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Removal of primary and secondary trace organic substrates in aerobic and anaerobic sewer biofilm

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Introduction

Sewer biofilm is known to have significant impact on the transformation of organic chemicals present in untreated sewage (Hvitved-Jacobsen et al. 2002; Thai et al. 2014). Biofilm structure and activity are influenced by the design of the sewer network. Pressurized sewers are predominantly anaerobic and favor the growth, among others, of sulfate reducing bacteria (SRB), thereby promoting the release of hydrogen sulfide causing corrosion problems. Conversely, gravity sewers are predominantly aerobic due to reaeration where heterotrophic biomass prevails in the biofilm with comparably high activity. Understanding the role of sewer biofilm on the transformation of organic chemicals can help improving sewer maintenance and predicting pollutant loadings to downstream wastewater treatment plant, where organic substrate limitation may occur (e.g. in pre-denitrifying systems) (Hvitved-Jacobsen et al. 2013). More recent research focuses on sewer processes in the emerging field of wastewater-based epidemiology (estimation of illicit drug consumption at community level based on analysis of urinary drug biomarkers in wastewater) whereby in-sewer illicit drug removal by biofilm and suspended solids is assessed (Thai et al. 2014). To the best of our knowledge, there has been no comprehensive study correlating the functionality of in-sewer biofilm on transformation of primary pollutants (e.g. COD fractions) and trace organic chemicals (e.g., illicit drugs) under different redox conditions. The aim of this study was to investigate the removal of illicit drugs (e.g., mephedrone) and primary pollutants (COD, sulfate) in well-controlled biofilm systems mimicking in-sewer conditions (e.g., controlled shear stress on biofilm) under aerobic and anaerobic conditions.

Material and Methods

Two annular rotating biofilm reactors (ARBRs), consisting of an inner rotating drum and an outer stationary cylinder (operating volume = 0.96 L), were operated continuously with preclarified wastewater feeding from cooled external containers ($T \leq 4^\circ\text{C}$). The containers were sparged with compressed dry atmospheric air or nitrogen over one year prior to batch experiments. As a result, stable biofilm developed in both aerobic (0.75 mm, 55.7 mg cm^{-3}) and anaerobic (1 mm, 83.4 mg cm^{-3}) ARBRs. Batch experiments were carried out using 5 L of wastewater inoculum for each ARBR, which was prepared with previous filtration (0.6 μm GA, Advantec, USA) to reduce suspended active biomass content (resulting concentration = 9 gCOD m^{-3}). The prepared inoculum was collected in external feeding containers and continuous recirculation (4 L h^{-1}) was established with ARBRs. During operation time rotation speed was kept at 20 rpm for both reactors. Experiments were performed by spiking a mixture of drug biomarker standards to the feeding reactors (final concentration of $10 \mu\text{g L}^{-1}$). Nine samples (240 mL) were taken from ARBR outlets over 48 h. Immediately after sampling, samples were spiked with deuterated standards (final concentration 360 ng L^{-1}) and kept in darkness at -20°C . During the experiments, temperature (aerobic $T_{\text{ave}}=17^\circ\text{C}$; anaerobic, $T_{\text{ave}}=17.8^\circ\text{C}$) and pH (aerobic, $\text{pH}_{\text{ave}}=8.7$; anaerobic, $\text{pH}_{\text{ave}}=9.2$) were continuously measured. Control blank experiments were also performed using mineral water under the same experimental conditions to assess abiotic removal. Sample preparation and analysis were carried out according to Bijlsma et al. (2013).

Results and Conclusions

Removal of soluble COD was higher in the aerobic sewer biofilm (88%) compared to the anaerobic biofilm (58%) (Fig. 1). The increase of COD measured at the beginning of the experiment was related to the addition of drug biomarker standard solution dissolved in methanol. Sulfate concentration was found to be reduced 2-fold under anaerobic condition indicating sulfate respiration by SRBs. Conversely, we observed an increase in sulfate concentration in the aerobic ARBR, indicating either hydrogen sulfide oxidation by autotrophic bacteria even at low oxygen level in anaerobic ARBR ($1.6 \text{ gO}_2 \text{ m}^3$) or chemical oxidation of sulfide. Mephedrone concentration dropped by approximately 30% in mineral water, suggesting partial abiotic removal under both redox conditions. However, different removal rates of mephedrone were observed in the aerobic (85%) and anaerobic (67%) ARBR, indicating different transformation capacity of the biofilms. The higher mephedrone removal was in agreement with the higher soluble COD removal in the aerobic ARBR, probably due to higher heterotrophic activity in presence of oxygen. As opposed to the present study, mephedrone has been previously reported to be transformed to a negligible extent (5% and 6% removal in milli-Q water and sewage respectively; 24-h experiment at room temperature; Östman et al. 2014). Our study further suggests biofilm activity under different redox conditions determines differences in the degradation for mephedrone. As previously proposed (Plósz et al. 2010), we thus recommend accounting for the interaction between primary and secondary metabolic processes (e.g. biotransformation of trace organic chemicals) when modelling the fate of trace chemicals in sewer networks. Microbial analysis based on 16S rRNA and functional genes will be performed to characterize the microbial community of biofilms in aerobic and anaerobic ARBRs and to elucidate the role of sulfate reducing and heterotrophic bacteria on the biotransformation of illicit drugs.

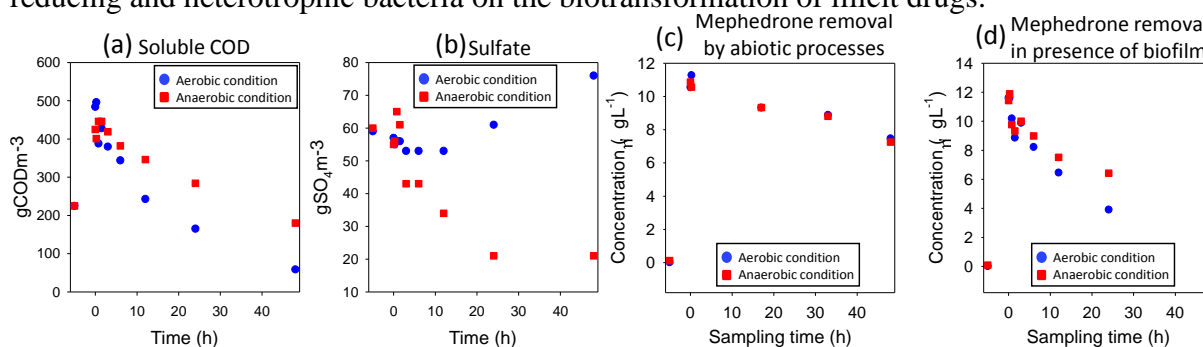


Figure 1. Concentrations of soluble COD (a), sulfate (b) and mephedrone (c, d) measured during batch experiments with ARBR under aerobic and anaerobic conditions.

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