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Application of Vertical Reed Beds as a Buffer for Effluent from SBR ANAMMOX Treatment for Reject Water from Centrifugation

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Abstract. The main purpose of this study is to determine the removal efficiency of nitrogen compounds in the effluent from ANAMMOX process used to treat reject water after centrifugation. A pilot model was bulit consisting of four different Treatment Wetlands beds with different filter substrate and with or without macrophytes growth. Vertical subsurface flow type filters have been choosen thanks to their highest efficiency in NH4-N removal and better resistance to high fluctuations of influent composition. The pilot was feed with synthetic sewage prepaired on-site every day during the study. Samples have been taken for analysis to determine the changes of NH4-N, NO3-N and NO2-N in the effluent of each filter. In bed "0" the removal of nitrogen compounds was caused only by sorption and lasted till its capacity was reached. In bed "I" and "II" the NH4-N concentration in effluent and production of NO2-N with simultaneous changes of NO3-N indicated that nitrification was occurring. Furthermore assimilation by plants and sorption processes by substrate contributet to the removal of nitrogen compunds. The investigation reviles different pattern of processes responsible for N - compounds transformation and removal, depending on the bed substrate and vegetation or without vegetation

Keywords: ANAMMOX, rejest water, treatment wetlands, vertical subsurface flow beds.

Conference topic: Environmental protection.

Introduction

The return flows of reject water from sewage sludge dewatering alter the activated sludge process in majority of conventional WWTPs (wastewater treatment plants) and increase TN (total nitrogen) concentration in final effluent from WWTPs. The reject water (RW) is characterized by a very high concentration of nitrogen mainly in the form of ammonium nitrogen and organic matter as well as total suspended solids. Another problem with reject water management is connected with its irregular generation and a huge fluctuation of pollutant concentrations, even for the same WWTP. The most promising way of handling reject water is to pre-treat it before it returns to the first stage of treatment in WWTP. High-tech solutions like unconventional methods (ANAMMOX, SHARON etc.) are usually applied (Wett, Alex 2003; Gajewska, Obarska–Pempkowiak 2011). A lot of publications show very good but often unstable performance of these technologies (van Loosdrecht, Salem 2005; van Hulle *et al.* 2010; van Kempen *et al.* 2001, 2005; Fux *et al.* 2002, 2006). Thus the idea of application of treatment wetland (TW) to buffer the effluent from ANAMMOX reactor arise.

TWs are artificially built highly efficient treatment systems based on natural wetlands. Processes occurring in such system are very similar to those existing in natural ones, such as: sedimentation, filtration, vegetation of macrophytes, activity of bacterias and microorganisms that cause the removal of nitrogen, phosphorus, carbon and other compounds. TW systems are engineer designed in such a manner as to increase the efficiency and control over those processes (Vymazal, Kröpfelová 2008; Obarska-Pempkowiak *et al.* 2015). TWs have already proven their potency in numerous applications including municipal, industrial wastewater treatment or even landfill leachate (Wojciechowska *et al.* 2017; Kadlec, Wallace 2009). Besides that its cost-effectiveness makes it a good alternative for other very expensive and complicated biological treatment systems.

Treatment efficiency of wastewater is the most important factor while choosing the right TW system, which could be surface flow (kind of pond) or subsurface flow (vertical or horizontal flow beds, VSSF or HSSF respectively). Depending on what conditions are needed to achieve in the effluent, a right system has to be chosen. In subsurface flow beds occur good conditions for both nitrification and denitrification while having low flow. In HSSFs the main process is denitrification, however in VSSFs nitrification (Kadlec, Wallace 2009; Obarska-Pempkowiak *et al.* 2015). VSSFs have a high removal efficiency of organic compounds and TSS by filtration. Nitrogen is treated mainly by nitrification, due to better oxygen diffusion created by periodic feed of sewage. Sorption is the primary process of removing phosphorus on filter material (Vymazal, Kröpfelová 2008; Obarska-Pempkowiak *et al.* 2015; Szymura *et al.*

2010). The objective of this research is to study the removal efficiency of nitrogen compounds in vertical subsurface flow (VSSF) beds in TWs from effluent originating from a ANAMMOX treatment system. Between all other TW systems, VSSFs were chosen because of their highest efficiency in NH_4-N removal and better resistance to high fluctuations of influent composition.

Material and methods

Experimental design

The pilot consists of four single VSSF beds located in stainless steel tanks working parallel marked as BED “0”, “I”, “II” and “III” as seen in Figure 1. All tanks have the same inner size: 40 cm x 40 cm x 80 cm (LxWxH) with a bottom slope of 4%, and are based on a supporting structure 70 cm above the ground level. Each bed consists of a 45 cm high main filtration layer. A thin geotextile assures keeping smaller particles from getting downwards the other layers and hereby not allowing them to mix. Moreover a geosynthetic supporting the mesh above it and a 10 cm drainage layer made of 16–32 mm gravel. The substrate depends on the filter number: I- 0.5-1.2 mm sand; “0”, II and III- 2-8 mm gravel. Beds I, II and III are planted with common reed. “0” remains unplanted as so called control bed. Each bed is equipped with a manual ball valve and a flexible ending pipe to control the contact time in the bed in case of need to prolong the contact time for removal both ammonium and nitrate forms of nitrogen. The ending pipes are mounted to 4 separate 30 dm^3 sampling tanks.

Please take note that BED III was not used during this stage of study, as it is intended for future research related with artificial aeration which will be published in another paper.

To each one of the four filter beds there is one 30 dm^3 polipropylen tank (PP) sampling tank provided. Equipped with a sealed lid to ensure minimum contact with atmospheric air, as well as a manual valve for the run off pipe. The effluent is discharged to sewage system.

A main distribution tank (20cm x 20cm x 60cm; LxWxH) of maximum volume 24 dm^3, made of stainless steel is located 1.62 m above the ground level. It is divided into five sections: 5, 10, 15, 20 and 24 dm^3 which are set manually with a ball valve. The distribution tank is connected to each filter bed. It is equipped with a special system consisting of 2 inch stainless steel pipes, solenoid valves and sprinkler heads for automatic feeding and even distribution of influent on each filter. All valves are connected to a control box with electronical timers. Additionally the tank is equipped with a safety overflow pipe which redirects the overflow to the preparation tank.

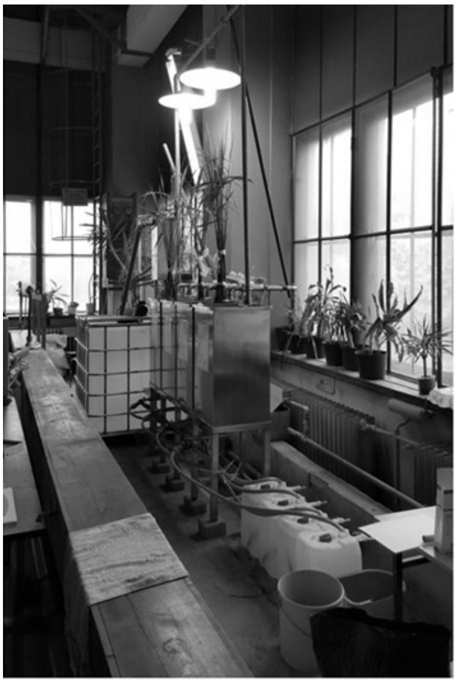

Fig. 1. The schematic picture of indoor VSSF beds with the equipment

As a preparation tank a 1000 dm^3 HDPE tank (IBC- Intermediate Bulk Container) for preparation of synthetic sewage. It is equipped with a pump to supply the distribution tank. Moreover the tank has also a emptying ball valve at the bottom and upper lid for fresh water intake. In case of empty. Additional the pump is protected from running dry by a non returning valve.

Grown out common reed plants, around 1.8 m height with 50 cm root length, were excavated from a natural wetland and planted in the filter beds. Before the main start of the pilot the filter beds where washed through with clean water for one week to avoid future clogging. During this period the system was checked for its functionality, its settings and possible malfunctions. Results were successful. First start with synthetic sewage was on the 21st August 2016.

Due to limited light conditions (indoor), UV lights were placed on a supporting construction above the beds to ensure photosynthesis and better growth.

Sampling and analysis

During the period 21st August–15th December 2016 each day a new batch of synthetic sewage was prepared with a load of 63 mg/dm^3 ammonium nitrogen (NH_4-N) and 26 mg/dm^3 nitrate nitrogen (NO_3-N) and 6 mg/dm^3 of carbon source in the form of glucose. The compounds used are NH_4Cl, KNO_3 and different sources of carbon.

The system was set for 4 feeds of 24 dm^3/d resulting in 96 dm^3 per bed per day assuring the assumed hydraulic load of 600 mm/m^{2}d. The filtration through the system took between 1.5–2 hours depending on the bed. After the daily cycle has stopped, if needed samples were taken from each sampling tank. Later on each tank was emptied to assure next day average daily sample. The regular temperature in the facility was around 21°C.

To measure the concentration of NH_4-N, NO_3-N and NO_2-N a spectrophotometer with cuvette tests from Hach Lange were used according to standards given in Table 1. Several samples and analysis were conducted to ensure right parameters of NH_4-N, NO_3-N and NO_2-N in the synthetic influent.

Table 1. Scope of analysis and methodology used.

Parameter	Test kit	Methodology
NH_4-N	LCK 303	Hach
NO_3-N	LCK 340	Hach
NO_2-N	LCK 341	Hach

Results and discussion

Influent concentration and working conditions

Based on data given in numerous articles (Fux *et al.* 2003; van Loosdrecht, Salem 2005; van Hulle *et al.* 2010; van Kempen *et al.* 2001) about ANAMMOX reject water the following nitrogen loadings were assumed: 63 mg/dm^3 NH_4-N, 26 mg/dm^3 NO_3-N and 0 mg/dm^3 NO_2-N with a hydraulic load of 600 mm/m2d (Table 2). Additional a source of carbon was used in the amount of 6 mg/l to enhance possible denitrification. For the pilot a higher concentration of NH_4-N was assumed due to enhance the process of nitrification in the bed layer. The goal was to research the influence and treatment efficiency of high concentrated ANAMMOX reject water on VSSFs with high hydraulic load.

Table 2. Parameters of synthetic ANAMMOX reject water.

Parameters	Inflow mg/dm^3	Load of TN, g/m^{2}d	Synthetic influent load	
			Feed volume dm^3/ bed per day	Hydraulic load mm/m^{2}d
NH_4-N	63.0	37.8	96	600
NO_3- N	26.0	15.6		
NO_2- N	0.0	0.0		
TN	89.0	53.4		

Comparison of nitrogen compounds concentrations during treatment

In Figure 2, 3 and 4 the changes of influent concetrations of nitrogen compounds in each bed are presented.

For bed "I", with the smallest substrate, since the start of the pilot on the 21st August until the first sample was taken no real treatment was noticed, just a drop of 2.21 mg/dm^3 of NH_4-N was indicated. The first significant drop of NH_4-N in the effluent was observed in sample 2 on the 28th August resulting in a treatment efficiency of 48.57% NH_4-N indicating that nitrification is occurring due to significant increase in of NO_2-N. Between sample 2–10, there was a "stable" treatment efficiency between 48.57% up to 63.02%.

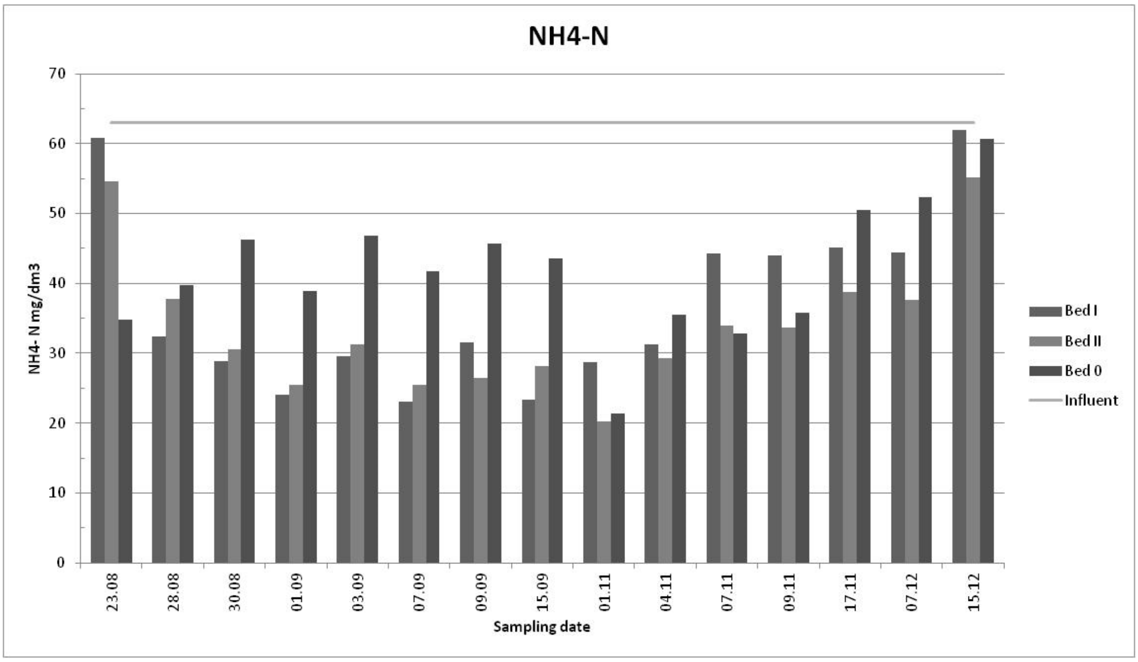

Fig. 2. Fluctuation of NH_4-N in effluent from analised beds “0”, “I”and “II”.

On the 7th November a visual change in plants was realised indicating the close by ending of their vegetation. A significant rise of NH_4-N in the last sample from 15th of December indicates clearly a stop of any treatment processes which prove also observation on site that the plants have finally finished their biological cycle and changed into winter sleep.

In case of bed “II”, with core sand as a substrate, similar patern of NH_4-N has been observed, but the efficency removal was higher in comparison to the one observed in bed “I” with a minimum 46.03% on the 7th November and maximum 67.78% on 1st November.

Supraslingly the second highest removal efficiency of amonium nitrogen was observed for the bed without reed. On the 1st November it reached 21.3 mg/dm^3 reuslting in a 66,19% efficiency. This high removal effectiveness of NH_4-N in the initial period of VSSF bed exploatation could be explained by sorption process observed also by other Authors (Saeed, Sun 2012; Wojciechowska *et al.* 2017). Important is that when the sorption capacity has been exhausted since middle of November other removal procesess become of more importance Figures 3 and 4.

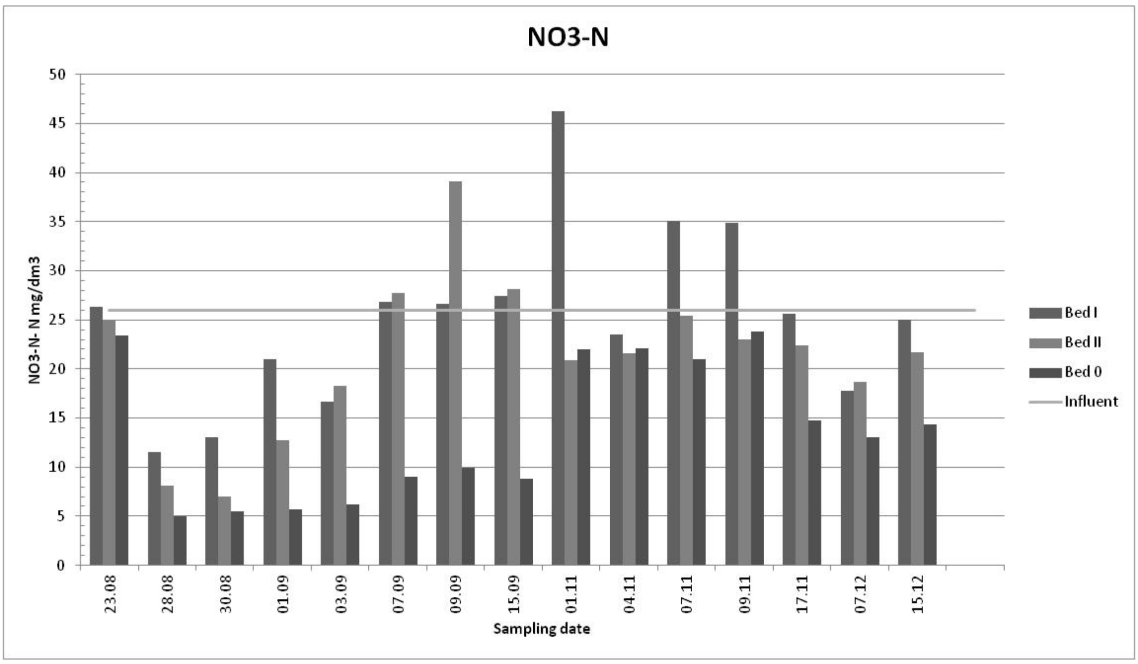

Fig. 3. Fluctuation of NO_3-N in effluent from analised beds “0”, “I”and “II”.

Significant drop of NO_3-N in the effluent at the beginning indicates either that sorption by filter material was occurring or assimilation by plans, more likely even both. The amount of NO_3-N was rising till 7th of August staying stable up to 15th August indicating that production of NO3 was higher that the concentration assimilated through sorption and plants, maybe even sorption capacity has been exhausted.

Generally it has been already proven that faster and more effective nitrification occurs in beds with fine substrate like in bed "I" (Kadlec, Wallace 2009) In case of this investigation for the beginning of nitrification process the 1st of November could be assumed since the concentration of N-NO3 started to raise above the discharged concentration indicating the transformation of ammonium nitrogen into nitrates in nitrification process.

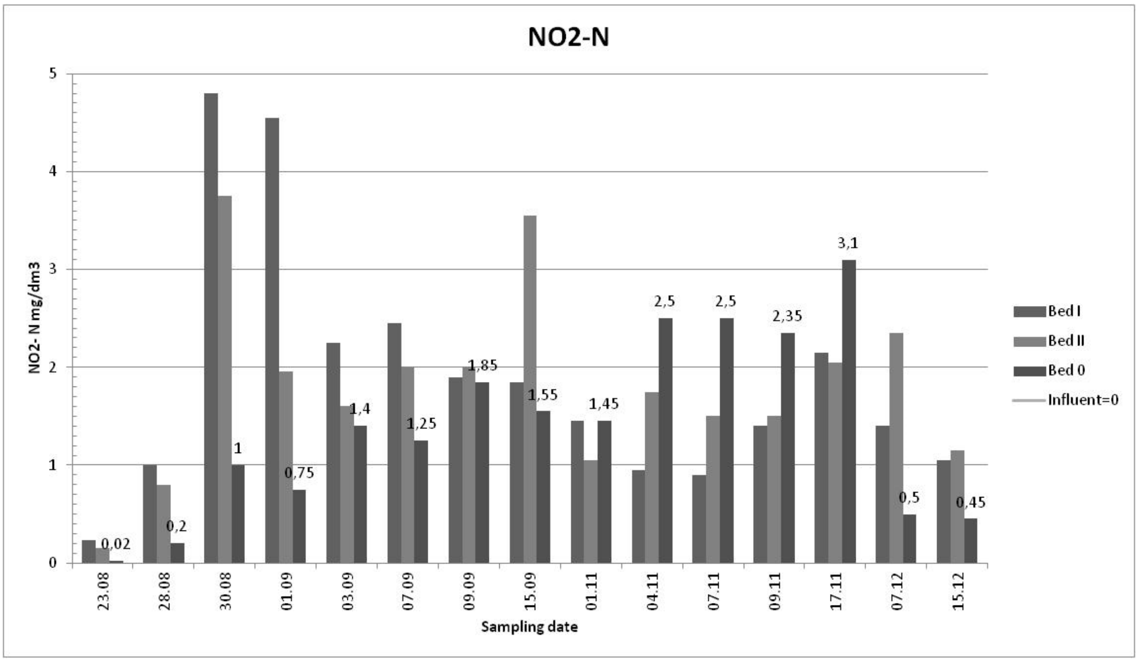

Fig. 4. Fluctuation of NO_2-N in effluent from analised beds "0", "I"and "II".

The NO_2-N presence in the effluent could be explained only by occurrence of partial nitrification process. It is important to notice that in first two weeks of the experiment the NO_2-N concentrations were very low and in the third week rapid growth appeared in beds inhabited by reed indicating the initiation of nitrification process. Since that time the concentration of NO_2-N has been fluctuating significantly indicating that the transformation process was unstable.

Upraising concentration of NO_2-N in bed "II" effluent between 28th August and 1st September indicates that the ammonia oxidizing bacteria (AOB) which are the first group of nitrifiers in nitrification and are responsible for oxidizing ammonia to nitrite (Ward 2013) were in their highest function.

The initial concentration of nitrogen present only in the form of NH_4-N and NO_3-N due to treatment in VSSF beds models reviled different pattern of processes responsible for their transformation and removal, depending of the bed substrate and vegetation or without vegetation.

Conclusions

Based on the carried out investigation it could be concluded:

1. Initial relatively high removal of ammonium nitrogen in bed "0" could be attributed only to the sorption process by substrate. When sorption capacity has run out, after four months, no further removal of ammonium nitrogen have been observed.

2. For the beds inhabited by reed drop of NH_4-N concentration in effluent and production of NO_2-N with simultaneous changes of NO_3-N indicates that nitrification was occurring.

3. VSSF beds inhabited by reed create a better environment for N - compounds transformation and in consequence reviled a better removal of N - compounds.

4. The investigation reviles different pattern of processes responsible for N - compounds transformation and removal, depending on the bed substrate and vegetation or without vegetation.

Further research has to be done with different loads and additional air input to recognized the processes responsible for N removal as well as working conditions of VSSF beds applied for treatment of effluent after the SBR with ANAMMOX.

Acknowledgements

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