COD removal, nitrogen removal,
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and intermittent aeration (SBRRIA)

Carla Eloísa DINIZ DOS SANTOS,
Márcia Helena RISSATO ZAMARIOLLI DAMIANOVIC*

EVALUATION OF SIMULTANEOUS NITRIFICATION AND DENITRIFICATION (SND) IN STRUCTURED-BED REACTORS OPERATED WITH DIFFERENT WASTEWATER

This study aimed to show the application of a structured-bed reactor subjected to recirculation and intermittent aeration (SBBRIA) for nitrogen and carbon removal from three different wastewater streams. Three different types of sludge were used for inoculation of the reactors: sludge from an UASB reactor (reactor R1), sludge from an activated sludge reactor with nitrifying activity (reactor R2) and a mixture of sludge used in R1 and R2 (reactor R3). Different operational procedures were applied in order to analyze the influence of HRT in R1, the influence of aerobic/anoxic phases in R2 and the influence of COD/N ratio in R3. The efficiencies of COD removal remained higher than 85%, regardless of the decrease in HRT, the adoption of different cycles of intermittent aeration or different COD/N ratios. The total-N removal efficiencies obtained for both reactors suggested that HRT is the operational parameter that has more influence in the nitrogen removal performance. Moreover, considering the results obtained with the treatment of three different types of wastewater, the SBRRIA reactor is adequate in conditions of high or low availability of electron donors for heterotrophic denitrification, due to the establishment of the anaerobic ammonium oxidation (anammox) process as an additional pathway of nitrogen removal under conditions of reduced COD/N ratio.

1. INTRODUCTION

In conventional treatment systems, biological nitrogen removal is carried out in two steps: nitrification and denitrification. In this process, denitrification requires the

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[*] Laboratory of Biological Processes, Department of Hydraulics and Sanitation, School of Engineering of São Carlos, University of São Paulo, Av. Trabalhador São-Carlense, 400, CEP 13566-590, São Carlos, São Paulo, Brazil, c.diniz@ymail.com, mdamianovic@sc.usp.br.

introduction of electron donors, usually added in the form of readily biodegradable organic matter. A possible alternative to reduce the costs involved in the nitrogen removal process is by using compacts systems that integrate the processes of nitrogen and organic matter removal within a single unit. Several systems have been proposed to remove nitrogen and organic matter in a single reactor, through simultaneous nitrification and denitrification (SND) [1, 2, 3, 4].

In this case, the development of reactors that provide suitable conditions for the growth of nitrifying and denitrifying communities is necessary. Batch reactors have been extensively used due to the possibility of altering aerated periods for nitrification and non-aerated periods for denitrification. Continuous reactors are also used, as carrousel oxidation ditch [3], fluidized bed reactor [5], systems with aerobic granules [6] and membrane [7]. Structured-bed reactors subjected to recirculation and intermittent aeration (SBRRIA) have been successfully used at Biological Processes Laboratory in School of Engineering of São Carlos (University of São Paulo, Brazil) for the nitrogen removal of a variety of wastewater. These systems can promote a regular distribution of the support medium inside the reactor, which avoids the clogging. Based on these studies, this work aims to show the application of a SBBRIA reactor for nitrogen and carbon removal from three different wastewater streams.

2. MATERIALS AND METHODS

2.1. EXPERIMENTAL SETUP

Bioreactor. The cylindrical-shaped reactors constructed of acrylic were 90 cm height (70 cm working height), with an internal diameter of 14 cm. The conical bases of the reactors were 13 cm height, with a total reactor volume of 11 L. Continuous feed and effluent recirculation inlets were located at the bottom of the reactors, represented by A1 and A2 respectively (Figure 1). The outlets for recirculation and effluent discharge were at 65 cm (A4) and 70 cm (A3) from the bottom of the reactors, respectively. Oxygen was supplied to the systems using a Regent, Model 8500, aquarium aerators. Porous stones (A5), periodically replaced after sufficient mechanical wear, were used for air diffusion in the liquid.

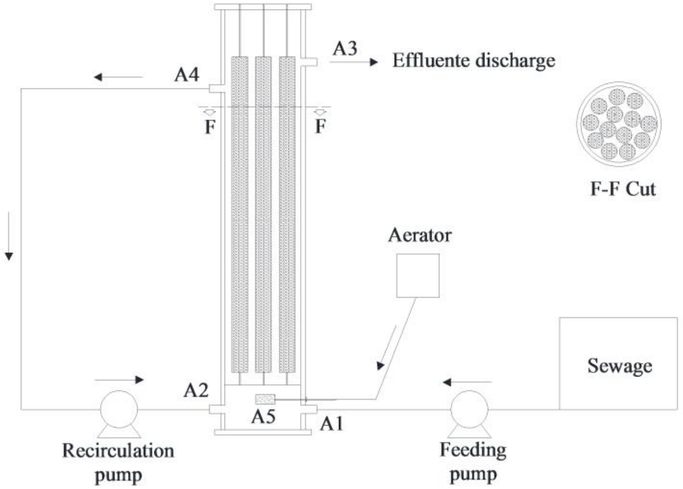

Fig. 1. Schematic representation of the up-flow structured bed reactor submitted to recirculation and intermittent aeration [4]

Support media and inoculum. Thirteen cylinders of polyurethane foam (diameter of 3 cm and 60 cm height) were used as support for biomass growth. The cylinders were disposed vertically inside the reactors, as can be seen in figure 1 (Cut F-F). This material presented a porosity of 92%, 22 g L^{-1} in density and surface area of 43.8 m^2 g^{-1}. The reactors were inoculated according to Zaiat [8], however three different types of sludge were used for inoculation:

- Reactor 1 (R1): This system was inoculated with sludge from an up-flow anaerobic sludge blanket (UASB) reactor used for treating poultry slaughterhouse wastewater. The reactor was applied to synthetic wastewater treatment. The wastewater simulated a domestic sewage after the removal of oils and greases with COD/N ratio equal to 11.2;
- Reactor 2 (R2): This reactor was inoculated with biomass from an activated sludge reactor with nitrifying activity. During the 117 days of operation, it was fed by the effluent from a UASB reactor used for poultry slaughterhouse treatment, with average COD/N ratio equal to 2.4;
- Reactor 3 (R3): The biomass was obtained considering a mixture (50% by volume) of sludge used in R1 and R2. This system also was fed by synthetic wastewater, with which two different carbon sources were tested (sucrose and meat peptone) in different COD/N ratios.

2.2. MONITORING OF THE REACTOR

Chemical-physical tests. During the experiments, the following variables were analyzed: pH, alkalinity, TKN (Total Kjedahl Nitrogen), NH_4^+-N (ammonium nitrogen), NO_2^--N (nitrite nitrogen), NO_3^--N (nitrate nitrogen), TSS (total suspended solids), VSS (volatile suspended solids), DO (dissolved oxygen) and COD (chemical oxygen demand). Analyses of NO_3^--N, NO_2^--N and NH_4^+-N were performed using Ion Chromatography (Dionex ICS 5000). The following conditions were used: a flow rate of 1.0 mL min-1, an electrochemical conductivity detector with gradient pump, IonPac AS23 column (4 mm x 250 mm) and IonPac CG12A column (4 mm x 250 mm) at a temperature of 30°C. Alkalinity was determined according to Dilallo and Albertson [9] modified by Ripley et al. [10]. All other analyses were according to APHA [11].

Study of anammox activity. To verify the existence of bacteria capable of performing the anammox process, tests were carried out using biomass obtained from R2 and R3, stored in an acclimatized chamber at 30°C. The synthetic medium used in the tests was similar to the medium described by Van de Graaf et al. [12]. To maintain anaerobic conditions, prior the beginning of the tests, the reactors (250 mL of volume) were bubbled with argon for 15 minutes. Samples were regularly taken over a period of 8 h for analysis of NH_4^+-N, NO_2^--N and NO_3^--N.

2.3. EXPERIMENTAL PROCEDURE

In order to promote the nitrifying growth, all reactors were initially operated with an hydraulic retention time (HRT) of 24 h and continuous aeration (acclimation period). After this, different operational procedures were applied in order to analyze the influence of HRT in R1, the influence of aerobic/anoxic phases in R2 and the influence of COD/N ratio in R3. Table 1 shows some operational characteristics of R1, R2 and R3.

3. RESULTS AND DISCUSSION

The reactors R1, R2 and R3 were continuously operated for 160, 124 and 243 days, respectively. During the aerobic periods, DO concentration was maintained between 2.0 and 3.5 mg L^{-1}. Data obtained during the monitoring of each reactor are summarized in table 2. In all studies was demonstrated the high potential of SBRRIA reactor for organic matter removal. The efficiencies of COD removal remained higher than 85% (table 2), regardless of the decrease in HRT, the adoption of different cycles of intermittent aeration or different COD/N ratios.

Table 1. Operational characteristics of the reactors studied

Reactor	Phases	Duration (days)	HRT (h)	Aeration periods	COD/N	Wastewater
R1 [4]	I	55	12	2 h aer/1 h non-aer	11.2	Synthetic
	II	30	8			
	III	36	10			
R2 [13]	I	24	24	6 h aer/0 h non-aer	2.4	Effluent from a UASB reactor
	II	11		4 h aer/2 h non-aer		
	III	8		2 h aer/1h non-aer		
	IV	25		1.5 h aer/1.5h non-aer		
	V	56		1 h aer/2h non-aer		
R3 [14]	I	58	12	2 h aer/1h non-aer	9.7	Sucrose
	II	75			7.6	Meat peptone
	III	71			2.9	Meat peptone
	IV	31			2.9	Sucrose

About the nitrogen, the results obtained from R1 (table 2) have shown that lower HRT can result in a decrease in the total nitrogen removal efficiency. A possible explanation for this might be that with a low HRT occurs an increase of applied organic load. In this case, the aerobic heterotrophic growth is favored over that aerobic autotrophic one, reducing the ammonia oxidation and then, affecting the total-N removal. The data from R2 and R3 indicate total-N removal with average efficiencies of 62% and 84%, respectively. This efficient performance was observed in both systems although there was a reduced availability of electrons for heterotrophic denitrification. Moreover, in R2 and R3 the anammox process was also observed as an additional pathway of nitrogen removal under conditions of reduced COD/N ratio. The anammox metabolism was observed after an operational period of 131 and 150 days in R2 and R3, respectively.

Several factors may be associated with the suitable performance of SBRRIA reactor in COD and nitrogen removal. Efficient nitrogen and organic matter removal results can be explained by the spatial distribution of organic matter oxidizers, nitrifiers, denitrifiers and anammox inside the support material [15]. The adoption of aerated and non-aerated periods promoted the SND process in this unit. As a result, compared to continuous aerated systems, systems submitted to intermittent aeration can save approximately 33% of energy. During the aerobic phase, higher NH_4-N oxidation can be observed, generating NO_3-N which is immediately consumed by the denitrifiers during the anoxic phase.

Table 2. Mean values of the characterization of the reactor effluent during the three experiments

	Variables	Phase I	Phase II	Phase III	Phase IV	Phase V
Reactor 1	pH (average value)	8.2 ± 0.1				
	Alkalinity (mg $CaCO_3$ L^{-1})	664.5 ± 16	655 ± 16.3	666.4 ± 11		
	TKN (mg L^{-1})	3 ± 1	11 ± 4	15 ± 4		
	NH_4^+-N (mg L^{-1})	1.2 ± 0.9	11.9 ± 4.8	13.3 ± 1.4		
	NO_3^--N (mg L^{-1})	1.6 ± 0.7	0.7 ± 0.7	0.5 ± 0.2		
	NO_2^--N (mg L^{-1})	0.5 ± 0.5	-	-		
	TN (mg L^{-1})	5.3 ± 1.7	12.1 ± 4.0	16± 4.0		
	COD (mg L^{-1})	39 ± 12	54 ± 16	43 ± 16		
	COD removal (%)	89 ± 3	85 ± 5	88 ± 4		
	Total-N removal (%)	82 ± 6	49 ± 17	45 ± 12		
Reactor 2	pH	6.4–8.0	6.1–8.2	5.6–7.3	6.4–8.1	6.9–8.2
	Alkalinity (mg $CaCO_3$ L^{-1})	114 ± 65	136 ± 30	15 ± 18	72 ± 8	160±76
	TKN (mg L^{-1})	35.5 ± 32	9.6 ± 0	9.0 ± 1	7.0 ± 3	6.4 ± 5
	NH_4^+-N (mg L^{-1})	19.7 ± 20	8.0 ± 4	7.5 ± 4	5.3 ± 2	6.4 ± 6
	NO_3^--N (mg L^{-1})	103 ± 16	92 ± 11	100 ± 8	84 ± 12	58 ± 11
	COD (mg L^{-1})	18 ± 2	4 ± 0	49 ± 11	31 ± 17	5 ± 2
	COD removal (%)	88				
	Total-N removal (%)	8	30	25	42	62
	TKN oxidation (%)	76	92	93	95	96
Reactor 3	pH (average value)	7.66 ± 0.08	8.08 ± 0.10	8.06 ±0.20	7.66±0.11	
	Alkalinity (mg $CaCO_3$ L^{-1})	123 ±3 9.9	219 ± 41.0	455 ± 77.5	139 ±67.3	
	TKN (mg L^{-1})	15.1 ± 4.0	4.7 ± 4.0	5.9 ± 2.8	30 ± 15.4	
	NH_4^+-N (mg L^{-1})	12.0 ± 5.5	1.7 ± 2.0	4.3 ± 3.0	24.4 ± 7.3	
	NO_3^--N (mg L^{-1})	1.5 ± 0.7	13.4 ± 11.9	11.0 ± 11.9	4.7 ± 3.4	
	NO_2^--N (mg L^{-1})	1.1 ± 0.7	1.1 ± 1.1	2.5 ± 1.4	2.0 ± 0.9	
	TN (mg L^{-1})	17.6 ± 2.9	17.7 ±7.4	21.0 ± 10.2	36.7±14.7	
	COD (mg L^{-1})	45.0 ± 19.4	29.0 ± 12.4	13.0 ± 9.7	23.0 ± 9.0	
	COD removal (%)	94 ± 5	94 ± 3	97 ± 2	96 ± 2	
	Total-N removal (%)	63.8 ± 8.7	71.8 ± 12.5	84.6 ±10.1	81.5 ± 5.3	
	TKN oxidation (%)	60 ± 14	92 ± 7	92 ± 11	85±6	

The adoption of a recirculation ratio of 5 can maintain constant effluent concentrations at the reactors outlet, without peaks of ammonia and intermediate compounds. From the intermittent aeration periods tested in R2 was possible to choose the best aeration cycle for this reactor configuration which promote efficient organic carbon and nitrogen removal for treatment of anaerobic reactor effluent.

4. CONCLUSIONS

The results aforementioned indicated that a structured-bed reactor operated under intermittent aeration and effluent recirculation is a suitable system for simultaneously removal of nitrogen and organic matter. Considering the results obtained with the treatment of three different types of wastewater, the SBRRIA reactor is adequate in conditions of high or low availability of electron donors for heterotrophic denitrification, which was confirmed by the establishment of the anammox process as an additional pathway of nitrogen removal under conditions of reduced COD/N ratio.

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OCENA PROCESU SYMULTANICZNEJ NITRYFIKACJI I DENITRYFIKACJI (SND) W REAKTORZE ZE ZŁOŻEM STAŁYM PROWADZONEGO PRZY UŻYCIU RÓŻNEGO RODZAJU ŚCIEKÓW

Celem badań było ukazanie możliwości zastosowania reaktora ze złożem stałym do usuwania azotu i węgla z trzech różnych rodzajów ścieków. Badania przeprowadzono w trzech reaktorach nazwanych R1, R2 i R3, które zaszczepiono odpowiednio osadem pochodzącym z reaktora UASB, biomasą z reaktora pracującego w procesie nitryfikacji oraz mieszaniną obu wspomnianych typów biomasy. W badaniach określano także wpływ parametrów technologicznych, takich jak hydrauliczny czas zatrzymania (HRT) (R1), sposób napowietrzania (R2) oraz stosunek ChZT/N (R3) na szybkość usuwania azotu i węgla. Efektywność usuwania ChZT we wszystkich reaktorach była wyższa niż 85%, niezależnie od spadku HRT, zmiany długości faz napowietrzania i mieszania czy wartości stosunku ChZT/N. Otrzymane w reaktorach efektywności usuwania azotu wskazują, że HRT jest parametrem operacyjnym, mającym większy wpływ na skuteczność usuwania azotu niż pozostałe czynniki. Ponadto, wyniki badań prowadzonych dla trzech różnych typów ścieków wskazują, że reaktor SBBRIA jest właściwym rozwiązaniem zarówno w warunkach wysokiej jak i niskiej dostępności donorów elektronów dla procesu heterotroficznej denitryfikacji. Dodatkowo zauważono, iż w warunkach niekorzystnego stosunku ChZT/N w reaktorze tworzą się strefy beztlenowe, w których zachodzi proces beztlenowego usuwania azotu (anammox).