Nitrous oxide generation and emission in a laboratory-scale pumped flow biofilm reactor

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Introduction
Nitrous oxide (N2O) is an intermediate product of the nitrification and, to a larger extent, the denitrification processes (Tallec et al., 2008). N2O is a known greenhouse gas with a global warming potential (GWP) almost 300 times that of carbon dioxide (CO2) over a 20–100 year period (Denman, et al., 1996). In a Japanese study, it was found the N2O (associated with the treatment process) accounted for 33% of the total greenhouse gas emissions from wastewater treatment plants (Okamoto, 2008). Factors such as the process type, nitrogen loading rates and other influent characteristics are useful tools in establishing the N2O emission potential of different wastewater treatment processes (Kampschreur et al., 2009; Park et al., 2000; Tallec et al., 2006a; Tallec et al., 2006b). Its generation is dependent on a number of parametric concentrations, such as: (i) total nitrogen (TN); (ii) NH4+-N; (iii) 5-day biochemical oxygen demand (BOD5); and, (iv) bulk fluid DO (Lu and Chandran, 2010).

The pumped flow biofilm reactor (PFBR), first developed by Rodgers et al. (2004a) in NUI Galway, is a patented wastewater treatment process typically comprising two reactor tanks (Feed and Discharge Reactors), each containing stationary biofilm media modules, and operates as a sequencing batch biofilm reactor (SBBR). Aeration is achieved by alternately exposing the stationary biofilm media in either of its two reactor tanks to air and wastewater through the movement of water using hydraulic pumps between the two reactor tanks. To date, no research has been carried out on the PFBR in terms of N2O generation and emission. The aim of this study was to investigate and quantify N2O generation and emission in the laboratory-scale PFBR using N2O microsensors.

Methods
The laboratory-scale PFBR comprised two 22 litre reactor tanks each containing a PVC biofilm media module providing an effective surface area of 2 m² per module. When one reactor was empty, microorganisms in the biofilm were exposed to atmospheric allowing for the diffusion of oxygen into the biofilm. Alternately, while the second reactor was full with wastewater, organic carbon and nutrients were diffused into biofilms for microorganisms to access. A high strength synthetic domestic wastewater was pumped into the Feed Reactor at the beginning of each treatment cycle and had the following average characteristics: chemical oxygen demand (CODc) 1247 mg/l; filtered chemical oxygen demand (CODf) 1094 mg/l; total nitrogen (TNc) 149 mg/l; filtered total nitrogen (TNf) 137 mg/l; and orthophosphate-phosphorus (PO43-P) 19.9 mg/l. A treatment cycle comprised the following phases: fill (5 minutes), anaerobic (355 minutes), aerobic (525 minutes), settle (10 minutes), and draw (5 minutes).

Dissolved N2O and O2 concentrations were measured in the bulk fluid during pseudo steady-state conditions in both the Feed Reactor and Discharge Reactor during a
number of treatment cycles using Unisence \( \text{N}_2\)O and \( \text{O}_2 \) microsensors. To quantify \( \text{N}_2\)O emission rates from the laboratory-scale PFBR, both parameters were separately measured while operating the laboratory-scale PFBR using clean water when all biofilm had been removed from the biofilm modules and sludge had been removed from the tanks. This allowed for the calculation of the mass transfer coefficients of molecular diffusion, \( K_{m-dif} \) (applicable to quiescent anaerobic conditions), and enhanced diffusion, \( K_{e-dif} \) (applicable to mixed aerobic conditions). Following polarisation and calibration, the microsensors were mounted, in turn, in the Feed and Discharge Reactors where dissolved \( \text{N}_2\)O and \( \text{O}_2 \) readings were logged every 0.5 seconds.

**Results**

The mass transfer coefficients, \( K \), in association with \( \text{N}_2\)O emissions from the water to the atmosphere were determined for both quiescent and bulk fluid circulation conditions using a linear equation: \( r_e = -KC_{\text{N}_2\text{O}} \), where \( r_e \) is the \( \text{N}_2\)O emission rate (µM/min); \( C_{\text{N}_2\text{O}} \) is the soluble \( \text{N}_2\)O concentration (µM); and, \( K \) is the mass transfer coefficient (min\(^{-1}\)).

In the clean water monitoring experiment where \( \text{N}_2\)O generation was nil, \( r_e \) was equal to the accumulation rate of \( \text{N}_2\)O in the bulk fluid, \( dC_{\text{N}_2\text{O}}/dt \). In quiescent conditions, \( K_{m-dif} \) was calculated as 0.002 min\(^{-1}\). In bulk fluid circulation conditions, \( K_{e-dif} \) was calculated as 0.16 min\(^{-1}\) (Figure 1).

The \( \text{N}_2\)O generation rate in the PFBR while operating at a steady-state treating a high strength wastewater was calculated using the mass balance equation: \( r_e = r_c-r_g \), where \( r_c \) is the \( \text{N}_2\)O accumulation rate (µM/min), and \( r_g \) is the \( \text{N}_2\)O generation rate (µM/min). The quantities of \( \text{N}_2\)O generated and emitted were calculated using the mass transfer coefficients and the \( \text{N}_2\)O emission and generation rates with respect to time for both quiescent conditions (i.e., anaerobic periods) and mixed bulk fluid conditions and are presented in Table 1.

**Discussion and Conclusions**

On average, 128 mg TNf/l was removed from the PFBR (93% removal efficiency), equating to 2.1% TNf removed as \( \text{N}_2\)O-N. \( \text{N}_2\)O emission rates for the laboratory-scale PFBR compared well with literature.

**References**


