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Influence of carbon to nitrogen ratio on nitrous oxide emission in an Integrated Fixed Film Activated Sludge Membrane BioReactor plant

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ABSTRACT

In this study a University of Cape Town (UCT) Integrated Fixed Film Activated Sludge (IFAS) Membrane BioReactor (MBR) wastewater treatment plant was monitored in terms of nitrous oxide (N_2O) emissions. The short term effect on the N_2O emission due to the influent carbon-to-nitrogen (C/N) ratio variation (C/N ratios of 2, 5 and 10 gCOD/gN) was evaluated. Since in a previous study, the effect of the C/N ratio was studied in the same system without biofilm (UCT-MBR configuration) the main aim here was to investigate the role of biofilms on N_2O emissions. Under all the investigated C/N ratios, the N_2O fluxes and the average emission factors were lower than that of previous studies with no biofilm presence. The total average N_2O emission was 0.5% of the influent nitrogen with biofilm (IFAS system) and 3.5% without biofilm. This result emphasizes the potential role of the biofilms in attenuating the N_2O emissions especially in the case of stress conditions (i.e., low C/N influent ratios). An increase of N_2O flux from the anoxic reactor (till 28 $mgN_2O\ m^{-2}h^{-1}$) occurred at the lowest influent C/N tested (2 gCOD/gN - phase III). At C/N equal to 2 gCOD/gN the anoxic reactor was the main source of N_2O, contributing 45% of all produced N_2O. This result was attributed to an incomplete denitrification caused by a lack of organic carbon and a slight increase of dissolved oxygen concentration.

1. Introduction

During the last ten years, the interest towards greenhouse gas (GHG) emission from wastewater treatment plants (WWTPs) has increased considerably with the aim to design and operate plants that have the minimum environmental impact (Mannina et al., 2016a). In addition to the “traditional pollutants” such as organics compounds (indirectly measured by chemical oxygen demand - COD, biochemical oxygen demand - BOD_5), nitrogen - N or phosphorus – P, WWTPs can also emit GHGs (i.e., carbon dioxide – CO_2, methane – CH_4 and nitrous oxide – N_2O). GHGs can be emitted as a direct consequence of the biological processes (Mannina et al., 2016a) or indirectly due to the power requirements (Papa et al., 2016). Among the GHG emitted from WWTPs, N_2O has caused the greatest interest among scientist and researchers due to its high global warming potential (GWP) (298 times higher than that of CO_2) (IPCC et al., 2013). N_2O from WWTPs is mainly produced by the biological nitrogen removal (BNR) processes through nitrification and subsequent denitrification both from autotrophic and heterotrophic bacteria (Kampschreur et al., 2009).

Ammonia oxidizing bacteria (AOB) have been identified as responsible of producing N_2O due to: i. the reduction of NO_2 as terminal electron acceptor to N_2O (AOB denitrification) (Kim et al., 2010); ii. the incomplete oxidation of hydroxylamine (NH_2OH) to NO_2 (Law et al., 2012). The predominance of AOB pathway to the other has not yet been demonstrated (Pocquet et al., 2016).

WWTP operating factors (such as, dissolved oxygen, C/N ratio, sludge retention time – SRT and temperature) may strongly influence the N_2O emission (Kampschreur et al., 2009). Stenström et al. (2014) have found that decreasing the oxygen concentration during nitrification lead to the increase of N_2O emission during the denitrification; similar results were also found by Frison et al. (2015). Recently, Mannina et al. (2017a) reported the effect of the influent C/N ratio on N_2O emissions from the same UCT- MBR pilot plant

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List of abbreviations

AOB	ammonia oxidizing bacteria
ATU	Allylthiourea
b_H	endogenous decay coefficient
BNR	biological nutrient removal
BOD	biochemical oxygen demand
BOD_5	biochemical oxygen demand in five days
C	carbon
$C_3H_8O_3$	glycerol
CAS	conventional activated sludge
CH_3COONa	sodium acetate
CH_4	methane
CIP	clean in place
CO_2	carbon dioxide
COD	chemical oxygen demand
COD_{in}	influent COD
COD_{out}	permeate COD
COD_{SUP}	supernatant COD
COD_{TOT}	total COD
DO	dissolved oxygen
DPAOs	denitrifying phosphate accumulating organisms
ECD	Electron capture detector
FA	free ammonia
GC	Gas Chromatograph
GHG	greenhouse gas
GWP	global warming potential
HRT	hydraulic retention time
IFAS	Integrated Fixed Film Activated Sludge
K_2HPO_4	dipotassium hydrogen phosphate
MBBR	moving bed biofilm bioreactors
MBR	Membrane BioReactor
N	nitrogen
N_2O	nitrous oxide
$N_{assimilation}$	assimilated nitrogen
NH_2OH	hydroxylamine
NH_4^+-N_{in}	influent nitrogen ammonia concentration
NH_4^+-N_{out}	permeate nitrogen ammonia concentration
NH_4Cl	ammonium chloride
NH_4–N	ammonium nitrogen
NO_2–N	nitrite nitrogen
NO_3–N	nitrate nitrogen
NOB	Nitrite Oxidizing Bacteria
NO_x-N_{in}	influent nitrite and nitrate concentration
NO_x-N_{out}	permeate nitrite and nitrate concentration
ODR	oxygen depletion reactor
OHO	ordinary heterotrophic organism
OP	ortho-P
OUR	Oxygen Uptake Rate
P	phosphorus
PAOs	phosphate accumulating organisms
PHA	poly-β-hydroxyalkanoates
P_{IN}	influent orthophosphate concentration
O_4–P	phosphate
P_{OUT}	permeate orthophosphate concentration
$Q_{air,i}$	volumetric gas flux
SBR	sequential batch rectors
SNDPR	simultaneous nitrification, denitrification, and phosphorus removal
SRT	Sludge Retention Time
TKN	Total Kjeldahl Nitrogen
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solid
UCT	University Cape Town
VSS	volatile suspended solids
WWTPs	wastewater treatment plants
ηP_{TOT}	TP removal efficiency
η_{BIO}	biological COD removal efficiency
η_{denit}	denitrification efficiency
η_{nit}	nitrification efficiency
ηP	OP removal efficiency
η_{TOT}	total COD removal efficiency
ηN_{total}	total nitrogen removal efficiency
$\mu_{H,max}$	heterotrophic growth rate

here discussed and, they found the highest N_2O emissions at the lowest investigated C/N ratio (5 gCOD/gN).

The variability of the influent features and of the used process configuration make the weight that each operating factor has on the total N_2O emission unknown. Such a fact leads, as a consequence, to a huge variability of the N_2O emission factors (with respect to the influent nitrogen load) available in the literature: 0.01–1.8% (Ahn et al., 2010; Rodriguez-Caballero et al., 2015), 0.036% (Aboobakar et al., 2013), 0.04–11% (Daelman et al., 2015).

Further, the existing difficulties in capturing and measuring the real overall N_2O produced from WWTPs (Marques et al., 2016) make data more case study specific and difficult to transfer to other systems (Mannina et al., 2016a).

Despite the knowledge on the N_2O emission from WWTP has considerably increased, it has been mostly acquired on conventional activated sludge systems (CAS) (Todt and Dörsch, 2016). Therefore, current knowledge may not directly be transferred into innovative systems such as MBR or moving bed biofilm bioreactors (MBBR or hybrid biological systems such as Integrated Fixed Film Activated Sludge –IFAS) Mannina et al. (2011). MBR systems as well as IFAS systems are characterized by specific peculiarities that would strongly influence the N_2O production/emission. For example, the intensive aeration for fouling mitigation in MBR can promote the N_2O stripping. Therefore, further studies to better understand how the peculiarities of MBR or IFAS systems influence the N_2O emissions are required.

With this regard, only few studies have been reported in literature. Todt and Dörsch (2016) found that the AOB denitrification and the incomplete heterotrophic denitrification as the main sources of N_2O production in biofilm systems. These two N_2O formation pathways occur mainly in hypoxic or anaerobic zone of biofilm, where the low O_2 concentration and the presence of NO_2 favor the N_2O formation.

Lo et al. (2010) demonstrated that from the hybrid system the production of N_2O was significantly higher (21.2% of the influent nitrogen) than that of pure biofilm systems (0.5% of the influent nitrogen) and suspended biomass systems (4.2% of the influent nitrogen).

Very recently, Kinh et al. (2017) have demonstrated that membrane-aerated biofilm reactor (MABR) provides lower N_2O emission than conventional biofilm reactor (CBR). Specifically, N_2O emission factor was 0.0058 ± 0.0005% in the MABR and 0.72 ± 0.13% in the CBR.

Studies on the quantification of N_2O from biofilm systems, such