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Review

Methane emission from sewers

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HIGHLIGHTS

- Sources and sinks of methane in sewers are identified.
- Both offline and online methane quantification methods are reviewed and assessed.
- Comprehensive methane production/emission data is presented and synthesized.
- Models for predicting methane production in sewers are reviewed.
- Effects of sulfide-control chemicals on methane production in sewers are detailed.

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ABSTRACT

Recent studies have shown that sewer systems produce and emit a significant amount of methane. Methanogens produce methane under anaerobic conditions in sewer biofilms and sediments, and the stratification of methanogens and sulfate-reducing bacteria may explain the simultaneous production of methane and sulfide in sewers. No significant methane sinks or methanotrophic activities have been identified in sewers to date. Therefore, most of the methane would be emitted at the interface between sewage and atmosphere in gravity sewers, pumping stations, and inlets of wastewater treatment plants, although oxidation of methane in the aeration basin of a wastewater treatment plant has been reported recently. Online measurements have also revealed highly dynamic temporal and spatial variations in methane production caused by factors such as hydraulic retention time, area-to-volume ratio, temperature, and concentration of organic matter in sewage. Both mechanistic and empirical models have been proposed to predict methane production in sewers. Due to the sensitivity of methanogens to environmental conditions, most of the chemicals effective in controlling sulfide in sewers also suppress or diminish methane production. In this paper, we review the recent studies on methane emission from sewers, including the production mechanisms, quantification, modeling, and mitigation.

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1. Introduction

Methane (CH_4) is a highly potent fugitive greenhouse gas (GHG) that contributes significantly to climate change (IPCC, 2006). Over a 100-year horizon, 1 ton of CH_4 will induce a warming effect equivalent to 21 tons of CO_2 (IPCC, 2006). The global average atmospheric concentration of methane increased from approximately 0.7 ppm in 1750 to 1.8 ppm in 2013. It is estimated that up to 50% of methane emission is due to anthropogenic activities (IPCC, 2006).

The plentiful carbon flow into wastewater systems creates potential for GHG emission (Keller and Hartley, 2003). If just a minor fraction of the carbonaceous compounds contained in wastewater was converted to CH_4, it would result in significant GHG emission, and consequently, concern has grown significantly in recent decades (Scanlan et al., 2008). Wastewater systems comprise wastewater treatment plants (WWTPs) and sewer networks. However, studies to date have considered methane emission from WWTPs to be the major contributor (Czepiel et al., 1993; Daelman et al., 2012; Souza et al., 2012; Wang et al., 2011). Further, due to the lack of data, the Intergovernmental Panel on Climate Change (IPCC) concluded that, "…wastewater in closed underground sewers is not believed to be a significant source of methane" (IPCC, 2006).

The IPCC conclusion has been challenged by the methane data reported by Guisasola et al. (2008). The authors measured liquid phase CH_4 concentrations of up to 20–25 mg/L in rising main sewers in Australia. The authors highlighted that, with this level of methane production, CH_4 emission from these sewers could contribute an additional GHG contribution of roughly 48–60% above that from a WWTP. Depending upon the ventilation conditions, methane could also accumulate to high concentrations in sewer headspace. Gas phase methane concentrations of up to 50,000 ppmv, i.e., 5% by volume (vol), have been detected in the air of a gravity sewer (GWRC, 2011). This is concerning because CH_4 is a highly volatile gas and displays a Lower Explosive Limit (LEL) of approximately 5% vol. Uncontrolled release of methane could cause an explosion when in contact with air in confined spaces such as sewers, and thus poses a serious safety risk (Spencer et al., 2006). In addition, methane generation in sewers may consume a significant amount of soluble chemical oxygen demand (COD) (Guisasola et al., 2008), which is detrimental to nutrient removal in downstream WWTPs.

The work undertaken by Guisasola et al. (2008) stimulated systematic studies on methane formation in sewers. The fundamental mechanisms underpinning methane formation in sewers have been illustrated by Guisasola et al. (2008) and Sun et al. (2014). Increased quantitative monitoring of methane in sewers has enabled significant progress to be made in terms of GHG accounting (Chaosakul et al., 2014; Foley et al., 2009; Guisasola et al., 2008; Liu et al., 2014, 2015b; Shah et al., 2011). Based on current limited data, several models have been proposed for the prediction of methane production in sewers (Chaosakul et al., 2014; Foley et al., 2009; Guisasola et al., 2009). In addition, effects of different chemical dosing strategies on methane formation in sewers have been studied in detail (Ganigué and Yuan, 2014; Gutierrez et al., 2009; Jiang et al., 2011b, 2013b; Zhang et al., 2009). This body of work illustrates the recognition of the importance of understanding, quantifying and mitigating methane emission from sewers in recent years.

In this paper, we present a review of the important outcomes and findings arising from the research on methane production and emission from sewer systems to date. Included is a description of sources and potential sinks of methane in sewers, methods for methane measurement, and rates for methane production and emission thus far measured. Also discussed are models available to predict methane production, and the effects of chemical dosing on methane production in sewers. Finally, current knowledge gaps are highlighted.

2. Sources and potential sinks of methane in sewers

Sewer systems are an important and integral component of urban water infrastructure, which collects and transports wastewater from residential houses or industry to WWTPs. Operationally, sewer systems can be divided into two categories, i.e., fully-filled pressure sewers (rising main sewers), which are anaerobic, and partially-filled gravity sewers, where re-aeration takes place.

In addition to transporting wastewater, sewers also act as biological reactors with various microbial processes. Generally, there are five major phases in a sewer pipe: namely the suspended wastewater phase, the wetted sewer biofilms, the sediments, the sewer air phase, and the biofilm on pipe surface exposed to sewer air, with the latter two being present in gravity sewers only. In-sewer microbial processes mainly take place in biofilms and sediments, with little contribution from the suspended biomass in the water phase or in the gas phase (Mohanakrishnan et al., 2009a). Wetted anaerobic biofilms with a thickness of a few hundred micrometers feature in rising main sewers. In gravity sewers, both biofilms and sediments below the water surface are in partially anaerobic or fully anaerobic conditions even when oxygen is present in the bulk wastewater, due to limited penetration of the oxygen (Gutierrez et al., 2008). Therefore, anaerobic fermentation and sulfate reduction using organic matter or sulfate as electron acceptors can occur in deeper layers of biofilms and sediments (Hvitved-Jacobsen, 2002).

2.1. Methane production in anaerobic sewer biofilms

Utilizing the products of anaerobic fermentation, methanogenic archaea (MA) within sewer biofilms can produce CH_4 from acetate or