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Combined biodegradation of carbon, nitrogen and phosphorus from wastewaters

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Abstract

The objective of this study was to develop an integrated system for simultaneous removal of carbon, nitrogen and phosphorus from industrial wastewaters. The system consisted a two step anaerobic digestion reactor for carbon removal coupled with a sequencing batch reactor (SBR) for nutrient removal. In the proposed system, carbon is converted into biogaz by methanogenic activities. The volatile fatty acids (VFA) produced during the first step of anaerobic digestion were used as electron donors for biological dephosphatation in the SBR in which anaerobic and aerobic phases were cyclically applied. It was shown that nitrification of ammonia took place in the SBR reactor, during the aerobic phase. Furthermore, denitrification and VFA production were achieved together in the acidogenic reactor, when the efflux of nitrate from the SBR is added to the acidogenic influx. The proposed process was fed with a synthetic wastewater with composition characteristics: Total Organic Carbon (TOC) = 2200 mg l^{-1}; Total Kjedahl Nitrogen (TKN) = 86 mg l^{-1}; Phosphorus under phosphate form ($P–PO_4$) = 20 mg l^{-1}). In these conditions, the removal of carbon, nitrogen and phosphorus were 98%, 78% and 95%, respectively. The benefits from the system are the saving of (i) an external carbon source for denitrification and dephosphatation, (ii) a reactor for the denitrification step.

Keywords: Dephosphatation; Denitrification; Biogaz; Volatile fatty acids; Sequencing batch reactor (SBR)

1. Introduction

Eutrophication is a worldwide water pollution problem and control of the access of phosphate to the aquatic environment is widely used as a eutrophication control strategy, this requiring its removal from effluents by chemical and/or biological means [1]. For biological phosphate removal, it is necessary to subject cyclically microbial population to anaerobic and aerobic conditions. The behavior of phosphate (P) removal systems is characterized by a P release in the anaerobic stage followed by excess P uptake in the aerobic stage. The presence of readily bioassimilable compounds during the anaerobic step is fundamental for phosphorus removal. The carbon source, commonly used is acetic acid [2]. Previous results demonstrated that volatile fatty acids (VFA) are an efficient carbon source for phosphate removing bacteria and that acidogenic reactors have denitrification potential [3–5]. The aim of this paper is to study

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an integrated process for phosphorus, nitrogen and carbon removal from a synthetic industrial wastewater, using the above cited capacities of microbial ecosystems. The system consists in a two step anaerobic digester for carbon removal coupled with a sequencing batch reactor for biological nitrogen and phosphorus removal.

2. Material and methods

2.1. Process configuration

Fig. 1 shows the configuration of the system used in the present work.

2.2. Carbon removal

The acidogenic and methanogenic units are continuously stirred reactors with a working volume of 1 and 9 l, respectively. Temperature was maintained at 35°C in both reactors and pH was adjusted to 6.5 in the acidogenic reactor and to 7.5 in the methanogenic reactor by automatic addition of NaOH 2 N. The reactors were inoculated with anaerobic digester sludge from a municipal treatment plant, at a concentration in volatile suspended solids (VSS) of 5 g l^{-1}.

2.3. Nitrogen and phosphorus removal

The study was carried out in a 2 l Biolaffite reactor (1.5 l working volume) at room temperature. The fermentor content was agitated continuously at 200 rpm by impellers except in the setting period. Inoculation sludge for the SBR was obtained from a phosphorus and nitrogen removal process operating on municipal wastewaters at Roanne (Fr).

The SBR was operated in a cycle of 6 h. The cycle consisted of three phases: anaerobic (2.5 h), aerobic (3 h) and settling period (0.25 h). A total of 0.5 l of effluent was pumped into the reactor within the first 0.13 h of the anaerobic phase. A total of 0.5 l of clarified supernatant was removed from the reactor at the end of the settling period. Overall hydraulic retention time was 18 h and the concentration in VSS was maintained at 5000 mg l^{-1}, resulting in a sludge age of 12 days. The pH was adjusted to 7.5 by addition of HCl 2 N and the temperature was maintained at 25°C.

2.4. Synthetic waste water

The composition per liter of the synthetic wastewater used in this study was: glucose 5.0 g; peptone 50 mg; yeast extract 50 mg; NH_4Cl 38 mg; $(NH_4)_2\ SO_4$ 295 mg l^{-1}; $MgSo_4 \cdot 7H_2O$

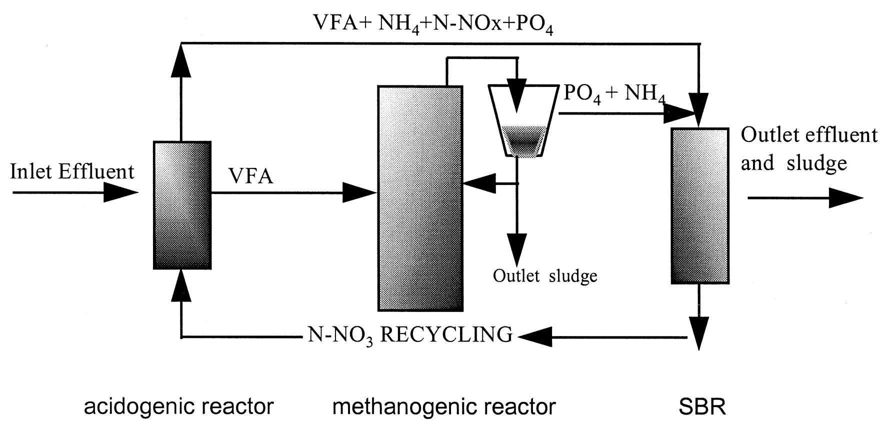

Fig. 1. Proposed process for combined removal of carbon, nitrogen and phosphorus.

600 mg; $CaCl_2 \cdot 2H_2O$ 70 mg; EDTA 100 mg; KH_2PO_4 50 mg; K_2HPO_4 90 mg and 2.0 ml of oligo-elements solution. The oligo-elements solution composition per liter is: $FeCl_3 \cdot 6H_2O$ 1.5 g. H_3BO_3 150 mg; $CuSO_4 \cdot 5H_2O$ 30 mg; KI 30 mg; $MnCl_2 \cdot 4H_2O$ 120 mg; $Na_2MoO_4 \cdot 2H_2O$ 60 mg; $ZnSO_47H_2O$ 120 mg; $CoCl_2 \cdot 6H_2O$ 150 mg.

2.5. Analytical methods

The characteristics of the influent and the effluent of each reactor of the process were measured. Samples were centrifuged at $1200 \times g$ for 15 min then analyzed for TOC, nitrogen oxides, TKN, ammonia and VFA concentrations, as described elsewhere [5]. Total solids and biogaz composition were also determined [5].

3. Results and discussion

In the proposed system (represented in Fig. 1) carbon is eliminated into biogaz by anaerobic digestion in two steps: acidogenesis and methanogenesis. The VFA produced during the first step of anaerobic digestion can be used as electron donor for both dephosphatation and the denitrifying process. In the third reactor (SBR), dephosphatation and nitrification are induced through the application of an anaerobic–aerobic cycle. Finally, solids recirculation is minimized by settling of methanogenic and SBR outlets after recycling. In the present system, nitrate elimination and VFA production are proposed to be achieved together in the acidogenic reactor.

The system is fed with a mixture of a 20 folds concentration medium (100 ml day^{-1}) and of SBR effluent (1900 ml day^{-1}). Acidogenic outlet is the methanogenic inlet (1320 ml day^{-1}). The flux of $N–NO_3$ recycling from SBR to acidogenic reactor is 1900 ml day^{-1}. SBR is fed with a mixing of acidogenic (680 ml day^{-1}) and methanogenic (1320 ml day^{-1}) outlets. The process was continuously operated over a long period (80 days) to investigate feasibility and stability of the system.

The steady-state data for the influent and the effluent from each reactor of the process are reported in Table 1.

3.1. Carbon flux

3.1.1. Acidogenic reactor

The acidogenic outlet contained 2.5 g VFA l^{-1}, with acetic acid (1.9 g l^{-1}) as the predominant fermentation product. The acidification degree was 57% of initial COD concentration and the rate of VFA production was 0.48 g l^{-1} h.

3.1.2. Methanogenic reactor

The biogaz produced was composed of methane (75%) and carbon dioxide (22%). At steady state, TOC removal efficiency was 88% (Table 1). Methane was produced at high rates: 302 ml CH_4/g COD removed.

3.2. Nitrogen flux

In the acidogenic reactor, ammonia was assimilated at a rate of 74.2 mg $N–NH_4$/g

Table 1
Average influent and effluent characteristics of the process

	TOC (mg l^{-1})	TOC–VFA (mg l^{-1})	$P–PO_4$ (mg l^{-1})	VSS (g l^{-1})	TKN (mg l^{-1})	$N–NO_3$ (mg l^{-1})	$N–NH_4$ (mg l^{-1})	N total (mg l^{-1})
Influent	2200	0	19.6	0	75.04	10.86	36.4	85.9
Acidogenic effluent	1460	1056	16.9	0.5	32.47	0	8.4	32.47
Methanogenic effluent	220	0	30.63	3.8	50.96	0	15.12	50.96
SBR Influent	710.4	698.3	26.13	0.16	42.56	0	11.2	42.56
SBR Effluent	80	0	2.79	4.7	8.72	12.64	0	21.36

VSS/day. Denitrification took place in the acidogenic reactor: the denitrification rate was 44.4 mg $N–NO_3$/g VSS/day.

The amount of ammonia increased in the methanogenic reactor, probably in relation with the lysis of acidogenic cells brought with the influent.

In the SBR, ammonia concentration was constant under the anaerobic phase of the cycle and it dropped almost to zero at the end of the aerobic phase with nitrification (Table 1). Nitrification rate was 2.75 mg/g VSS/day.

3.3. Phosphorus flux

During the first period (0–35 day) of the run, biological phosphorus removal in the SBR deteriorated. Then, the P removal activity was recovered: both significant anaerobic P release and aerobic P removal were obtained, as illustrated by the changes of phosphorus, TOC and nitrate concentrations in a cycle at day 65 (Fig. 2).

As shown in Fig. 2, P release was correlated with consumption of the carbon source (VFA). Phosphate concentrations at the end of the anaerobic and aerobic phases were 26 and 2.8 mg l^{-1}, respectively and 90% of $P–PO_4$ removal was reached, for an applied $N/P–PO_4$ ratio of 1.63. Youg et al. [6] obtained 87% of $P–PO_4$ removal using a $N/P–PO_4$ ratio of 4 with a single reactor combining anaerobic conditions.

With the conditions used, the process can remove carbon, nitrogen and phosphorus with 96%, 75% and 86% efficiency, respectively. An additional experiment showed that the performances could be enhanced through the increase of the VFA flux from the acidogenic reactor to the SBR. In similar operational conditions, except that the SBR is fed with 800 ml day^{-1} of acidogenic outlet and 1200 ml day^{-1} of methanogenic outlet, the removal of carbon, nitrogen and phosphorus were 98%, 78% and 95%, respectively.

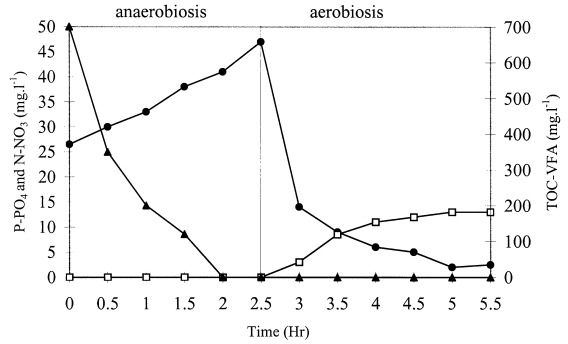

Fig. 2. Profiles of phosphorus (●), nitrate (□) and TOC–VFA (▲) concentrations during an operational cycle in the SBR.

These results show that the combination of two step anaerobic digester with SBR is effective for simultaneous carbon, nitrogen and phosphorus removal. The existence of zones in which the different microbial populations can coexist was possible through the reactors arrangement and the operational conditions. The VFA produced in the acidogenic reactor can be used for both denitrification and dephosphatation. With this process, the highest performances for removal of carbon, nitrogen and phosphorus were 98%, 78% and 95%, respectively. The additional benefits from this process are the saving of an external carbon source for denitrification and dephosphatation. Furthermore, the system did not require a specific reactor for the denitrification step, as complete denitrification occurred in the acidogenic reactor.

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