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Functional evaluation of pollutant transformation in sediment from combined sewer system☆

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ABSTRACT

In this study, a pilot combined sewer system was constructed to characterize the pollutant transformation in sewer sediment. The results showed that particulate contaminants deposited from sewage could be transformed into dissolved matter by distinct pollutant transformation pathways. Although the oxidation-reduction potential (ORP) was varied from −80 mV to −340 mV in different region of the sediment, the fermentation was the dominant process in all regions of the sediment, which induced hydrolysis and decomposition of particulate contaminants. As a result, the accumulation of dissolved organic matter and the variation of ORP values along the sediment depth led to the depth-dependent reproduction characteristics of methanogens and sulfate-reducing bacteria, which were existed in the middle and deep layer of the sediment respectively. However, the diversity of nitrifying and polyphosphate-accumulating bacteria was low in sewer sediment and those microbial communities showed a non-significant correlation with nitrogen and phosphorus contaminants, which indicated that the enrichment of nitrogen and phosphorus contaminants was mainly caused by physical deposition process. Thus, this study proposed a promising pathway to evaluate pollutant transformation and can help provide theoretical foundation for urban sewer improvement.

1. Introduction

Sewer systems, an important component of urban infrastructure, are used to collect and transport sewage. In recent decades, according to the design criteria, sewer systems are designed as either combined or separated sewer systems, and due to the economic and technological conditions, combined sewer systems are mainly implemented in older and under-developed cities (Chhetri et al., 2016). Due to the collection requirements of residential wastewater, industrial wastewater and rainwater (Liu et al., 2015), the sewer pipe diameter in combined sewers is much larger than that in separated sewer systems, which results in that the sewage is transported at a low flow velocity in normal weather (Jalliffier-Verne et al., 2016). Therefore, particulate matter deposition occurs and generates the formation of sewer sediment in the sewer (Ashley et al., 2003), and the study showed that 30–500 g of particulate matter was deposited per meter length of the sewer per day. Furthermore, to clarify the sediment transport process, diverse models of these physical processes were established (Skipworth et al., 1999; Mouri and Oki, 2010). Previous studies have mainly focused on physical deposition processes, while these studies did not reveal the change of the properties and characterize the transformation mechanism of sediment, where the complex reactions might occur in urban sewer systems.

Many urban sewers are under the dark and anaerobic environment (Jin et al., 2015), and the abundant particulate matter depositing from sewage could induce the accumulation of substrate in sewer sediment. All the conditions mentioned above in sewer sediment are the same as the anaerobic wastewater treatment systems where the diverse matters were decomposed, therefore, it could be inferred that the same bioreactions might be also occurred in sewer sediment. Previous studies have shown that bio-production of sulfide and methane cannot be ignored in sediment (Liu et al., 2015), and it indicated the small organic molecules which

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were utilized by methanogens and sulfate-reducing bacteria might be abundant in the sewer sediment. In fact, the processes of methanogenesis and sulfate reduction mainly consume acetic acid and propionic acid (Pender et al., 2004; Muyzer and Stams, 2008), while the formation of sewer sediment is mainly attributed to particulate matter deposition. Therefore, diverse particulate matter hydrolysis processes must occur in the sediment that produce abundant, easily degradable substrates. The conversion of particulate matter mainly results from the reproductive processes of homologous microbial communities, and in addition to the utilization of carbon substrates, the bioreactions generally involve the transformation of nitrogen and phosphorus matters, which has been also verified in anaerobic wastewater treatment systems (Tabatabaei et al., 2010). Accordingly, significant decomposition of these contaminants may occur under the similar anaerobic conditions of sewer sediment. However, to our best knowledge, although the WATS and the SeweX models (Hvitved-Jacobsen et al., 1998; Sharma et al., 2008) were proposed to evaluate biological reactions in sediment, those models only predicted the bioreactions occurred in biofilms, and the understanding of diverse matters transformation in sewer sediment is poor. Due to the potential risks of poisonous gas emission and corrosion as well as the effect on the influent quality of wastewater treatment plants caused by those biochemical reactions, it is necessary to gain a better understanding of pollutant transformation processes in sewer sediment.

In order to reveal the unknown mechanism mentioned above, a pilot experimental sewer system was established to discover the pollutant transformation pathways in different longitudinal profiles and depths of sewer sediment. By using high-throughput sequencing, the microbial community distribution in the inner sediment was characterized. Considering the effect of environmental factors e.g. oxidation and reduction potential (ORP), correlations between the pollutants and functional bacteria in different regions of the sediment were established. Therefore, a promising method to analyze and predict pollutant transformation in sewers was proposed, which can be a reliable guideline for urban sewer improvement and the prevention of urban accidents in sewer systems.

2. Materials and methods

2.1. Sewer system operation and sample collection

The simulated sewer system constructed for this study is shown in Fig. 1(a). The total effective length of this sewer was 32 m, and the diameter of the pipe was 200 mm. The different layers were connected by a cylindrical inspection well that was 400 mm × 600 mm. The sewage was raised to the top layer by a submersible pump from a cyclic water tank, and the sewage flowed to the bottom layer via gravity. To fully simulate the gravity flow state of an urban sewer, the simulated sewer was designed with a slope of 5%. The inner surface of the pipe was polished to simulate real pipes and to ensure the proper resistance coefficient and Reynolds number in the sewer system. The sewage was collected from wastewater treatment plant in Xi'an, China, in addition, the particulate matters which deposited from sewage induced the formation of sediment in 180 d, and then the pollutant transformation and microbial community distribution were detected in 60 d.

To evaluate the diverse pollutant transformation characteristics, sediment samples were collected in seven regions of the sewer sediment at seven different times (1, 10, 20, 30, 40, 50, 60 day at the operation process of pilot sewer system) (Fig. 1(b)). When the sewer sediment was sampled, two perspex sheets (semicircle and the size was the same as the pilot sewer pipe) were used to insert the sewer sediment (the distance between two perspex sheets was 3–5 cm), and then pick up a longitudinal section of sediment which could guarantee that the sediment structure were not damaged. One of the perspex sheets were drilled in advance, and the positions of holes were same as the seven sampling position in sediment (shown in Fig. 1(b)), therefore, after the sediment was picked up, the target sewer sediment could be taken out from the seven holes in the perspex sheet.

2.2. Chemical analysis

Total chemical oxygen demand, nitrogen and phosphorus were measured in accordance with standard methods (APHA et al., 2002). All sludge samples were filtered through a 0.45 μm filter before SCOD detection. The ORP of sediment was measured by a HQ30d meter (HACH. USA). The methane and hydrogen sulfide was measured by a GC310 meter (China).

SCFAs and CH_4 were measured by gas chromatography. For the detection of short-chain fatty acids (SCFAs): Phosphoric acid (3%) was dropwise added to regulate the pH of the samples to approximately 4. The SCFAs concentration was characterized by the COD concentration: 1.07 for acetic acid, 1.51 for propionic acid, 1.82 for butyric and isobutyric acid, and 2.04 for valeric and isovaleric acid (Feng et al., 2009).

2.3. Illumina high-throughput sequencing

2.3.1. Extraction of genome DNA

The total genome DNA was extracted from the samples using the CTAB/SDS method. The DNA concentration and purity was monitored on 1% agarose gels. According to the concentration, the DNA was diluted to 1 ng/μl using sterile water.

2.3.2. Amplicon generation

The sludge samples were sent to the Novogene Institute (Beijing,

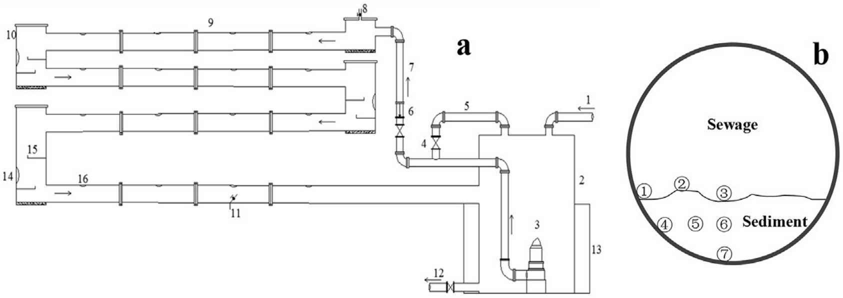

Fig. 1. Experimental setup. (a) Schematic representation of the simulated sewer system (b) Schematic view of sample collection regions in the sewer pipe.