

Effect of selective organic fractions on denitrification rates using Salsnes Filter as primary treatment

V. A. Razafimanantsoa, L. Ydstebø, T. Bilstad, A. K. Sahu and B. Rusten

ABSTRACT

The purpose of this project was to investigate the effect of selective particle removal during primary treatment on downstream biological nutrient removal processes. Bench-scale Salsnes Filter fine mesh sieves were used as a primary treatment to obtain different organic fractions to test the effect on denitrification. Activated sludge and moving bed biofilm reactor anoxic tests were performed on municipal wastewater collected from two full-scale wastewater treatment plants located around the Oslo region (Norway). About 43% of the suspended solids in the wastewater was less than 18 μm , and 14% was between 18 and 150 μm . The effect of particulate chemical oxygen demand (COD) removal on denitrification rates was very minor.

Key words | denitrification, organic matter, primary treatment, wastewater treatment

V. A. Razafimanantsoa (corresponding author)

L. Ydstebø

T. Bilstad

A. K. Sahu

Faculty of Science and Technology,

University of Stavanger,

N-4036 Stavanger,

Norway

E-mail: aristide.v.razafimanantsoa@uis.no

A. K. Sahu

B. Rusten

Aquateam COWI AS,

P.O Box 6875,

Rodeløkka,

N-0504 Oslo,

Norway

INTRODUCTION

Biological nitrogen removal (BNR) is the most reliable and cost-effective process for nitrogen removal from wastewater (Abufayed & Schroeder 1986). Nitrogen compounds from wastewater are removed by a combination of two processes of nitrification and denitrification (Wang & Yang 2004). These processes need sufficient organic matter (chemical oxygen demand: COD) to provide the energy required for the removal of nitrogen from wastewater (Tas *et al.* 2009). The origin of organic matter might be from the influent wastewater or self-generated by microorganisms through lysis or provided externally. Since a major part of the influent COD consists of particulate forms (about 70%), which are linearly related to the total suspended solids (TSS), advanced particle removal during pretreatment will result in a lower organic load on the biological treatment process (Abufayed & Schroeder 1986; Van Nieuwenhuijzen 2000; Henze *et al.* 2008).

The evaluation of different solids separation technologies for primary treatment, such as dissolved air flotation, large septic tanks, primary clarifiers, deep bed filtration and several types of sieve-based technologies, including Salsnes Filter (SF), revealed that the SF fine mesh sieve is the most suitable technology to achieve a removal of at least 50% of suspended solids and 20% of the organic material measured as biochemical oxygen demand (BOD) as required by the European Union for primary treatment

(Bixio *et al.* 2000; Rusten & Ødegaard 2006). A saving of about 50% of the costs for primary treatment was achieved with an SF fine mesh sieve compared to the conventional primary clarifier, and a reduction of about one-third of the aeration power consumption was observed at an activated sludge plant upgraded with SF fine mesh sieve primary treatment (Rusten 2005). Moreover, the anaerobic digestion of the primary sludge with the excess sludge from the biological processes, to produce biogas for power generation, contributed to the overall operational cost savings (Bixio *et al.* 2000).

The resultant effective pore size of the SF screen can reach as low as 10–20 μm when operated properly, allowing a removal of about 40% of the total COD (Newcombe *et al.* 2011). However, according to Tas *et al.* (2009), removal of such an amount of COD can have a significant effect on denitrification potential of the treatment plant. In that aspect, the objective of this study was to investigate the effect on denitrification of the removal of a certain particle fraction by means of SF fine mesh sieves, in order to define the optimum particle size cut-off for particulate COD (pCOD) removal prior to BNR. Therefore, the following activities were performed: (1) characterization of influent wastewater before and after physical separation with GF/C filters and SF fine mesh sieves; (2) nitrate utilization rate (NUR) tests with activated sludge (AS) and

moving bed biofilm reactor (MBBR) processes; (3) finally, the computation of the denitrification rates.

METHODOLOGY

Sampling location

Wastewater from two municipal wastewater treatment plants (WWTPs) around the Oslo region (Norway) were investigated during this study, which are Bekkelaget (BRA) and Nordre Follo (NFR) WWTPs. These two WWTPs served also as source of nitrifying mixed liquor and Kaldnes K1 biofilm carriers, which were used during the laboratory tests. Grab samples of influent wastewater were collected just after the grit removal section at both WWTPs. Recycled activated sludge (RAS) was taken from the recycle line from the secondary clarifiers at BRA, while the biofilm carriers, Kaldnes K1, were taken from the anoxic Reactor 1 in Line 2 at NFR.

Separation process

A standard vacuum filter apparatus, typically used for suspended solids analysis, and a bench-scale SF (Rusten & Lundar 2006) were used for the physical separation of wastewater in order to get samples with different concentration of particulate organic matter. The separation process with SF was carried out by filtering an influent grab sample through different sieves, from 150 to 18 μm pore size. It was necessary to perform all tests without mat formation, allowing only the removal of particulates above a given size to provide a good picture of the size distribution of particles (Rusten & Lundar 2006).

Whatman GF/C filters (1.2 μm pore size) were used on the vacuum filter apparatus to provide samples free of suspended solids. Some of the samples were pre-flocculated (ff) with aluminum sulfate (alum) before separation with GF/C filter to remove both particulates and colloids from the influent wastewater. Flocculation was carried out with an alum dose of 12 mg-Al/L, a rapid mix at 150 rpm for 1 min and a flocculation at 20 rpm for 15 min. Since alum has a tendency to decrease the pH, small aliquots of 1 M NaOH were added until the set-point pH was attained (pH = 7).

During this study the SF fine mesh sieve with 150 μm pore size was only used once (Test 1), as this was the first experiment performed. Since there was not much difference in the results with untreated wastewater and 150 μm filtered

wastewater, sieves with lower openings were used during the rest of the tests.

Wastewater characterization

Good characterization of wastewater is very important in order to predict the removal efficiencies that can be expected for a given sieve (De Lucas *et al.* 2005; Rusten & Lundar 2006). During each anoxic test, influent wastewater was characterized before and after the separation process. Suspended solids were analyzed according to *Standard Methods* (2005), while chemical parameters such as COD, ammonium (NH₄-N), nitrate (NO₃-N), nitrite (NO₂-N) and orthophosphate (PO₄-P) were analyzed using the Dr Lange cuvette test kits and a DR 5000 UV-Vis spectrophotometer (Hach Lange, Germany).

Experimental setup

Two bioreactors were set up during each test, where degrittied influent wastewater was used in Reactor 1 and filtered wastewater in Reactor 2. The experiments were carried out from August 14 through October 9, 2012. The setup of the NUR experiment and the computation of the specific denitrification rate (SDNR) were adopted from the protocol outlined by Gu & Onnis-Hayden (2010). Activated sludge and MBBR anoxic tests were performed during this study. Table 1 summarizes the characteristics of the different tests.

Adjustment of SDNR for temperature effect and active biomass

Studies have shown that different temperature coefficients, Θ , apply to SDNRs associated with the different COD fractions: 1.20, 1.08 and 1.03 for the first, second and third rates, respectively (Clayton *et al.* 1991; Henze *et al.* 2008). The first and highest rate reflects the denitrification when utilizing readily biodegradable COD (rbCOD) (Rate 1). Then, pCOD will be used by denitrifiers to continue the nitrogen removal process, resulting in a second lower rate (Rate 2). Finally, the third and lowest rate is the endogenous denitrification rate (Rate 3) (Kujawa & Klapwijk 1999). The fraction of the active biomass was estimated from the measured test mixed liquor volatile suspended solids concentration and plant data related to BOD or biodegradable COD removed (Metcalf & Eddy Inc. 1991).

Table 1 | Experimental plan

Process	Test	Reactor ^d composition	Sieves tested
AS ^a	Test 1	wastewater from NFR + RAS from BRA	1.2 µm (ff) ^c , 1.2 µm, 33 µm, 150 µm
	Test 2	wastewater from BRA + RAS from BRA	1.2 µm (ff) ^c , 1.2 µm, 33 µm, 90 µm
MBBR ^b	Test 3	wastewater from NFR + Kaldnes K1 from NFR	1.2 µm (ff) ^c , 1.2 µm, 18 µm, 33 µm, 90 µm
	Test 4	wastewater from BRA + Kaldnes K1 from NFR	1.2 µm (ff) ^c , 1.2 µm, 18 µm, 33 µm, 90 µm

^aVolume ratio of wastewater and RAS of 1:1.

^bVolumetric filling of about 50% of Kaldnes K1 biofilm carriers.

^cff: flocculated with alum prior to filtration.

^dReactor volume: 3 L.

Table 2 | Characteristics of influent wastewater from BRA and NFR WWTPs during the experimental period (August 14–October 9, 2012)

Parameter	BRA WWTP		NFR WWTP	
	Range	Mean	Range	Mean
TSS (mg/l)	94–528	281 ± 110	132–262	218 ± 38
VSS (mg/l)	72–457	245 ± 105	105–228	190 ± 38
VSS/TSS		0.86 ± 0.07		0.86 ± 0.03
Total COD (mg/l)	143–801	494 ± 183	231–577	460 ± 100
pCOD (mg/l)	93–547	315 ± 127	156–375	299 ± 66
sCOD (mg/l) ^a	50–271	179 ± 69	75–205	161 ± 46
rbCOD (%) ^b		25 ± 4		20 ± 4
sbCOD (%) ^b		52 ± 5		51 ± 3
NO ₃ -N (mg/l)	0.26–1.16	0.57 ± 0.27	0.27–1.81	0.74 ± 0.57
NO ₂ -N (mg/l)	0.01–0.10	0.07 ± 0.04	0.02–0.17	0.08 ± 0.05
NH ₄ -N (mg/l)	9–24	18 ± 6	8–27	21 ± 6
PO ₄ -P (mg/l)	1–5	2 ± 1	1–5	3 ± 1

Average results given with the standard deviation. Number of samples per WWTP = 9.

^aAfter filtration through 1.2 µm GF/C Whatman glass fiber filter.

^brbCOD: readily biodegradable COD; sbCOD: slowly biodegradable COD (Melcer et al. 2003).

RESULTS AND DISCUSSION

Wastewater characterization

Characterization results of the influent wastewater during the experimental period (August 14–October 9, 2012) are outlined in Table 2. The soluble COD (sCOD) fractions, which contain the readily biodegradable substrate, made up only about one-third of the total substrate. A GF/C filter of 1.2 µm pore size was used to differentiate the soluble and particulate COD. The ratio of particulate COD to volatile suspended solids (VSS) found at the NFR and BRA WWTPs were 1.50 ± 0.16 and 1.35 ± 0.17 , respectively. The average results obtained in both WWTPs compare well with the typical values suggested for municipal wastewater composition (Tas et al. 2009).

Separation performance

The removal efficiencies, in terms of COD and TSS, associated with separation by means of GF/C filters and SF fine mesh sieves are illustrated in Figure 1. The graph combines

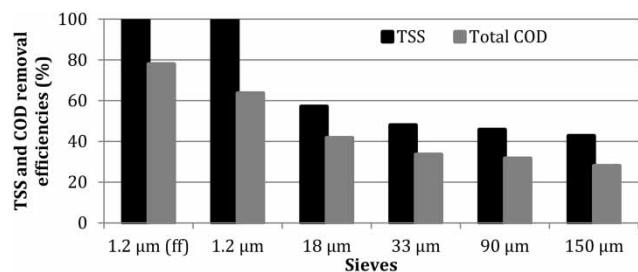


Figure 1 | TSS and COD removal efficiencies after separation with different sieves, given as averages.

both results from the separation of wastewater collected at the BRA and NFR WWTPs, given as averages. The graph shows that about 43% of the suspended solids (corresponding to 58% of total COD) in the influent wastewater was smaller than 18 μm and about 43% (corresponding to 28% of total COD) was larger than 150 μm . From 18 to 150 μm , the amount of particles in the tested wastewaters was only about 14% (the same for total COD). However, the amount of solids removed depends not only upon the sieve openings, but also upon the particle size distribution in the influent wastewater (Newcombe *et al.* 2011).

Characterization of the influent wastewater based on COD/TSS ratio is an important parameter for understanding and interpreting the fate of different COD fractions before biological treatment. It was observed during the separation process that SF fine mesh sieves decreased the pCOD/TSS ratio (Table 3), indicating the removal of a TSS with high COD/TSS ratio.

Denitrification rate

The SDNR obtained with AS and MBBR process anoxic tests are outlined in Table 3. The SDNRs were calculated based on the biomass (VSS) concentration in the reactor for the AS process (Kapagiannidis *et al.* 2006), while bio-film surface area was used in the MBBR process (Rusten *et al.* 2000).

The results summarized the different rates and the corresponding influent total COD to nitrate ratio (C/N) for the different tests. In general, the SDNRs were higher during the tests performed with the wastewater from BRA WWTP in comparison to the NUR tests using NFR wastewater in both processes. For instance, with AS process, the first rates were all above 0.17 $\text{gNO}_3\text{-N}/(\text{gVSS}\cdot\text{d})$ in Test 2 compared to a maximum of 0.14 $\text{gNO}_3\text{-N}/(\text{gVSS}\cdot\text{d})$ in Test 1. However, the second and third rates were similar in both tests, about 0.08 and 0.05 $\text{gNO}_3\text{-N}/(\text{gVSS}\cdot\text{d})$, respectively. The difference observed on the first SDNR might be attributed to the amount of rbCOD available in each influent wastewater. About 25% of the total COD was readily biodegradable in the wastewater from BRA, while it is only about 20% in the wastewater from NFR.

The SDNR results observed in the AS process fed with unfiltered wastewater were similar to the results found in the literature; the first SDNR ranges from 0.07 to 0.32 $\text{gNO}_3\text{-N}/(\text{gVSS}\cdot\text{d})$ (Barnard & Meiring 1977; Kapagiannidis *et al.* 2006), 0.08 $\text{gNO}_3\text{-N}/(\text{gVSS}\cdot\text{d})$ for the second rate (Barnard & Meiring 1977) and between 0.04

and 0.05 $\text{gNO}_3\text{-N}/(\text{gVSS}\cdot\text{d})$ for the endogenous rate (Randall *et al.* 1992). In the MBBR process, the SDNRs for unfiltered wastewater were in accordance with the literature data; overall rates of 0.8–1 $\text{gNO}_3\text{-N}/(\text{m}^2\cdot\text{d})$ (at 20 °C, Θ : 1.05) were observed in Rusten *et al.* (1995, 2000).

Due to the large variations in wastewater composition and other operating parameters it was difficult to compare results from one test to another. For this reason one reactor (R1) has been operated with unfiltered wastewater in all tests, for direct comparison with a reactor (R2) receiving filtered wastewater. The comparison of the two reactors showed that the SDNR results were quite similar in both treatment processes, despite the large difference in the influent total COD/N. It was observed earlier that sCOD was a small fraction of the whole; then the denitrification was mostly driven by hydrolyzed particulate COD (Abufayed & Schroeder 1986). In the case of wastewater with sCOD fraction only, the required carbon source must be from the hydrolysis of the biomass itself as no external carbon was added during the experiment.

In all these experiments, it can be concluded that endogenous carbon was utilized to drive the denitrification reaction, leading to the similarity in denitrification rates. Based on the results, no significant effect on denitrification rates were observed while removing part of the influent organic material. Newcombe *et al.* (2011) reached the same conclusion while removing 45% of the TSS with SF fine mesh sieve from the influent and still achieving an effluent total nitrogen of less than 10 mg/l.

CONCLUSIONS

Activated sludge and MBBR anoxic batch tests were performed to investigate the impact on denitrification of removal of certain fractions of particulate COD by means of SF fine mesh sieves. Separation with SF allowed the removal of about 57% of the suspended solids (corresponding to 42% of total COD) with 18 μm openings and about 43% (corresponding to 28% of total COD) with 150 μm pore size. From 18 to 150 μm , the amount of particles in the tested wastewaters was only about 14%. It was observed that solids removal during primary treatment had no significant effect on the denitrification process downstream. But further studies should be carried out as many factors could affect the denitrification, making it difficult to document the effects of a single parameter (Rusten *et al.* 2000).

Table 3 | SDNRs with the corresponding influent C/N and pCOD/TSS ratios from NUR tests with AS (Tests 1 and 2) and MBBR (Tests 3 and 4) processes

Test 1 (NFR wastewater)		Unfiltered wastewater			Filtered wastewater		
Sieves	Rate	SDNR^a	pCOD/TSS^c	C/N^d	SDNR^a	pCOD/TSS^c	C/N^d
1.2 µm (ff)	1	–	1.207	7.19	–	–	1.29
	2	0.08			0.06		
	3	0.04			0.03		
1.2 µm	1	0.10	1.250	8.40	0.10	–	3.41
	2	0.07			0.05		
	3	0.05			0.03		
33 µm	1	0.14	1.477	7.75	0.13	0.920	5.41
	2	0.07			0.07		
	3	0.05			0.05		
150 µm	1	0.08	1.227	7.67	0.10	1.473	6.10
	2	0.06			0.06		
	3	0.04			0.04		
Test 2 (BRA wastewater)		Unfiltered wastewater			Filtered wastewater		
Sieves	Rate	SDNR^a	pCOD/TSS^c	C/N^d	SDNR^a	pCOD/TSS^c	C/N^d
1.2 µm (ff)	1	0.24	1.266	9.66	0.22	–	2.38
	2	0.07			0.07		
	3	0.04			0.03		
1.2 µm	1	0.29	1.037	11.99	0.29	–	4.33
	2	0.09			0.08		
	3	0.05			0.05		
33 µm	1	0.37	0.936	8.56	0.36	0.812	6.38
	2	0.09			0.08		
	3	0.05			0.05		
90 µm	1	0.18	1.284	9.71	0.17	1.091	5.86
	2	0.07			0.07		
	3	0.04			0.04		
Test 3 (NFR wastewater)		Unfiltered wastewater			Filtered wastewater		
Sieves	Rate	SDNR^b	pCOD/TSS^c	C/N^d	SDNR^b	pCOD/TSS^c	C/N^d
1.2 µm (ff)	1	0.81	1.180	8.02	0.80	–	1.45
	2	0.61			0.60		
	3	0.34			0.30		
1.2 µm	1	1.23	1.320	19.18	1.19	–	7.52
	2	0.90			0.79		
	3	–			–		
18 µm	1	2.40	1.443	16.93	1.82	1.000	9.87
	2	1.83			1.67		
	3	1.39			1.28		

(continued)

Table 3 | continued

Test 3 (NFR wastewater)		Unfiltered wastewater			Filtered wastewater		
Sieves	Rate	SDNR ^b	pCOD/TSS ^c	C/N ^d	SDNR ^b	pCOD/TSS ^c	C/N ^d
33 µm	1	2.43	1.625	18.03	2.09	1.150	11.06
	2	1.63			1.56		
	3	1.11			1.14		
90 µm	1	0.97	1.178	16.01	0.94	1.320	12.79
	2	0.59			0.57		
	3	0.35			0.35		
Test 4 (BRA wastewater)		Unfiltered wastewater			Filtered wastewater		
Sieves	Rate	SDNR ^b	pCOD/TSS ^c	C/N ^d	SDNR ^b	pCOD/TSS ^c	C/N ^d
1.2 µm (ff)	1	2.69	1.421	18.18	2.43	–	5.43
	2	2.36			1.94		
	3	–			–		
1.2 µm	1	2.23	1.077	12.13	1.97	–	4.23
	2	1.63			1.56		
	3	1.15			1.13		
18 µm	1	1.22	0.983	4.78	1.23	0.925	2.91
	2	1.04			0.99		
	3	0.78			0.83		
33 µm	1	2.33	0.912	15.08	2.10	1.215	10.79
	2	1.60			1.49		
	3	–			–		
90 µm	1	2.17	1.200	13.45	2.20	1.049	8.65
	2	1.88			1.76		
	3	1.24			1.17		

Rates calculated for a temperature of 20 °C, using the temperature correction procedure described under 'Methodology'.

^aSDNR, expressed as g NO₃-N/(gVSS.d).

^bSDNR, expressed as g NO₃-N/(m².d).

^cpCOD/TSS expressed as g pCOD/g TSS.

^dC/N, expressed as g total COD/g NO₃-N.

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