Journal of Environmental Management 154 (2015) 307–315

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Impact of reduced water consumption on sulfide and methane production in rising main sewers

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ARTICLE INFO

Article history:
Received 11 April 2014
Received in revised form
21 October 2014
Accepted 25 February 2015
Available online

Keywords:
Reduced water consumption
Sulfide
Methane
Rising main sewers
Reduced flow rate
Wastewater composition

ABSTRACT

Reduced water consumption (RWC), for water conservation purposes, is expected to change the wastewater composition and flow conditions in sewer networks and affect the in-sewer transformation processes. In this study, the impact of reduced water consumption on sulfide and methane production in rising main sewers was investigated. Two lab-scale rising main sewer systems fed with wastewater of different strength and flow rates were operated to mimic sewers under normal and RWC conditions (water consumption reduced by 40%). Sulfide concentration under the RWC condition increased by 0.7–8.0 mg-S/L, depending on the time of a day. Batch test results showed that the RWC did not change the sulfate-reducing activity of sewer biofilms, the increased sulfide production being mainly due to longer hydraulic retention time (HRT). pH in the RWC system was about 0.2 units lower than that in the normal system, indicating that more sulfide would be in molecular form under the RWC condition, which would result in increased sulfide emission to the atmosphere as confirmed by the model simulation. Model based analysis showed that the cost for chemical dosage for sulfide mitigation would increase significantly per unit volume of sewage, although the total cost would decrease due to a lower sewage flow. The dissolved methane concentration under the RWC condition was over two times higher than that under the normal flow condition and the total methane discharge was about 1.5 times higher, which would potentially result in higher greenhouse gas emissions. Batch tests showed that the methanogenic activity of sewer biofilms increased under the RWC condition, which along with the longer HRT, led to increased methane production.

1. Introduction

Nowadays, a large proportion of the world's population is confronted with water shortage. The Human Development Report (2006) estimated that, by 2025, more than 3 billion people would be living in water-stressed countries and the number would further increase to more than 5 billion in 2050. To cope with this problem, many countries have tried to reduce water consumption by implementing a series of financial, operational and socio-political policies and regulations (Tate, 1990; White and Fane, 2002). The South East Queensland region (including Brisbane and three other cities/regions) is a good example. Following a long-lasting draught from 2000, water restriction was initiated in 2007, which resulted in the reduction of domestic water consumption in the region from 282 L per person per day in 2005 to 163 L per person per day in 2011 (QWC, 2011).

Reduced water consumption (RWC) changes both the composition and flow of wastewater discharged to sewer systems. Comparing wastewater characteristics before and after RWC, several studies (Cook et al., 2010; Dezellar and Maier, 1980; Min and Yeats, 2011; Parkinson et al., 2005; Sharma et al., 2005) reported an increased total suspended solid (TSS), chemical oxygen demand (COD) and biological oxygen demand (BOD) with RWC. Some of these studies also suggested there could be increases in sulfate, metal (Fe, Cu, Zn) and nitrogen (total Kjeldahl nitrogen (TKN) and ammonium) concentrations. This implies that more concentrated wastewater is discharged to sewers with RWC. In addition, reduced wastewater discharge would cause reduced flow rates thereby resulting in longer hydraulic retention time (HRT) of wastewater in

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http://dx.doi.org/10.1016/j.jenvman.2015.02.041
0301-4797/

sewers (Zornes et al., 2011). All these changes could have impacts on the in-sewer biotransformation processes and might aggravate the problems related to sewer systems (Marleni et al., 2012; Zornes et al., 2011).

Sulfide production and emission is a well-known problem in sewers, which causes corrosion of sewer pipes, odor nuisance and health hazards (Boon, 1995; Hvitved-Jacobsen, 2002). In sewers, sulfide is mainly generated anaerobically by the reduction of sulfate in wastewater through the respiration of sulfate-reducing bacteria (SRB). Rising main (also called pressurized mains) sewers are usually operated with full wastewater flows in the absence of oxygenation and thus contribute considerably to sulfide production. Sulfate concentration, COD concentration and HRT are among the key factors identified to influence sulfide concentration in sewers (Freudenthal et al., 2005; Hvitved-Jacobsen, 2002; Mohanakrishnan et al., 2009; Sharma et al., 2008), with higher sulfate and COD concentrations and longer HRT favoring higher sulfide production.

Methane has also been observed recently to be generated in rising main sewers with significant amount (Foley et al., 2009; Guisasola et al., 2008). Methane production in sewers could contribute considerably to the overall greenhouse gas emissions from wastewater systems (Guisasola et al., 2008, 2009). Meanwhile, due to the relatively low explosive limit of methane (down to 5%), the release of methane from sewer systems imposes potential health and safety risks (GWRC, 2011; Spencer et al., 2006). In addition, the loss of soluble COD by methanogenesis could cause detrimental impacts on biological nutrient removal at the downstream wastewater treatment plants. Guisasola et al. (2009) revealed that methane production in sewers depends heavily on the soluble COD concentration and the HRT of the wastewater, both of which positively correlate with methane concentration in sewers.

RWC is expected to be increasingly applied in future for the conservation of global water resources. However, as it could lead to more concentrated wastewater with longer HRT in sewers, its unintended potential impact on sulfide and methane production in sewers needs to be assessed. So far, few studies have been carried out to identify this impact (Marleni et al., 2012). Detailed studies on the effect of RWC would not only help the water industry to develop its sewer maintenance strategies in future but also provide information towards evaluating greenhouse gas emissions by sewer systems.

For this purpose, two lab-scale rising main systems were set up to mimic sewers under normal and RWC conditions. Domestic wastewater with different flow rates and strength were fed to the two systems. Sulfide and methane production in the two systems was investigated through both long-term performance monitoring and batch tests. A mathematical sewer model (Sharma et al., 2008) was set up and run for the two sewer conditions to evaluate the impacts of RWC on sulfide and methane emissions and on the chemical requirements for mitigation of sulfide.

2. Materials and methods

2.1. Wastewater composition

Two laboratory-scale rising main sewer systems were set up to mimic two sewer lines operated under normal and RWC conditions. The two systems were fed with domestic wastewater of different strength and at different flow rates. Statistics provided by water commissions revealed that, water consumption in Brisbane is approximately 150 L/capita/day at the time of this experimental study (2011), a legacy of 10-year drought (2000–2010) and water restrictions. It is much lower than the consumption rates in many other cities in Australia, such as Sydney (210 L/capita/day) and many other countries in America, Europe and Asia (China Statistical Yearbook, 2011; Marleni et al., 2012). Thus, in this study, domestic wastewater collected in Brisbane was used to represent wastewater under the RWC condition (referred to as 'concentrated wastewater') while wastewater under the normal water consumption condition (referred to as 'normal wastewater') was obtained by diluting the Brisbane wastewater with tap water by 40%, mimicking wastewater in Sydney and other cities with a water consumption rate that is 40% higher. Mimicking the 'normal wastewater' by diluting 'concentrated wastewater' with tap water is a suitable approach as reduced water consumption is realized by decreasing the use of tap water.

2.2. Laboratory reactors set-up and operation

Fig. 1 shows the schematic representation of the two laboratory sewer systems. Each consisted of three 1 L gas-tight reactors, made of Perspex™, connected in series. The system under the RWC condition, receiving 'concentrated wastewater' was named as the 'reduced flow line' (reactors labeled with 'RL1', 'RL2' and 'RL3', respectively). The system under the normal condition, receiving 'normal wastewater' was named as 'normal flow line' (reactors labeled with 'NL1', 'NL2' and 'NL3', respectively). The arrangement of connecting reactors in series was made to simulate possible spatial variation of sewer biofilms along a sewer line, with each reactor representing a section of a sewer pipe from upstream to downstream (Gutierrez et al., 2008). The inner diameter of each cylindrical reactor was 80 mm and the area to volume ratio (A/V) was calculated to be 55 m^{-1}, with biofilms growing on the wall and top of the reactor considered. Mixing was continuously provided by a magnetic stirrer (Heidolph MR3000) under each reactor, so there was no biofilms growing on the bottom.

'Concentrated wastewater' was collected from a local wet well at the Robertson Park pump station (Brisbane, Queensland) on a weekly basis. The wastewater characteristics, including dissolved sulfur species, soluble chemical oxidation demand (COD), volatile fatty acids (VFAs), nitrogen species concentrations, were monitored every week using the methods described in Section 2.5 and summarized in Supplementary Information (SI), Table S1. 'Normal wastewater' was obtained by diluting the "concentrated wastewater" with 40% of tap water as described in Section 2.1. The sulfate concentration of tap water was also monitored weekly, which was in the range of 5–18 mg-S/L. The feeding to both lines was stored in a cold room (4 °C) to minimize the biological transformation, but was heated to 20 ± 1 °C when being pumped into the reactors (Fig. 1).

The 'concentrated' and 'normal' wastewater was pumped into two sewer lines with two intermittently-operated peristaltic pumps (Masterflex 7520-47). For easier reactor monitoring (see Section 2.3), each day was divided into three identical 8-h periods. Fig. 1B shows the pumping patterns applied to the two lines over an 8-h period and the HRT of sewage in the two lines, respectively. During each pumping event, wastewater was pumped into the first reactor with a flow rate of 0.5 L/min. The 'reduced flow line' had 6 pumping events and each lasted for 2 min in an 8-h period while the 'normal flow line' had 8 pumping events and each lasted for 2.1 min so that the 'normal flow line' received 40% more wastewater flow. The duration between pumping events ranged between 15 min and 3 h, and consequently, the HRT in the 'reduced flow line' and in the 'normal flow line' varied between 2–6 h and 1.19–5 h, respectively. These ranges are similar to those observed in real sewer pipes (Guisasola et al., 2008).

Sulfide and methane production developed in all six reactors over time (with examples of their activities in the initial stage shown in SI, Fig. S1). A six-month transient period was allowed for