Nitrous oxide emissions of a mesh separated single stage deammonification reactor

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ABSTRACT

It is widely accepted that partial nitrification by ANAMMOX has the potential to become one of the key processes in wastewater treatment. However, large greenhouse gas emissions have been panobserved in many cases. A novel mesh separated reactor, developed to allow continuous operation of deammonification at smaller scale without external biomass selection, was compared to a conventional single-chamber deammonification sequencing batch reactor (SBR), where both were equally-sized pilot-scale reactors. The mesh reactor consisted of an aerated and an anoxic zone separated by a mesh. The resulting differences in the structure of the microbial community were detected by next-generation sequencing. When both systems were operated in a sequencing batch mode, both systems had comparable nitrous oxide emission factors in the range of 4% to 5% of the influent nitrogen load. A significant decrease was observed after switching from sequencing batch mode to continuous operation.

Key words | ANAMMOX, continuous operation, mesh reactor, N_2O, partial nitrification, wastewater

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INTRODUCTION

Due to its efficiency, the combined process of deammonification, also called partial nitrification (PNA), and anaerobic ammonium oxidation (ANAMMOX) is applied to treat reject water from sludge processing with high ammonia loads. Various process configurations are installed at hundreds of industrial and municipal treatment plants worldwide (Lackner *et al.* 2014), showing that PNA is a well-established technology. However, such side stream nitrogen treatments may lead to significant greenhouse gas emissions due to the generation of nitrous oxide as a process intermediate (Paredes *et al.* 2007).

PNA is more efficient than nitrification/denitrification because partial nitrification, also called nitritation, requires less aeration than nitrification and ANAMMOX, unlike denitrification, does not need a carbon source. Therefore, the carbon can be used for energy production. Taking these two factors into account, wastewater treatment plants (WWTPs) can increase their overall energy efficiency (Siegrist *et al.* 2008). So far, the implementation of PNA has been limited to side stream applications, but recent progress in mainstream applications makes it likely that these savings may be achieved on a much larger scale (Lotti *et al.* 2015; Wett *et al.* 2015). While the first implementations were based on a two-stage approach, in which PNA is carried out in two separate reactors; for example, the MBBR-based process in Hattingen (Rosenwinkel & Cornelius 2005), the combination of Single reactor system for High activity Ammonium Removal Over Nitrite (SHARON) with the ANAMMOX process in Rotterdam, The Netherlands (van der Star *et al.* 2007), or membrane aerated biofilm reactors (Gilmore *et al.* 2013), development has shifted towards single-stage systems (Dapena-Mora *et al.* 2007).

In anticipation of a widespread application of PNA systems, its greenhouse gas emissions are still the subject of investigation, in which nitrous oxide (N_2O) usually represents the most significant mass fraction considering its greenhouse gas potential (Weissenbacher *et al.* 2010; Wang *et al.* 2016). These N_2O emissions are evaluated as an emission factor (EF), which sets them in relation to the influent nitrogen load of the treatment system. As such, several studies have quantified the N_2O EFs of single-stage partial nitration and reported values ranging from 0.1% to values

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up to 6% (Ali *et al.* 2016). This shows that nitrogen removal systems such as PNA may lead to large emissions. Nevertheless, the reported values in the lower range also indicate that it is possible to maintain PNA processes at small greenhouse gas emissions.

Some operational factors, such as influent characteristics, may not be altered to reduce N_2O emissions, while other factors can be adjusted to foster low N_2O emissions such as: low dissolved oxygen level (Pijuan *et al.* 2014; Lv *et al.* 2016), intermittent aeration (Castro-Barros *et al.* 2015), pH and reactor configuration. In the case of single-stage PNA systems, the metabolisms of two groups of bacteria need to be kept in balance providing sufficient oxygen for nitritation but preventing anammox inhibition and inhibiting nitratation at the same time. Achieving this is fostered by increased temperatures of about 25 °C to 35 °C and limited oxygen supply that also kinetically selects ammonia oxidizing bacteria (AOB) over nitrite oxidizing bacteria (NOB) (Third *et al.* 2001) and reduces the chance to reversibly inhibit ANAMMOX bacteria due to the presence of oxygen (Strous *et al.* 1997). This approach is commonly applied in sequencing batch reactors (SBRs) that are operated with pH-controlled intermittent aeration at low DO set points (Zekker *et al.* 2012). SBRs allow the separation of the biomass fractions and therefore the selection of granular anammox biomass by controlling the settling time. The selection of anammox biomass is further improved at full scale by, for example, hydro-cyclones (Wett 2007) or screens (Han *et al.* 2016) (DEMON® process) that also allow continuous flow configuration of single-stage PNA.

Numerous PNA systems have been studied for greenhouse gas (GHG) emissions, such as SBR biofilm (Third *et al.* 2001), membrane aerated biofilm reactors (Ma *et al.* 2017), two-stage (Okabe *et al.* 2011), as well as granular/suspended growth (Kampschreur *et al.* 2009) systems. In this study, a novel reactor configuration that allows continuous operation and spatial instead of temporal separation of anoxic and aerobic conditions in one reactor was investigated for N_2O emissions. The reactor configuration with mesh-separated compartments was developed for smaller scale applications without the need for additional devices for ANAMMOX biomass retention (Fuchs *et al.* 2017).

METHODS

Pilot plant setup

The pilot plant consisted of two reactors: a single chamber and a two-compartment mesh system. Both had an average working volume of 375 L, whereby the working volume varied by ±3% during an SBR cycle. They were equipped with a hood for collecting the off-gas of the reactor. The effluent of each reactor was collected in separate containers for drawing composite samples of effluent flows according to the water level.

Both reactors were fed from the same influent 1.3 m^3 tank, using a peristaltic pump (Watson Marlow, USA) for each reactor; each was regularly readjusted to maintain defined volumetric loading rates. The influent tank was equipped with an impeller to allow substrate manipulation by spiking. The influent tank was supplied by two 5 m^3 storage tanks containing reject water. The single chamber system was equipped with an impeller, a plate membrane aerator (Aquaconsult, AT) and an influent hole at the bottom.

The mesh system was divided by an aluminium frame with a polyester mesh (0.2 to 0.3 mm pore size) which was supported by a net (1 mm pore size). The aerated side was equipped with a plate membrane aerator (Aquaconsult, AT). The non-aerated side, where the effluent was located, was equipped with an impeller. This allows the creation of two distinct zones, one being aerobic and turbulent and the other one being relatively laminar in the top section and turbulent in the lower section, being anoxic. Further, this induces a granular selection process when the reactor is operated in a continuous mode, as the effluent is taken from the upper section of the reactor, which could be observed through the transparent front plate. Due to the flexibility of the polyester mesh and the high turbulence of the aerated side fouling was prevented, allowing the passage of even larger granules from one chamber to the other, with a tendency for the larger granules to remain in the unaerated side. Further biofouling was prevented as the elasticity of the mesh provided some slack, inducing a rubbing motion against the supporting mesh, which eliminated the need for cleaning throughout the entire operation (7 months). The intention behind this reactor configuration and potential advantages are discussed elsewhere (Fuchs *et al.* 2017).

The pilot plant was controlled using a PC-based USB data acquisition device (USB 6210, National Instruments, USA). The pH of each reactor was measured on line (Orbisint CPS11, Endress Hauser, CH), as well as the dissolved oxygen Oxymax W COS61, Endress Hauser, CH). Airflow was switched using a magnetic valve at a pre-set flow rate, and the aeration volume was recorded using a positive displacement gas meter (Zweistutzen-Gaszähler 85817, Lingg und Janke, DE).

Reject water from sludge processing at a municipal wastewater treatment plant was collected in tanks and transported to the pilot plant. Unfortunately, the concentrations of the reject water available (295–410 mg NH_4-N L^{-1}, alkalinity 30–44 mmol L^{-1}) were lower than commonly applied for sidestream deammonification (700–1,800 mg NH_4-N L^{-1}) (Rosenwinkel & Cornelius 2005; Wett 2007; Yang et al. 2013). To reach comparable loading rates, ammonium bicarbonate and sodium bicarbonate were used to adjust the concentrations of ammonium and alkalinity (Table 1).

The reactors were inoculated identically with the sludge of a DEMON® side stream treatment process from a municipal WWTP (170,000 PE), taken from the recirculated fraction of the screen separating the ANAMMOX biomass from the waste activated sludge stream. At the time of extraction, the reactor was operated at 4 g volatile suspended solids (VSS) L^{-1} and had a nitrogen removal efficiency of 90% and a loading rate of 0.5–0.7 kg N m^{-3} d^{-1}. The initial sludge characteristics at the time of inoculation were 4 g L^{-1} VSS, an mixed liquor suspended solids (MLSS) of 5 g L^{-1}, a specific ANAMMOX activity of 0.22 g N g^{-1} VSS d^{-1} (Dapena-Mora et al. 2007). During continuous operation, average VSS and MLSS levels and SS effluent remained in the same range, whereby the single chamber system had an MLSS of 5.6 g L^{-1}, a VSS of 4.7 g L^1 , effluent suspended solids (SS) of 0.38 g L^{-1} and a sludge age of 34 d, the mesh separated system had an MLSS of 5.1 g L^{-1}, a VSS of 4.5 g L^{-1}, effluent SS of 0.43 g L^{-1} and a sludge age of 28 d.

Pilot plant reactor operation

To show the impact of the novel configuration on N_2O emissions, the system was run in continuous and SBR mode in parallel to a single chamber SBR. They were operated using the same controller settings for the SBR mode. It consisted of a 210 min reaction phase, 15 min settling, and 15 min decanting, giving a total cycle time of 4 h. The inflow was evenly distributed to the two reactors during SBR mode. During the continuous operation of the mesh reactor, the inflow to the continuous reactor was adjusted to assure the same daily loading rates in both systems. Both reactors were set to a temperature of 35 °C.

Table 1 | Influent characteristics

Parameter	Unit	Influent Average (SD)
Influent NO_3-N	mg L^{-1}	3.2 (1)
Influent NO_2-N	mg L^{-1}	3.1 (1)
Influent NH_4-N	mg L^{-1}	1,241 (141)
Influent TOC	mg L^{-1}	266 (59)
Influent alkalinity	mmol L^{-1}	126 (11)

TOC: total organic carbon.

In the reaction phase, the aeration control of both reactors was based on pH, DO, and a status timer. Primarily, aeration was turned on at the upper pH limit and turned off at the lower pH limit. Secondly, a DO limit was set to avoid oxygen inhibition, which turned the aeration on and off by overruling the pH control. Both systems had an upper DO limit of 0.3 mg L^{-1}, a lower pH limit of 7.36 and an upper limit of 7.365. To avoid over- and under-aeration of the system in case of malfunctions or instabilities of the system, a status timer operated as a backup limiting aeration time and non-aerated time. After 15 minutes of aeration or non-aeration the aeration was forced to change its status for 5 min, overruling pH and DO control.

After seeding, both reactors were run for 6 months, wherein the nitrogen loading rate was continuously increased while optimizing the reactor configuration. Finally, a nitrogen loading rate of 0.5 kg N m^{-3} d^{-1} was achieved at both reactors, comparable to full-scale conditions, which resulted in an HRT of 2.3 days in both reactors. To determine the community composition, samples for the next generation sequencing (NGS) analysis were taken from each chamber of the two systems while being aerated or mixed, respectively (three samples), on the day before starting the monitoring of gaseous N_2O emissions. The emissions of both systems operated in SBR mode were compared for 1 week, then the mesh-separated system was changed to continuous operation. After letting the system stabilize for 2 days, the single chamber operating in SBR mode and the mesh system operating in continuous mode were compared for 3 weeks.

Monitoring

During the N_2O monitoring period, the gas sampling alternated between the reactors on a daily basis and was combined with an intensified regular sampling campaign of the influent and effluent. The total off-gas flow was measured by an anemometer (EE75, EE Elektronik, AT). A suction tube collected the off-gas sample from the off-gas stream of the sealed reactor headspace, as shown in Figure 1. The off-gas sample was pumped to an insulated chamber containing a gas cooler and a Clark-type N_2O sensor (Unisens, Denmark), whereby values were recorded each minute. It was calibrated regularly by attaching gas bags with test gas and nitrogen to the suction tube.

Daily composite samples of the influent and effluent were taken for the analysis of nitrogen parameters. Alkalinity and

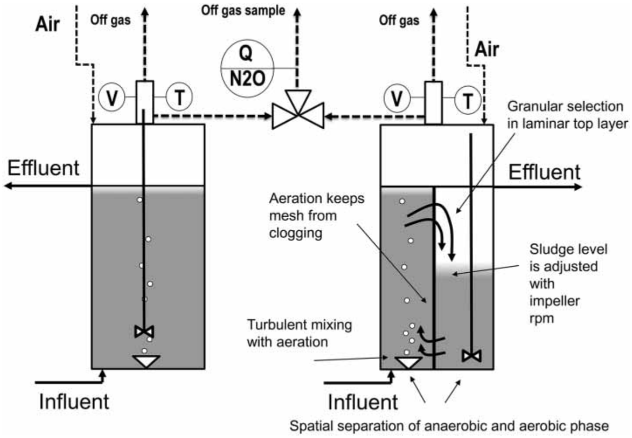

Figure 1 | Scheme of the pilot plant reactors with N_2O monitoring SBR (left), mesh reactor (right).

total organic carbon (TOC) were sampled every week. Total nitrogen bond (TNb), defining the total pollution of water with nitrogen compounds, was sampled for quality control of nitrogen parameters according to DIN EN 12260 (H34):2003 (DIN 2003).

Photometric analyses of nitrogen parameters were performed by a photometer and test tubes (Hach, USA). Alkalinity was determined according to DIN 38409 T7 (H7) (DIN 2005). TOC was analysed according to DIN EN 1484 (H3):1997 (DIN 1997).

To characterise the activated sludge, grab samples of 100 ml for SS and VSS were taken from each compartment and from the effluent tanks. The measurements were performed according to DIN 38409 (1987) (DIN 1987) and DIN EN 12879 (2001) (DIN 2001). A detailed description of the microbial diversity analysis by next-generation sequencing (NGS) is given in the Appendix (available with the online version of this paper).

RESULTS AND DISCUSSION

Microbial community composition

The presence of bacteria associated with nitrogen removal in PNA plants was confirmed by NGS. Each chamber of the mesh system and the single chamber contained similar amounts of SS and VSS. Thus it is possible to directly compare NGS results, which correlate to the relative abundances of DNA hereinafter. The present ANAMMOX bacteria belonged to the genus *Candidatus* Brocadia, which are frequently identified in ANAMMOX processes (Pereira *et al.* 2017). The non-aerated chamber of the mesh system showed the highest abundance of 12.4%, followed by 5.6% inside the single chamber system and 4.3% at the aerated side of the mesh system. The average ANAMMOX concentration of the mesh system was 8.35%, which suggests that the mesh system selects ANAMMOX more efficiently. This is supported by measurements of particle distribution, where more smaller particles were present in the aerated zone, which is known to favour AOB growth, and relatively more larger particles were detected in the anoxic zone, which is known to favour ANAMMOX growth (Vlaeminck *et al.* 2010; Wett *et al.* 2010b; Persson *et al.* 2014).

Both systems showed comparable amounts of AOB, represented by the genus *Nitrosomonas*. Among them, the species *Nitrosomonas europaea* was found to be the most abundant in the aerated side of the mesh system, with 1.9%, followed by 1.3% in the single chamber system and 0.8% in the non-aerated side of the mesh system. NOB, represented by the genus *Nitrospira*, were also present in both systems: the highest abundance of 1.1% was seen in the aerated chamber of the mesh system, followed by 0.7% in the non-aerated side of the mesh system and 0.8% in the single chamber system. This indicates that, in total, the single chamber system achieved a better suppression of NOB, which is consistent with the higher effluent NO_3-N concentrations observed at the mesh reactor (Table 3). The average difference in NO_3-N values during the N_2O monitoring period was 40 mg L^{-1} in SBR mode and 69 mg L^{-1} in continuous operation. As the overall nitrogen removal in the mesh system was lower during continuous operation, these higher NO_3-N concentrations were not due to higher ANAMMOX activity.

Comparison of the relative abundances of ANAMMOX, AOB, OHO (ordinary heterotrophic organisms) and

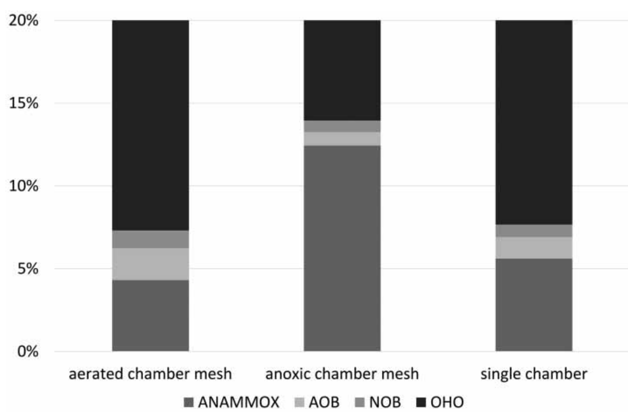

Figure 2 | Relative species distribution of biomass: ANAMMOX, ammonia oxidizing bacteria (AOB), nitrite oxidizing bacteria (NOB), and ordinary heterotrophic organisms (OHO). The range from 20 to 100% is only OHO, it is therefore excluded to highlight differences of AOB, NOB, and ANAMMOX.

NOB for all samples reveals (Figure 2) that the biomass composition of the pilot plant reactors differs from the composition of a full-scale PNA plant as simulated in Wett *et al.* (2010a). For the full-scale plant simulated by Wett *et al.* (2010a) with the BioWin – ASDM Model 26% of OHO, 18% of AOB, 0% NOB and 55% ANAMMOX were reported. This direct comparison of the biomass composition is likely subject to some bias, as concentrations based on NGS are compared to results from a simulation. Since NGS provides information on DNA ratios only, a direct reference to the absolute biomass composition regarding VSS can be biased. This is because DNA present in the sample might be from dead cells or different species may have different amounts of DNA in proportion to their total biomass. But part of the difference might be explained by the long-term operation and optimization of the full-scale reactor; in particular by the more efficient biomass selection achieved by hydro-cyclones (Wett 2007) or screens (Han *et al.* 2016) established at full scale.

Nevertheless, the mesh reactor achieved nitrogen loading rates around 0.5 up to 0.7 kg N m^{-3} d^{-1}, within the range of loading rates reported from full scale (0.11 to 1.2 kg N m^{-3} d^{-1}) (Fuchs *et al.* 2017), a difference that could be partly explained by the two times larger VSS fraction inside the pilot scale system (4 g VSS L^{-1} vs. 2 g VSS L^{-1}).

An even more important aspect is the AOB: ANAMMOX ratio achieved. The aerated side of the mesh showed an AOB:ANAMMOX ratio of 0.44, the non-aerated side 0.06, and the single chamber system 0.23. This result indicates that the separation of the aerobic and anoxic zones does influence the biomass composition. Although NOB suppression is not completely achieved and the concentration of OHO is much higher than in the full-scale system with external biomass selection, the ratio of AOB:ANAMMOX is comparable to the 0.33 (Wett *et al.* 2010a) of the large-scale system.

Although knowledge of the community composition in ANAMMOX based processes (Pereira *et al.* 2017) has increased over recent years, the implications for process performance are still vague.

N_2O emissions and reactor performance

Similar N_2O emissions were observed during the SBR operation of both systems, although with different magnitudes of emission peaks. Figure 3 depicts the typical pattern that could be observed, and Table 2 summarizes the emission factors and the cumulative monitoring times during the entire monitoring period. During SBR operation both reactors showed a step increase in emissions at the beginning

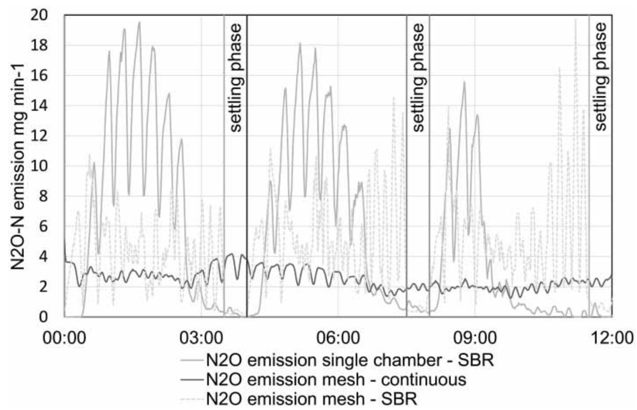

Figure 3 | Typical N_2O emission patterns of single chamber in SBR mode, and mesh system in SBR and continuous mode (5 days after switching operation mode).

Table 2 | N_2O emission factors

Parameter	Unit	SBR single chamber	Mesh SBR Average (SD)	Mesh continuous
N_2O EF (N load)[a]	[%]	4.3 (1.9)	3.7 (0.6)	1.8 (0.7)
N_2O EF (N removed)	[%]	6.8 (4.5)	5.2 (0.9)	2.8 (1.1)
Off-gas N_2O-N	mg L^{-1}	0.9 (0.5)	0.8 (0.2)	0.4 (0.2)
N_2O monitoring time	[d]	17.8	3.1	8.8
DO	mg L^{-1}	0.09 (0.093)	0.13 (0.026)	0.11 (0.031)
pH	–	7.38 (0.12)	7.36 (0.11)	7.32 (0.16)
Aeration	L h^{-1}	450 (135)	407 (69)	364 (61)

[a]The EF referred to in the paper.

of each cycle when the aeration was turned on again following the settling phase of the previous cycle. The emission peaks varied strongly in magnitude; while the single chamber had its peak towards the middle, the cycle pattern of the mesh system was less regular. The emission peaks of the mesh system decreased strongly once the system was changed to continuous operation.

When both systems were operated in SBR mode, the single chamber system had an average N_2O EF of 4.3%, and the mesh system had an average N_2O EF of 3.7% related to their influent N load. A large change was observed after switching the mesh system from SBR to continuous operation. Once the system had stabilized again, the continuous operation of the two-chamber mesh reactor reduced the N_2O EF to 1.8%, which corresponds to an average reduction of 50% of the N_2O emissions (Table 2). The single chamber system had a nitrogen removal rate of 76%, which was

Table 3 | Process parameters, performance and effluent values

Parameter	Unit	SBR single chamber	Mesh SBR Average (SD)	Mesh continuous
Ammonia removal rate	%	96 (4)	96 (1)	94 (3)
Nitrogen removal rate	%	76 (4)	71 (1)	69 (2)
Effluent NO_3-N	mg L^{-1}	246 (44)	286 (9)	315 (28)
Effluent NO_2-N	mg L^{-1}	3 (1)	1.6 (1)	4.3 (1)
Effluent NH_4-N	mg L^{-1}	56 (49)	51 (14)	84 (30)
Effluent TOC	mg L^{-1}	92 (40)	115	80 (4)
TOC removal	%	67 (6)	62	71 (5)
Effluent alkalinity	mmol L^{-1}	17 (9)	17	36 (19)
Volumetric loading rate	kg N m^{-3} d^{-1}	0.51 (0.07)	0.52 (0.06)	0.57 (0.05)
Reactor VSS	g VSS L^{-1}	4.6 (0.4)	4.2 (0.7)	4.2 (1)

higher in comparison to the mesh system with a nitrogen removal rate of 71% in SBR mode and a nitrogen removal rate of 69% in continuous mode. The difference in N-removal efficiency was due to NOB activity (higher NO_3-N-production in the mesh system), while ammonia conversion was at a comparable level (Table 3). Measurements of the particle size distribution and the VSS of the effluent of the fully mixed system indicated no decrease of VSS, as only the small particles were leaving the system.

With a view to the fact that the switch to continuous operation of the mesh system resulted in a strong reduction of N_2O emissions (Table 2), the operation mode appears to be more relevant than the community composition (Figure 2). Partly, this change can be associated with the different aeration requirements of the systems. Besides that, when changing from anoxic to aerobic conditions, the increased emissions may be explained by the faster recovery of AOB in comparison to the nitrite-consuming bacteria and the resulting accumulation of more intermediates, in comparison to continuous conditions (Brotto *et al.* 2015).

Furthermore, it has to be pointed out that the N_2O EFs presented in this study represent gaseous emissions only. Considering also liquid phase emissions, a relative increase in the N_2O EF of 2.5–10% can be expected using the data of Yang *et al.* (2013, 2016). For further comparison of EFs, overviews are provided by Ali *et al.* (2016) and Kampschreur *et al.* (2009).

The observations made in the present study indicate that continuous operation is a key factor in reducing N_2O emissions. We suspect that the factor most likely influencing this is the avoidance of prolonged unaerated periods that occur during the settling phase of the SBR. This is supported by the observation that the creation of two distinct zones in the mesh reactor had only a minor effect on reducing N_2O emissions, as long as SBR operation was performed. Under discontinuous operation conditions, both systems had very similar N_2O EFs during SBR operation.

This is in line with observations reported in the literature: Castro-Barros *et al.* (2015) observed that peak emission occurred when making a transition from low to high aeration conditions, and also reasoned that more continuous aeration would reduce overall emissions. In line with this reasoning, a reduction of N_2O emissions was observed for a membrane aerated reactor applying continuous aeration (Gilmore *et al.* 2013), highlighting an alternative approach for reducing emissions. Domingo-Félez *et al.* (2014) found that an increase in aeration frequency would decrease the EF. Observation made of a SHARON process leads to the conclusion that EF could be reduced if anoxic phases were avoided (Mampaey *et al.* 2016). Pijuan *et al.* (2014) was able to measure an increased N_2O production rate during the settling phase.

Unfortunately, this reduction of N_2O comes at a certain price, because there seems to be a minor trade-off between GHG emissions and NOB suppression. While the regular interchange between aerobic and anoxic conditions is known to be beneficial for the suppression of NOB (Ma *et al.* 2015), such conditions favour N_2O formation (Tsutsui *et al.* 2013). These observations are well in line with the results of this study, where the single chamber SBR showed slightly better nitrogen removal efficiency, but had a higher N_2O EF. Therefore, we conclude that superior selection mechanisms to suppress NOB, such as granular selection by hydro cyclones (Wett *et al.* 2010b) or screens, become increasingly important to maintain stable PNA systems with good removal efficiency while maintaining low N_2O emissions. Mesh reactors are a promising approach to achieve a relatively low-tech continuous PNA system, which was shown by the prolonged operation of a mesh reactor (Fuchs *et al.* 2017) and the first pilot plant system used in this study.

CONCLUSIONS

- It was shown that a mesh reactor provides a rather simple method to achieve continuous operation and reduction of N_2O emissions.

- In accordance with other findings in the literature, we assume that this reduction most likely occurs due to avoiding prolonged anoxic phases.
- Furthermore, we argue that the absence of NOB suppression by prolonged anoxic phases increases the importance of NOB suppression by mechanical means and thus is a key to maintaining efficient PNA systems with a low N_2O emission factor.
- NGS data available during SBR operation suggest that a difference of community composition exists in the mesh system. But the change to continuous operation better explains the differences in N_2O emissions due to its rapid decrease, which is much faster than an expected change in community composition. However, the collection of community data during prolonged continuous operation would be necessary to confirm this.

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DECLARATION OF INTERESTS

The following authors have no interests to declare: Thomas Schoepp, Johannes Bousek, Agime Beqaj, Christina Fiedler, Werner Fuchs, Thomas Ertl, Norbert Weissenbacher. Bernhard Wett is involved in self-employed engineering consulting in the field of wastewater treatment.

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