
SCR	Sulfide consumption rate
sCOD	Soluble chemical oxygen demand
SO_4^{2-}	Sulfate
soNRB	Sulfide-oxidizing nitrate-reducing bacteria
SPR	Sulfate production rate
TSS	Total suspended solids
VFAs	Volatile Fatty Acids
VSS	Volatile suspended solids
WWTP	Wastewater treatment plants

changes may affect on the subsequent wastewater treatment, the integrity of sewers and also produce health and environmental risks (Hvitved-Jacobsen, 2002).

A widely reported problem in anaerobic sewers is the production of sulfide (H_2S) as a result of oxidation of organic matter by sulfate reducing bacteria (SRB) (Boon, 1995; Hvitved-Jacobsen, 2002). When H_2S is released to the sewer atmosphere it causes malodor, corrosion and health problems. However, H_2S is not the only problematic compound produced under these conditions. Recently, the generation of methane (CH_4) by methanogenic archaea was also detected in sewers systems (Foley et al., 2009; Guisasola et al., 2008). Management of CH_4 is very important as it is a potent greenhouse gas with higher global warming potential than carbon dioxide (IPCC, 2013) and it is also a safety problem in confined spaces due to its low explosion limit (Spencer et al., 2006). Another problem caused as a consequence of methane production is the consumption of part of the chemical oxygen demand (COD) in wastewater that is needed for biological nutrient removal in WWTP.

Different mitigation strategies have been used to reduce H_2S and CH_4 production in sewers. Those include the addition to the sewer-liquid-phase of nitrate (Jiang et al., 2009; Mohanakrishnan et al., 2009a,b; Zhang et al., 2008), nitrite (Jiang et al., 2011a, 2010; Mohanakrishnan et al., 2008), free nitrous acid (Jiang et al., 2011b), iron salts (Firer et al., 2008; Gutierrez et al., 2010a), oxygen (Boon, 1995; Gutierrez et al., 2008), magnesium hydroxide (Gutierrez et al., 2009) or sodium hydroxide (Gutierrez et al., 2014). Although primarily designed to control sulfide, these chemical-dosing practices may also induce inhibitory effects on methanogens in sewers.

Nitrate (NO^{3-}), for instance, is an effective and widely used chemical especially in Europe (Ganigue et al., 2011; Zhang et al., 2008). Two main mechanisms have been suggested to control sulfide production by nitrate addition in sewers: anoxic sulfide oxidation and competitive exclusion of SRB. The first involves the growth of a chemolithotrophic sulfide-oxidizing nitrate-reducing community, able to oxidize sulfide to elemental sulfur as a major intermediate coupled to nitrate reduction. The latter triggers the development of a heterotrophic, nitrate reducing bacteria (hNRB) community, competing with SRB for organic electron donors. Jiang et al. (2013) proposed a conceptual biofilm model with competitive and synergistic interactions among hNRB, sulfide-oxidizing nitrate-reducing bacteria (soNRB), SRB and methanogenic archaea (MA) occurring in upstream sections of a sewer pipe. They suggested that microbial stratification within the biofilm plays a major role and that methane control is related to penetration of nitrate into the biofilm. Methanogenesis would persist in the deeper parts of the biofilm where soluble chemical oxygen demand (sCOD) would penetrate but not nitrate and/or sulfate (SO_4^{2-}).

Nitrate is normally dosed at wet wells or pumping stations. However the main limitation of this approach is that anoxic conditions must be continuously kept through the whole pipe, otherwise H_2S build-up resumes immediately after the depletion of the dosed nitrate (Mohanakrishnan et al., 2009a,b). This implies very high costs in chemicals, typically between 48.7 and 159.3 $/ML according to Ganigue et al. (2011), since the presence of nitrate has to be ensured along all the sewer pipe. The need for more cost-effective methods for H_2S and CH_4 mitigation has led to the development of new nitrate dosing strategies based on improved dosage rates and dosing locations. For instance, Gutierrez et al. (2010b) tested seven different nitrate dosing strategies in a laboratory-scale sewer system, providing strong support to H_2S-control optimization. The results showed the benefits of adding nitrate at a point close to the end of the pipe, named Downstream Nitrate Dosage (DND). With this strategy, H_2S production was still occurring in the first sections of the pipe not exposed to nitrate but was immediately consumed as soon as passing through the anoxic sections. Nitrate consumption was reduced by 42% while still ensuring complete abatement of H_2S. However the effects of the DND on methane production from sewers have not been established yet. The simultaneous presence of H_2S, CH_4 (generated in upstream pipe sections) plus NO_3^- (added in downstream sections) would lead to different conditions, not reported to date, that could be important to validate the overall effectiveness of the DND strategy.

The aim of this study is to determine the effects of Downstream Nitrate Dosage on anaerobic sewer biofilms with regards to sulfide oxidation and, for the first time, on methane production. The work was carried out in a laboratory main sewer system previously validated to mimic the main features of sewer rising mains (Gutierrez et al., 2011). The DND testing involved three phases, namely: the baseline phase, the dosage phase during which NO_3^- was added to the downstream section of the pipe, and a recovery phase, during which the performance of the pipe was monitored subsequent to the