ANAEROBIC-AEROBIC TREATMENT OF SWINE WASTEWATER IN UASB AND BATCH REACTORS IN SERIES

ESTEVÃO URBINATI[1], ROBERTO ALVES DE OLIVEIRA[2]

ABSTRACT: In this work it was evaluated the performance of two systems of swine wastewater treatment consisting of two-stage upflow anaerobic sludge blanket (UASB) reactors, with and without post-treatment in sequencing batch reactor (SBR), fed continuously, with aerobic phase. The UASB reactors in the first stage had 908 L in the sets I and II, and in the second stage 350 and 188 L, respectively. In the set II the post-treatment was performed in a SBR of 3,000 L. The hydraulic detention times in the anaerobic treatment systems were 100, 75 and 58 h in the set I; 87, 65 and 51 h in the set II; and 240 and 180 h in the SBR. The volumetric organic load applied in the first stage UASB reactors ranged from 6.9 to 12.6 g total COD $(L\ d)^{-1}$in the set I and 7.5 to 9.8 g total COD $(L\ d)^{-1}$ in the set II. The average removal efficiencies of total COD, total phosphorus (P_{total}), and Kjeldahl and organic nitrogen (KN and N_{org}) in the anaerobic treatment systems were similar and reached maximum values of 97%, 64%, 68%, and 98%. In the SBR, the removal efficiencies of total COD and thermotolerant coliforms were up to 62 and 92% resulting, respectively, in effluent concentrations of 135 mg L^{-1} and $2x10^4$MPN $(100\ mL)^{-1}$. For P_{total}, total nitrogen (TN) and N_{org}, the average removal efficiencies in the SBR were up to 58, 25 and 73%, respectively.

KEYWORDS: coliforms, methane, two-stage anaerobic reactors, nutrients removal, combined treatment.

TRATAMENTO ANAERÓBIO-AERÓBIO DE ÁGUAS RESIDUÁRIAS DE SUINOCULTURA COM REATORES UASB E BATELADA EM SÉRIE

RESUMO: O desempenho de dois sistemas de tratamento de águas residuárias de suinocultura com reatores anaeróbios de fluxo ascendente com manta de lodo (UASB), em dois estágios, foi avaliado com e sem pós-tratamento em reator operado em batelada sequencial alimentada (RBS), com etapa aeróbia. Os reatores UASB do primeiro estágio possuíam 908 L nos conjuntos I e II, e no segundo estágio, 350 e 188 L, respectivamente. No conjunto II foi realizado o pós-tratamento em RBS de 3000 L. Os tempos de detenção hidráulica nos sistemas de tratamento foram de 100; 75 e 58 h no conjunto I; de 87; 65 e 51 h no conjunto II, e de 240 e 180 h no RBS. As cargas orgânicas volumétricas nos reatores UASB do primeiro estágio variaram de 6,9 a 12,6 g DQOtotal $(L\ d)^{-1}$ no conjunto I, e de 7,5 a 9,8 g DQOtotal $(L\ d)^{-1}$ no conjunto II. As eficiências médias de remoção de DQOtotal, fósforo total (Ptotal), nitrogênio Kjeldahl (NK) e nitrogênio orgânico (Norg.) nos sistemas de tratamento anaeróbio atingiram valores máximos de 97; 64; 68 e 98 %, respectivamente. No RBS, as eficiências de remoção de DQOtotal e coliformes termotolerantes foram de até 62 e 92%, reduzindo para 135 mg L^{-1} e 2×10^4 NMP $(100\ mL)^{-1}$, respectivamente, os valores médios no efluente. Para o Ptotal, nitrogênio total (NT) e Norg, as eficiências de remoção no RBS foram de até 58; 25 e 73%, respectivamente.

PALAVRAS-CHAVE: coliformes, metano, reatores anaeróbios em dois estágios, remoção de nutrientes, tratamento combinado.

[1] Engº Agrônomo, Dr. em Microbiologia Agropecuária pela Faculdade de Ciências Agrárias e Veterinárias, UNESP, Universidade Estadual Paulista, Câmpus de Jaboticabal

[2] Engº Agrônomo e Tecnólogo em Construção Civil; Mestre em Agronomia pela UNESP, Câmpus de Jaboticabal; Doutor em Hidráulica e Saneamento pela EESC-USP; Prof. Assist. Dr., Faculdade de Ciências Agrárias e Veterinárias, UNESP, Câmpus de Jaboticabal, Departamento de Engenharia Rural, Fone (0XX16)32097281, raoder@fcav.unesp.br

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INTRODUCTION

Brazilian hog raising has been undergoing considerable changes since the last decade due to its increasing production scale. Improvements in the production process increased the rate of productivity through the use of high densities of animals, but created a major environmental problem with the waste generated, and improper disposal practices of waste. Swine waste is characterized by high concentrations of organic material, nutrients and pathogens, which prolonged application in soil and bodies of water can cause problems such as eutrophication, contamination of soil and water with fecal microorganisms and release of methane and other undesirable gases to the atmosphere (MIRANDA, 2007; KUNZ et al., 2009).

The treatment in upflow anaerobic sludge blanket (UASB) is an attractive alternative, which has advantages such as low sludge production, small area of installation and low power consumption (FORESTI et al., 2006). Several authors attest to the viability of this technology for the treatment of swine wastewater. Among them, SONG et al. (2010) operated UASB 35,000 L at temperature of 35ºC, applying hydraulic detention time (HDT) decreasing from 7.0 to 3.5 d with increasing the volumetric organic load (VOL) from 1.3 to 5.8 g COD $(L\ d)^{-1}$, and achieved efficiencies of 74.0 to 78.7 % for COD, with swine wastewater with COD from 7.3 to 30.9 g L^{-1}. RODRIGUES et al. (2010) evaluated the performance of UASB reactor of 11,500 L operated at VOL from 1.1 to 17.5 g COD $(L\ d)^{-1}$, HDT of 1.7 to 4.1 d, average temperature of 20 ºC, fed decanted swine wastewater with COD of 14.8 g L^{-1} and TSS of 2.7 g L^{-1}, and observed average removal efficiencies of COD of 85% and 63% of TSS.

However, it is possible to enhance the removal of pollutants from swine wastewater and to decrease the volume of UASB reactors by using the procedure in two stages. According to SANTANA & OLIVEIRA (2005), BICHUETTE et al. (2008), OLIVEIRA et al. (2008), ABREU NETO & OLIVEIRA (2009), DUDA & OLIVEIRA (2009 and 2011), TREVISAN & MONTEGGIA (2009) and OLIVEIRA & SANTANA (2011), with the anaerobic treatment systems in two stages it was possible to increase removals of suspended solids, COD, nutrients, metals, and coliform bacteria with reduced HDT and to increased stability even with fluctuations of organic and hydraulic load.

SANTANA & OLIVEIRA (2005) and OLIVEIRA & SANTANA (2011) treated swine wastewater in a wide range of TSS concentrations (2.2 to 16.4 g L^{-1}) and total COD (8.8 to 28.5 g L^{-1}) using two-stage UASB reactors with HDT from 82.2 to 20.0 h and VOL from 3.4 to 24.4 g total COD $(L\ d)^{-1}$, and achieved removal efficiencies of 53 to 93% for total COD, 52 to 89% for TSS, 21 to 63% for TKN and 28 to 57% for total-P.

Despite the good results, the anaerobic reactors hardly produce effluents that meet the standards established by the Brazilian environmental legislation (FORESTI et al., 2006), even in two stages (OLIVEIRA & SANTANA, 2011). Therefore, the post-treatment for removing the remaining of COD and constituents less affected in anaerobic process, such as nutrients, and pathogens is required. According to CHERNICHARO (2006), the use of combined anaerobic-aerobic processes provides advantages such as low power required for aeration in the aerobic phase, lower production of biological sludge and low cost of deployment and operation.

The reactor operated in sequencing batch (SBR) has been investigated for the secondary and tertiary treatment of swine wastewater (BERNET et al, 2000; ZHANG et al, 2006; DENG et al, 2008; OLIVEIRA et al, 2008; OLIVEIRA & SANTANA, 2011). The fundamental characteristic of SBR is the flexibility of the steps of a cycle of operation, which allows the sequential establishment of process conditions (anaerobic, anoxic and aerobic) to promote greater efficiency transformations required for the biological removal of organic matter remaining, coliforms and nutrients from the anaerobic effluent.

Treating swine wastewater with COD of 19 g L^{-1} and TSS of 9.7 g L^{-1}, in a two-stage UASB followed by a sequencing batch reactor fed continuously (SBR), with HDT of 13.8 d, OLIVEIRA et al. (2008) obtained effluent with total COD of 221 mg L^{-1}, dissolved COD of 100 mg L^{-1} and thermotolerant coliform count of 2.0 x 10^3 MPN (100 mL)$^{-1}$, which is below the limit of 4,000 MPN (100 mL)$^{-1}$, which in class 3 fresh water is classified for the use in irrigation of tree crops, grain and fodder (BRASIL, 2005).

Thus, for the treatment of swine wastewater, studies are needed for the development of projects with increased removal efficiency of organic matter, nutrients and pathogens in these systems. This study evaluated the performance of two sets of two-stage UASB reactors, with and without post-treatment at the SBR, for the removal of organic matter, nitrogen, phosphorus and coliforms from swine wastewater, varying HDT and VOL, with two relations between the volumes of anaerobic reactors of the first and second stages.

MATERIAL AND METHODS

The experimental units consisted of boxes for storing the affluent, helical pumps and two sets (I and II) with two upflow anaerobic sludge blanket (UASB) each, installed in series (R1 and R2). In the set I the useful volume (V) of the R1 was 908 L and R2 of 350 L, with VR2 = 0.4VR1. In set II, the VR1 was of 908 L and the VR2 of 188 L with VR2 = 0.2VR1. The post-treatment of the effluent from set II was carried out in a sequencing batch reactor fed continuously (SBR), with aerobic stage, constructed of polyethylene, with V = 3,000L. An air compressor, with an average flow of 1.87 m^3 h^{-1}, injected air for five circular coarse bubble membrane diffusers brand BF Dias, installed in the lower region of the SBR, effecting aeration and mixing of the liquid inside the reactor in the aerobic step (Figure 1).

Sets I and II were operated simultaneously. The feeding of the affluent for UASB reactors of the first stage (R1) was carried out by means of a helical pump, and from these routed by gravity in PVC pipes of 1 ½ " to the inside of the respective reactors of the second stage (R2). The UASB reactors of the first stage were fed with sieved swine wastewater (sieve with 3 mm square mesh), reaching average concentrations of total suspended solids (TSS) in the affluent from 9135 to 13160 mg L^{-1}.

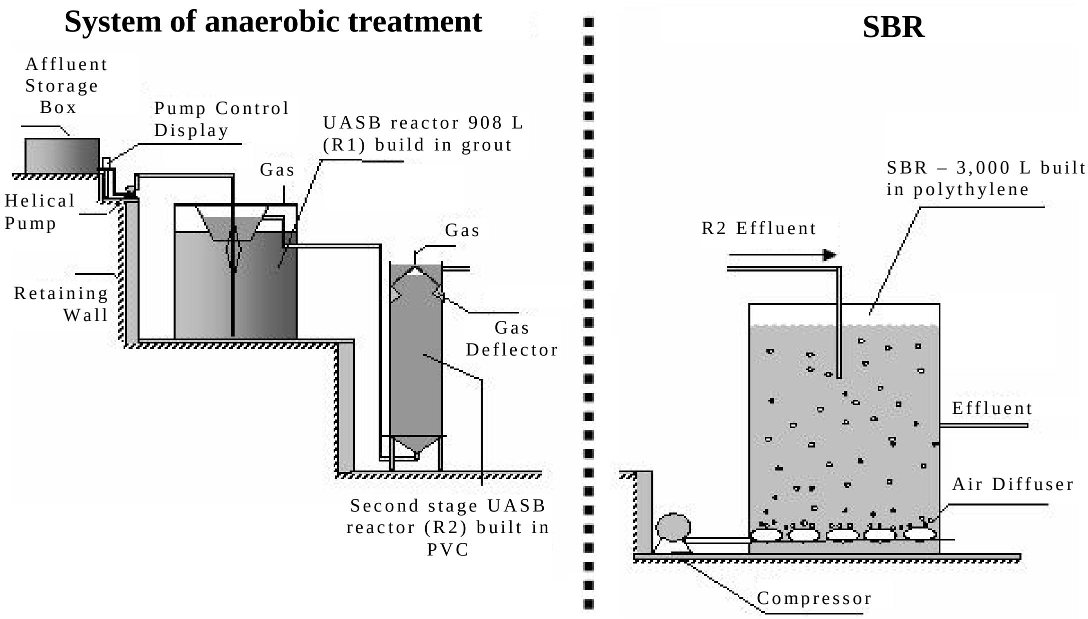

FIGURA 1. Scheme of the two-stage UASB reactors (R1 and R2), in the sets I and II (left), and of the sequencing batch reactor fed continuously (SBR) (right) installed at the exit of R2 of the set II.

The experiment was divided into three assays of 51, 137 and 96 days. The HDT in the anaerobic reactors used systems were 100, 75 and 58 h and 87, 65 and 51 h in sets I and II in assays

1, 2 and 3, respectively. The volumetric organic load (VOL) applied in R1 were increased by 6.9, 9.4 and 12.7g total COD $(L\ d)^{-1}$ and 7.5, 8.0 and 9.8 g total COD $(L\ d)^{-1}$, in assays 1, 2 and 3, of the sets I and II, respectively (Table 1).

The HDT used in the SBR was of 240 h in assay 1. In assays 2 and 3, HRT of 240 h was initially used, which was subsequently reduced to 180h. These HDT were adopted similar to those used by OLIVEIRA et al. (2008), who obtained SBR effluent of good quality for COD and coliform.

The SBR was continuously fed with the entire effluent from the second UASB (R2) of the set II, which resulted in a volume of 900 L per cycle in assay 1. In assays 2 and 3, the initial feeding volume was of 900L and then of 1,200L per cycle. These values were 30 and 40%, respectively, of the volume of the SBR, which were also considered as the volume of supernatant to be removed in each cycle. Consequently, maintaining 60 to 70% of the volume of the SBR as settled sludge was adopted based on the recommendation of METCALF & EDDY (2003).

In order to evaluate the effect of air volume injected per cycle at the SBR, in assays 1, 2 and 3, aeration times were of 4, 10 and 8 h, respectively (Table 2). This started from the aeration time used by OLIVEIRA et al. (2008), which has been increased to improve the conditions for nitrification and therefore to remove ammonia nitrogen (N_{am}) and total nitrogen (TN). Variations in the characteristics of operating cycles, regarding the feeding volume of the sequencing batch reactor fed constinuously (SBR), were made in order to carry out the post-treatment of the entire effluent produced in the anaerobic treatment of the set II, testing different HDT and aerobic reaction times.

TABLE 1. Operation time and conditions of the two-stage UASB reactors (R1 and R2) and of the sequencing batch reactor fed constinuously (SBR) in the sets I and II and assays 1, 2 and 3.

Assay	**Operation Time (**d)	**UASB Reactors set**	**HDT** (h)				**VOL** (g total COD $(L\ d)^{-1}$)			
			R1	**R2**	**SBR**		**R1**	**R2**	**SBR**	
1	54	I(1)	72	28	---	---	6.9	0.7	---	---
		II	72	15	240		7.5	1.6	0.081	
2	137	I(1)	54	21	---	---	9.4	0.9	---	---
		II	54	11	240	180	8.0	1.6	0.054	0.072
3	97	I(1)	42	16	---	---	12.7	1.2	---	---
		II	42	9	240	180	9.8	2.4	0.061	0.081

HDT: hydraulic detention time, VOL: volumetric organic load, (1) set without post-treatment.

Initially, a sedimentation time of 2.5 h and of 0.5 h to remove of supernatant were adopted, which were successfully used by OLIVEIRA et al. (2008). In assay 2, the sedimentation time was reduced to 2.0 h owing to find good sludge characteristics. In the third assay, this time was increased to 4.0 h seeking further improvement of the effluent quality decreasing VSS concentration. The other times of 65.0, 59.5 and 59.5 h (cycle time minus the time of the aerobic reaction, sedimentation and supernatant removal) adopted as anaerobic reaction in test 1, 2 and 3, respectively, were obtained by the difference regarding the time of the SBR cycle of 72 h (Table 2). The sequence of the steps of the cycle (anaerobic, aerobic, sedimentation and disposal) was defined considering the operation of the SBR with the possibility of removal of COD, N and P, based on the recommendations of METCALF & EDDY (2003) and WEF & ASCE (1998a and 2005).

At the beginning of each assay the disposal of sludge was held in all UASB reactors (R1 and R2), leaving 30% of the volume of each reactor filled with sludge, which served as inoculum. In the SBR the sludge was maintained in all assays. In sets I and II and SBR, the first assay was initiated after the completion of the researches by BICHUETTE et al. (2008) and DUDA et al. (2009).

TABLE 2. Characteristics of operational cycles used in the sequential batch reactor fed constinuously (SBR) in the assays 1, 2 and 3.

Characteristics of operational cycle l	Assay 1	Assay 2		Assay 3	
Operation Time (d)	54	29	108	44	53
HDT (h)	240	240	180	240	180
Cycle time (h)	72	72	72	72	72
Feeding volume/cycle (L)	900	900	1,200	900	1,200
Feeding volume/ day (L)	300	300	400	300	400
Feeding time (h)	72	54	72	42	56
Anaerobic reaction time (h)	65.0	59.5	59.5	59.5	59.5
Aerobic reaction time (h)	4	10	10	8	8
Sedimentation time (h)	2.5	2.0	2.0	4.0	4.0
Supernatant removal time (h)	0.5	0.5	0.5	0.5	0.5

HDT: hydraulic detention time.

Twice weekly, composite samples were collected at the exits of each of UASB reactors (R1 and R2) and of the SBR. In these samples determinations of partial (AP) and total (TA) alkalinities, pH, temperature, Kjeldahl nitrogen (KN), ammonia nitrogen (N_{am}), organic nitrogen (Norg = KN – Nam), nitrate ($N\text{-}NO_3^-$), nitrite ($N\text{-}NO_2^-$), total nitrogen (NT = KN + $N\text{-}NO_3^-$ +$N\text{-}NO_2^-$), total phosphorus (P_{total}), total oxygen chemical demand (total COD) and dissolved oxygen chemical demand (CODdiss), total (TSS) and volatile (VSS) suspended solids as described by APHA et al. (2005), JENKINS et al. (1983) and SANTANA & OLIVEIRA (2005), and total volatile fatty acids (VFA) according to DILALLO & ALBERTSON (1961) were performed. Twice, at the end of each assay, we determined the most probable number (MPN) of total and thermotolerant coliforms in all affluent and effluent, with the multiple tube technique described in APHA et al. (2005).

In each disposal of effluent in SBR, we determined the concentrations of $N\text{-}NO3^-$, $N\text{-}NO_2^-$ dissolved oxygen (DO) and temperature, as described by APHA et al. (2005).

The daily average air temperatures were obtained from the agrometeorological station of Exact Sciences Department, UNESP, *Campus* of Jaboticabal (UNESP, 2011).

The daily biogas production in UASB reactors were monitored through measures in gasometers (SANTANA & OLIVEIRA, 2005). Biogas composition was determined weekly by gas chromatography as described in APHA et al. (2005).

RESULTS AND DISCUSSION

The average values of daily average air temperature were 21.9, 21.6 and 24.5ºC, in assays 1, 2 and 3 respectively, with average daily temperature ranges of 14.0, 9.0, 12.0, and 12.5ºC, respectively . Thus, it was found that the reactors were operated predominantly in the mesophilic range (20°C to 45ºC), considered suitable for the anaerobic process, but below the optimum temperature of 35°C for the multiplication of microorganisms, cited by GERARDI (2003).

The average values of total alkalinity (TA) in the affluent remained between 914 and 1091 mg L^{-1} and partial alkalinity (PA) between 267 and 375 mg L^{-1} (Table 3). These values increased during the passage through the UASB reactors, in all assays. In the sets I and II, TA effluents ranging from 1,005 to 1,224 mg L^{-1} and PA from 687 to 887 mg L^{-1} were obtained. There was contribution of the alkalinity found in the affluents, as also evidenced by ABREU & OLIVEIRA NETO (2009) when using a reactor compartment (ABR) followed by a UASB reactor for treating swine wastewater. In the effluents of two-stage UASB reactors, SANTANA & OLIVEIRA (2005) and OLIVEIRA &

SANTANA (2011) found higher values of TA, 848 to 3492 mg L^{-1} and PA, 610 to 960 mg L^{-1}, because of the wider range of VOL applied to the R1, from 3.4 to 24.4 g total COD $(L\ d)^{-1}$.

TABLE 3. Average values and coefficients of variation (cv) of pH, total alkalinity (TA), partial alkalinity (PA) and total volatile fatty acids (VFA) in the affluent and effluent, obtained during operation of the two-stage UASB reactors (R1 and R2) and the sequential batch reactor fed constinuously (SBR) of the sets I and II, in the assays 1 to 3.

Assay	Set	Sample	HDT[1] (h)	VOL[1] (2)	Attribute							
					pH		TA[2]		PA[2]		VFA[2]	
					A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]
1	I	Affl.	---	---	6.5	7	1,074	31	326	50	530	52
		Effl. R1	72	6.9	7.0	2	1,132	22	805	22	211	56
		Effl. R2	28	0.7	7.2	3	1,144	19	830	19	174	52
	II	Affl.	---	---	6.5	5	1,020	22	291	47	493	45
		Effl. R1	72	7.5	7.0	3	1,170	18	834	23	227	46
		Effl. R2	15	1.6	7.2	2	1,203	18	887	18	195	46
		Effl.SBR	72	0.081	7.6	2	1,262	11	947	14	206	40
2	I	Affl.	---	---	6.4	8	970	38	363	52	629	50
		Effl. R1	54	9.4	6.9	3	986	27	656	32	200	58
		Effl. R2	21	0.9	7.2	3	1,025	29	719	30	190	55
	II	Affl.	---	---	6.5	9	914	38	375	47	602	51
		Effl. R1	54	8.0	6.9	3	984	26	647	30	199	56
		Effl. R2	11	1.6	7.2	4	1,005	25	687	29	195	62
		Effl.	240	0.054	7.5	4	720	4	552	5	137	40
		SBR	180	0.072	7.7	4	992	33	674	40	195	58
3	I	Affl.	---	---	6.4	5	1,091	49	268	59	732	47
		Effl. R1	42	12.6	7.1	4	1,171	39	820	40	312	109
		Effl. R2	16	1.2	7.3	3	1,215	42	862	42	312	124
	II	Affl.	---	---	6.4	5	1,039	50	267	54	674	38
		Effl. R1	42	9.8	7.1	3	1,182	43	827	46	266	54
		Effl. R2	9	2.4	7.3	2	1,224	45	866	44	231	53
		Effl.	240	0.061	7.7	1	1,082	50	819	51	234	48
		SBR	180	0.081	7.8	2	1,252	21	935	22	179	77

[1] HDT: hydraulic detention time, VOL: volumetric organic load , A: average, [2]Units: VOL: g total COD $(L\ d)^{-1}$, TA and PA: mg L^{-1} of $CaCO_3$, VFA: mg L^{-1} of CH_3COOH, cv: %.

The pH of the effluent ranged from 6.4 to 6.5. After R1, with the generation of alkalinity, the values stabilized between 6.9 and 7.1 in the effluent. In R2 the pH values increased, reaching average values of 7.2 and 7.3 (Table 3). There were increases in alkalinity in the UASB reactors under any of the conditions imposed, being the carbon dioxide system always efficient in the maintenance of the pH in the range from 6.6 to 7.4; cited as great by CHERNICHARO (2007).

There was intake of total volatile fatty acids (VFA) in two-stage UASB reactors in all assays. In the affluent the values ranged from 493 to 732 mg L^{-1}, decreasing to values from 174 to 312 mg L^{-1} in the effluent of R2 (Table 3), demonstrating that there was no accumulation in any of the conditions imposed in the assays. The average values of VFA were below the limit of 500 mg L^{-1}, recommended by GERARDI (2003), indicating that the process remained stable during the assays.

With lower VOL, SONG et al. (2010) obtained higher values of pH in the effluent, from 7.8 to 8.2, and reductions of VFA, of 89 to 97%. SANTANA & OLIVEIRA (2005) and BICHUETTE et al. (2008), with similar VOL from 5.2 to 14,4 g total COD $(L\ d)^{-1}$, observed similar pH values in the range from 7.1 to 7.5, and TVA from 75 to 177 mg L^{-1}. OLIVEIRA & SANTANA (2011) applied VOL of up to 24.4 g total COD $(L\ d)^{-1}$ and there were no marked changes in pH and VFA compared to those obtained in this work. Therefore, the imposed conditions of HDT and VOL in a two-stage UASB were adequate to maintain balance between production and consumption of alkalinity and volatile fatty acids.

In the affluent, the average values of total COD in assays 1, 2 and 3 ranged from 20,755 to 22,105 mg L^{-1} in set I and from 17,086 to 22,382mg L^{-1} in set II (Table 4). The high values of coefficient of variation (cv 51 to 103%) to the average of total COD and TSS of the affluent were due to changes in the composition of the affluent by variations in age and management of animals, as was also observed by SANTANA & OLIVEIRA (2005), OLIVEIRA et al. (2008), ABREU NETO & OLIVEIRA (2009), RODRIGUES et al. (2010) and OLIVEIRA & SANTANA (2011). It was observed that, even with these changes, the anaerobic treatment systems remained stable, showing its robustness in situations that may occur in pig properties.

The average values of total COD removal efficiencies were high and suffered slight decrease, from 95 to 94 and 93% in the set I, with increased VOL from 6.9 to 9.4 and 12.6 g total COD $(L\ d)^{-1}$ in R1 , respectively, in assays 1, 2 and 3. In set II, the average total COD removal efficiencies were similar to those observed in the set I with values of 95, 92 and 90% in assays 1, 2 and 3, and also decreased with increased VOL from 7.5 to 8.0 and 9.8 g total COD $(L\ d)^{-1}$, respectively (Table 5). Accordingly, with the highest HDT, of 72 h in assay 1, when occurred the lowest VOL in R1 in sets I and II, it was possible to obtain the greatest efficiency of total COD removal (95%) in both R1.

These removals of total COD were higher than those obtained by RODRIGUES et al. (2010), due to higher HDT used in R1 reactors. It may also be associated with higher fractions of volatile suspended solids in the affluent, which favored the removal of organic matter particulate by sedimentation and interception in the sludge blanket. The efficiencies obtained by SONG et al. (2010) were also lower, possibly because a full scale UASB with greater production of biogas increases turbulence and dragging of suspended solids with the effluent.

In R2, the average total COD removal efficiencies were lower, of 38, 45 and 37% in set I and of 25, 33 and 39% in set II in assays 1, 2 and 3, respectively. The highest average value of total COD of 22382 mg L^{-1} in the affluent of the set II made its R2 receive effluent with total COD of 1007 mg L^{-1}, a value higher than that observed in the effluent of R1 in the set I. This resulted in a marked increase in the VOL in R2 of set II, due to the lower volume, and contributed to the decrease of the total COD removal (25%) in relation to that obtained in R2 of set I (38%).

With an R2 of smaller volume under similar VOL of 1.6 g total COD $(L\ d)^{-1}$, in assays 1 and 2, a higher removal efficiency of total COD was observed using the lowest HDT of 11 h in the assay 2. This can be explained by the dragging of the sludge of the R2 of set I in assay 1, with coefficients of variation for total suspended solids of 198% (Table 4), which may have occurred due to higher daily temperature ranges.

Even with such variations in the affluent and hence in the VOL applied in the reactors R1 and R2, in the anaerobic treatment systems (R1 + R2) total COD removal efficiencies were observed with slight differences of 97, 96 and 94% and 96 , 94% and 94 in sets I and II in tests 1, 2 and 3, respectively (Table 5).

TABLE 4. Average values and coefficients of variation (cv) of total chemical oxygen demand (total COD) and dissolved (COD_{diss}), and of total (TSS) and volatile suspended solids (VSS) concentrations in the affluent and effluent obtained during operation of the two-stage UASB reactors (R1 and R2) and the sequential batch reactor fed constinuously (SBR) of the sets I and II, in the assays 1 to 3.

Assay	Set	Sample	HDT[1] (h)	VOL[1] (2)	Atribute							
					total COD[2]		CODdiss.[2]		TSS[2]		VSS[2]	
					A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]
1	I	Affl.	---	---	20,755	51	1,423	67	11,819	77	3,433	54
		Effl. R1	72	6.9	841	32	235	31	829	184	299	225
		Effl. R2	28	0.7	536	37	208	38	354	198	142	44
	II	Affl.	---	---	22,382	57	2,251	61	9,135	69	4,855	82
		Effl. R1	72	7.5	1,007	54	363	42	554	109	284	111
		Effl. R2	15	1.6	808	39	321	54	653	109	359	133
		Effl. SBR	240	0.081	325	26	187	44	131	84	59	51
2	I	Affl.	---	---	21,239	80	1,530	69	13,160	77	7,405	83
		Effl. R1	54	9.4	781	75	180	34	429	91	221	90
		Effl. R2	21	0.9	392	50	167	46	179	148	122	148
	II	Affl.	---	---	17,909	90	1,217	59	10,706	77	6,049	83
		Effl. R1	54	8.0	747	67	162	37	455	114	262	96
		Effl. R2	11	1.6	539	63	150	52	244	75	145	64
		Effl. SBR	240	0.054	135	26	92	46	30	34	24	41
			180	0.072	223	32	130	24	85	42	60	51
3	I	Affl.	---	---	22,105	84	1,593	40	11,693	89	5,228	103
		Effl. R1	42	12.6	818	59	252	52	471	123	312	165
		Effl. R2	16	1.2	705	87	198	47	317	107	156	94
	II	Affl.	---	---	17,086	76	1,877	42	9,657	87	5,044	99
		Effl. R1	42	9.8	874	61	220	35	325	95	159	61
		Effl. R2	9	2.4	606	53	164	35	279	62	201	118
		Effl. SBR	240	0.061	248	36	137	47	89	68	55	78
			180	0.081	221	27	139	22	97	59	57	74

HDT: hydraulic detention time, VOL: volumetric organic load, A: average [2]Units: VOL: g total COD $(L\ d)^{-1}$, COD, TSS and VSS: mg L^{-1}, cv: %.

In general, comparing the sets I and II in each assay, operated under the same conditions of temperature and HDT in R1, it was observed that in the assays 1 and 2 the total COD removal efficiencies of the anaerobic treatment system (R1 + R2) were slightly higher in set I, which had the lowest volume ratio (VR1/VR2) with HDT of the system (R1 + R2) about 15% higher than those applied in set II. In the third assay, with HDT of 58 h (R1 + R2) that did not happen, but the set I was able to keep the same efficiency of 94% observed in set II, even when operating with higher VOL in R1. In the assay 2, the highest VOL applied in R1 of the set I also did not stop it from reaching total COD removal slightly higher than that observed in set II.

With the placement of the second-stage reactor (R2), the sets I and II obtained effluent with lower average values of total COD and their coefficients of variation (except for assay 3 of set I) (Table 4) . Therefore, a better performance with greater stability occurred. However, the highest volume of R2 in the set I did not provide a proportional increase of the total COD removal efficiencies.

Using the set I, BICHUETTE et al. (2008) found similar efficiencies of total COD removal, of 97%, when they applied VOL of 5.2 and 8.6 g total COD $(L\ d)^{-1}$ in R1 and HDT of 100 and 75 h, respectively, in the anaerobic treatment system (R1 + R2). In set II, SANTANA & OLIVEIRA (2005) obtained 93% removal of total COD with VOL of 7.4 g total COD $(L\ d)^{-1}$ in R1 and HDT of 37.6 h in R1 + R2. Thus, it was confirmed that it is possible to obtain high total COD removal efficiencies with anaerobic treatment systems in two stages under the conditions of HDT and VOL applied in this work. However, when SANTANA & OLIVEIRA (2005) increased the VOL to 14.4 g total COD $(L\ d)^{-1}$ in R1 with HDT of 37.6 h in R1 + R2, the average total COD removal efficiency decreased to 87%, indicating that the reduction of the HDT with an increase in VOL for values above the ones cited and used in this work may cause more pronounced decreases in total COD removal.

With the high total COD removal efficiencies verified in both sets of two-stage UASB reactors treating swine wastewater, it was possible to produce effluents of R2 reactors with total COD ranging from 392 to 808 mg L^{-1} (Table 4).

TABLE 5. Average values and coefficients of variation (cv) of the methane volumetric production (MVP) and of the removal efficiencies of total (total **COD**) and dissolved chemical oxygen demand (COD diss), and total (TSS) and volatile suspended solids (VSS), during operation of the two-stage UASB reactors (R1 and R2) and the sequential batch reactor fed constinuously (SBR) of the sets I and II, in the assays 1 to 3.

Assay	Set	Sample	HDT[1] (h)	VOL[1] (2)	MVP[1] (2)		Removal efficiencies (%)							
							total COD		CODdiss		TSS		VSS	
					A[1]	cv[2]	A[1]	Cv[2]	A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]
1	I	R1	72	6.9	0.287	37	95	3	76	24	97	3	96	3
		R2	28	0.7	0.075	42	38	61	29	52	34	80	56	39
		R1+R2	100	---	0.228	36	97	3	79	19	97	3	95	4
	II	R1	72	7.5	0.400	38	95	3	79	16	92	8	91	10
		R2	15	1.6	0.234	48	25	78	32	42	(3)	---	(3)	---
		R1+R2	87	---	0.351	45	96	3	84	8	92	13	90	20
		SBR	240	0.081	---	---	58	25	47	63	71	36	63	41
		R1+R2+SBR	327	---	---	---	98	1	89	7	98	4	97	5
2	I	R1	54	9.4	0.255	51	94	6	83	17	95	6	95	5
		R2	21	0.9	0.099	44	45	43	25	88	63	31	53	48
		R1+R2	75	---	0.210	51	96	5	85	12	98	2	97	4
	II	R1	54	8.0	0.425	54	92	9	83	12	94	6	92	10
		R2	11	1.6	0.179	58	33	68	23	77	44	59	51	47
		R1+R2	65	---	0.376	55	94	7	84	15	96	6	94	9
		SBR	240	0.054	---	---	43	47	46	59	43	40	55	38
			180	0.072	---	---	62	27	39	53	65	28	63	29
		R1+R2+SBR	305	---	---	---	96	3	78	26	98	2	97	2
			245	---	---	---	97	5	89	11	96	17	98	3
3	I	R1	42	12.6	0.480	52	93	8	82	13	93	9	88	21
		R2	16	1.2	0.193	70	37	40	30	60	61	41	59	54
		R1+R2	58		0.377	60	94	7	87	8	96	5	93	12
	II	R1	42	9.8	0.454	40	90	12	86	9	92	9	94	6
		R2	9	2.4	0.196	57	39	59	33	57	40	61	33	54
		R1+R2	51	---	0.402	42	94	6	90	6	93	11	91	15
		SBR	240	0.061	---	---	55	34	32	45	68	25	73	20
			180	0.081	---	---	53	44	27	59	64	41	64	35
		R1+R2+SBR	291	---	---	---	97	2	92	5	97	6	98	4
			231	---	---	---	97	4	92	3	97	3	96	6

HDT: hydraulic detention time, VOL: volumetric organic load, A: average, MVP: methane volumetric production. [2]Units: VOL: g totalCOD $(L\ d)^{-1}$, MVP: L CH_4 (L reactor $d)^{-1}$, cv: %. [3] No removal, or below 1%.

In order to the disposal in water bodies or soil, post-treatment of this anaerobic effluent may be required, even for assays with the best performance of anaerobic treatment systems. Hence the SBR in set II, with which it was possible to obtain average values of total COD and COD_{diss} in the effluent of 135 and 92 mg L^{-1}, respectively, in assay 2. With the same set II, OLIVEIRA et al. (2008) observed slightly higher average values (221 and 100 mg L^{-1}, respectively) with similar operating conditions in the SBR, confirming the possibility to achieve final effluent of good quality using the proposed treatment system. These values of COD can meet the standards for effluent discharge of the legislation of some Brazilian states (VON SPERLING, 2005).

The average removal efficiencies of COD_{diss} in the sets I and II ranged from 79 to 90% in assays 1, 2 and 3 (Table 5). With the inclusion of the SBR in set II it was possible to increase the removal efficiencies to 89-92% (Table 5).

The average concentrations of TSS in the affluent ranged from 9,657 to 13,160 mg L^{-1} and from 9,135 to 10,706mg L^{-1} in the sets I and II, respectively (Table 4). In effluents from R2 they decreased to average values between 179 and 653 mg L^{-1}. The removal efficiencies of TSS in the anaerobic treatment system reached 98% in the set I, with HDT of 75 h (R1 + R2) and VOL in R1 of 9.4 g total COD $(L\ d)^{-1}$ in assay 2 (Table 5). The average removal efficiencies of TSS were similar, 98 and 97% when BICHUETTE et al. (2008) treated swine wastewater with TSS concentrations of 9,980 and 9,880 mg L^{-1}, in UASB reactors of set I applying VOL of 5.2 and 8.6 g total COD $(L\ d)^{-1}$ in R1, respectively.

In the SBR, the highest removal efficiencies of COD_{diss} and TSS, with values of 47 and 71%, respectively, were obtained with HDT of 240 h in assay 1. For total COD, the highest removal of 62%, was observed with HDT of 180 h in assay 2 (Table 5), in which there was an increase of 6 h in the aeration time.

The average concentrations of total and volatile solids (TS and VS) in sludge from UASB reactors of the sets I and II and SBR were higher at the base and gradually decreased to the top of the reactors. The average values of VS in the sludge of the reactors R1 and R2 of set I varied during the tests, from 35,335 to 1,586 mg L^{-1} and 36,134 to 3,050 mg L^{-1} from the base to the top of the reactor, respectively. In the set II, they ranged from 47,946 to 9,369 mg L^{-1} and 37,854 to 8,621 mg L^{-1} in the reactors R1 and R2, respectively. In the SBR the average values of VS were from 5,360 to 1,852 mg L^{-1} from the bottom to the top of the reactor.

The high values of TS and VS of the sludge indicate that in the UASB reactors there was maintenance of a predominantly organic, dense and with microbial activity sludge, which was stratified into layers due to the mixing caused by the upward flow of affluent sludge and biogas. In the SBR the concentrations of VS of the sludge remained within the range of the design parameters of SBR for biological removal of COD, N and P recommended by WEF & ASCE (1998a) and METCALF & EDDY (2003).

Despite the high removal of total COD in the anaerobic reactors, the volumetric methane productions were low and the average values ranged from 0.255 to 0.480 L CH_4 $(L\ d)^{-1}$ and from 0.400 to 0.454 L CH_4 $(L\ d)^{-1}$ in R1 in the sets I and II, respectively (Table 5). The highest average daily temperatures and lowest temperature ranges, associated with higher VOL applied in assay 3, favored microbial activity, resulting in higher average values for the volumetric production of methane. The same occurred for the anaerobic treatment system (R1 + R2) of both sets.

These values of volumetric methane production were similar to those obtained by OLIVEIRA & SANTANA (2011), who used similar experimental conditions. However, they were lower than those verified by SANTANA & OLIVEIRA (2005) , when they operated the set II with VOL from 3.4 to 14.4 g total COD $(L\ d)^{-1}$ in R1 and reached volumetric productions from 0.594 to 1.130 L CH_4 $(L\ d)^{-1}$. The lowest concentrations of TSS (2,216 to 7,131 mg L^{-1}) and smallest sieving mesh size (square mesh sieve with 2 mm) of the affluent increased the proportion of the COD_{diss} in the total COD and decreased the size of the VSS in the affluent. These characteristics facilitated the conversion of the affluent organic matter into methane and provided the largest volumetric productions obtained by SANTANA & OLIVEIRA (2005). SONG et al. (2010) also obtained higher methane production, even applying lower VOL (from 1.3 to 5.8 g COD $(L\ d)^{-1}$), possibly due to higher HDT (84 to 168 h) and swine wastewater sieved with a mesh with an opening smaller than 3 mm.

The average values of KN, N_{am} and N_{org} in the affluent varied from 733 to 1,161 mg L^{-1}, 178 to 239 mg L^{-1} and 546 to 963 mg L^{-1}, respectively (Table 6). Variations in N_{am} concentrations in the outlet of UASB reactors were not proportional to the removal of N_{org} (78 to 98%), which was also observed by DUDA & OLIVEIRA (2009 and 2011) and OLIVEIRA & SANTANA (2011). This indicated that high removals of the N_{org} fraction occurred predominantly by physical entrapment in the sludge blanket and not by ammonification. The highest removal of the N_{org} fraction, of 98%, obtained in assay 1 of set I (Table 6) was favored by lower VOL and higher HDT which led to lower sludge dragging even with the highest temperature ranges in the period, which seem to have affected more pointedly the second stage of lowest volume of set II operated with lower HDT and higher VOL.

Thus, there was reflection in the KN removals, which ranged from 58 to 68% (Table 6), but not in the increase of the Nam concentration in the effluent from the UASB reactors. Treating swine wastewater in the set I, BICHUETTE et al. (2008) observed similar behavior between the fractions of nitrogen and removal efficiencies of similar KN, of 69%, with HDT of 100 h in R1 + R2, which decreased to 55% when decreasing the HDT to 75 h.

Therefore, with the reduction of HDT it may decrease KN removals confirming those mechanisms of sedimentation and interception in the sludge blanket are associated with the decrease of the Norg concentration, and consequently of KN, in the effluent from the two-stage UASB reactors. OLIVEIRA et al. (1997), DENG et al. (2008) and OLIVEIRA & SANTANA (2011) also assigned part of the removal of KN to the formation of struvite ($MgNH_4PO_4.6H_2O$) from Nam, phosphate and magnesium.

After the SBR, the average concentrations of Nam still remained similar to those of the affluent, ranging from 153 to 248 mg L^{-1} (Table 6). In assays 1 and 3 (with HDT of 180 h) an increase in the concentration of Nam in the effluent of the SBR occurred due to the ammonification of the Norg and low nitrification (Table 7).

TABLE 6. Average values and coefficients of variation (cv) of the concentrations of Kjeldahl nitrogen (KN), ammonia nitrogen (Nam.) and organic nitrogen (Norg.), in the affluent and effluent, and of the removal efficiencies of KN and Norg obtained during the operation of the two-stage UASB reactors (R1 and R2) and the sequential batch reactor fed constinuously (SBR) of the sets I and II, in the assays 1 to 3.

Assay	Set	Sample	HDT[1] (h)	Attribute						Removal eff. (%)			
				KN[2]		Nam.[2]		Norg.[2]		KN		Norg.	
				A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]	A[1]	cv[2]
1	I	Affl.	---	733	60	188	22	546	79	---	---	---	---
		R1	72	286	11	245	10	41	85	53	32	88	12
		R2	28	237	18	223	13	14	105	-(3)-	---	54	0
		R1+R2	100	---	---	---	---	---	---	61	27	98	3
	II	Affl.	---	798	77	178	22	621	97	---	---	---	---
		R1	72	304	25	235	13	70	79	69	30	91	8
		R2	15	301	11	237	11	64	86	14	113	41	70
		R1+R2	87	---	---	---	---	---	---	62	61	78	49
		SBR	240	283	14	248	7	35	103	7	118	73	36
		R1+R2+SBR	---	---	---	---	---	---	---	71	8	97	4
2	I	Affl.	---	955	58	223	29	732	73	---	---	---	---
		R1	54	288	29	229	26	59	57	67	30	85	21
		R2	21	267	32	204	40	63	80	33	103	53	51
		R1+R2	75	---	---	---	---	---	---	68	39	83	25
	II	Affl.	---	831	52	239	20	592	70	---	---	---	---
		R1	54	264	40	220	37	43	90	63	33	88	16
		R2	11	283	27	246	27	37	80	8	96	33	75
		R1+R2	65	---	---	---	---	---	---	61	30	89	14
		SBR	240	172	17	153	22	19	59	26	73	51	80
			180	263	37	227	40	36	69	24	94	(3)	---
		R1+R2+	240	---	---	---	---	---	---	66	64	85	17
		SBR	180	---	---	---	---	---	---	63	37	91	11
3	I	Affl.	---	1161	56	198	48	963	62	---	---	---	---
		R1	42	313	33	225	56	88	83	68	24	87	15
		R2	16	290	45	207	63	83	106	18	120	56	63
		R1+R2	58	---	---	---	---	---	---	63	39	86	18
	II	Affl.	---	800	70	199	57	601	79	---	---	---	---
		R1	42	311	42	238	57	73	85	59	32	80	30
		R2	9	285	48	223	63	61	101	22	149	39	91
		R1+R2	51	---	---	---	---	---	---	58	39	80	33
		SBR	240	272	36	212	57	60	93	25	72	(3)	---
			180	259	21	242	22	17	37	28	41	49	55
		R1+R2+	240	---	---	---	---	---	---	57	40	82	19
		SBR	180	---	---	---	---	---	---	73	27	86	17

[1] HDT: hydraulic detention time, A: average [2]Units : KN, Nam., Norg.: mg L^{-1} of N. [3]No removal or below 1%.

The volumes of injected air were not enough to provide dissolved oxygen in to meet the demands for the oxidation of the remaining organic matter and also for the nitrification, even with low VOL and organic load in the sludge in the SBR, from 0.054 to 0.081 g total COD (L d)$^{-1}$ and from 0.012 to 0.025 g total COD (g VS sludge d)$^{-1}$, respectively. METCALF & EDDY (2003) recommend higher values, VOL from 0.1 to 0.3 $BOD_{5,20}$ (L d)$^{-1}$ and ratio F/M from 0.04 to 0.10 g $BOD_{5,20}$ (g VSS sludge d)$^{-1}$, to the SBR with BOD removal and nitrification. In assay 3 (with HDT of 180 h) as the aeration time was longer, there were nitrite and nitrate concentrations in the effluent slightly higher than in assay 1.

It is removed 7.07 g of $CaCO_3$ to every 1.00 g of Nam converted into nitrate (METCALF & EDDY, 2003). Therefore, the total alkalinity in the effluent from R2 (Table 3) was sufficient to convert 170, 142 and 173 mg L^{-1} of Nam into nitrate in assays 1, 2 and 3, respectively. However, the highest values of reduction of Nam concentration, 93 and 19 mg L^{-1}, which occurred due to the nitrification, were observed in assay 2 with HDT of 240 and 180 h in the SBR (Table 6), respectively. In assay 2, the aerobic reaction time was longer (10 h) and also the volume of injected air (Table 2); moreover, with lower average air temperature and lower temperature range over the days, the average value of DO reached to a maximum of 1.4 mg L^{-1} of O_2 (Table 7).

Accordingly, it was observed in the second assay the highest concentration of N_{nitric} ($N\text{-}NO_2^-$ + $N\text{-}NO_3^-$), 50.1 mg L^{-1} (Table 7) in the effluent of the SBR (with HDT of 240 h) and the highest intake of TA, of 285 mg L^{-1} of $CaCO_3$ (Table 3). There was an accumulation of $N\text{-}NO_2^-$ with a concentration of 46.2 mg L^{-1}, due to some limitation of the activity of the nitrite-oxidizing bacteria. PARK et al. (2010) reported that ammonium-oxidizing bacteria and nitrite-oxidizing bacteria relate both synergistic and competitively since they compete for the same electron acceptor (O_2). Bacteria of the first group have some advantage in DO limiting conditions causing the accumulation of nitrite

The portion of 42.9 mg L of Nam removed (93.0 mg L^{-1} of Nam removed less 50.1 mg L^{-1} of N nitric) and which was not nitrified during assay 2 (with HDT of 240 h), must have had part of it immobilized in the sludge because there was an increase of the VS mass of the sludge from the SBR. The remainder might have been volatilized, considering that the pH value increased to above 7.0 in the effluent from the SBR (Table 3), a condition in which there is already NH_3, and still presented greater turbulence due to the 10-hour aeration. Also, the low removals of Nam and TN (Table 7) occurred in assays 1 and 3 can be attributed to the immobilization in the sludge and the volatilization of NH_3 in the SBR.

TABLE 7. Average values and coefficients of variation (cv) of the effluent concentrations of nitrate ($N\text{-}NO_3^-$), nitrite ($N\text{-}NO_2^-$), total nitrogen (TN) and dissolved oxygen (DO), and of the effluent temperature (T) in the sequential batch reactor fed constinuously (SBR) and of the removal efficiencies of Nam and TN in the SBR, in the assays 1 to 3, with HDT of 240 and 180 h.

Assay	HDT[1] (h)	Attribute										Removal efficiency (%)			
		*$N\text{-}NO_2^-$		*$N\text{-}NO_3^-$		*TN		*DO		T (º C)		Nam.		TN	
		A[1]	cv	A[1]	cv	A[1]	cv	A[1]	Cv	A[1]	cv	A[1]	cv	A[1]	cv
1	240	0.9	4	5.2	26	314	23	1.2	41	26.8	7	5	49	22	62
2	240	46.2	7	3.9	61	222	13	1.4	76	31.0	7	24	95	14	128
	180	17.8	95	2.3	43	283	34	1.1	72	23.8	13	31	72	24	82
3	240	5.2	134	3.8	42	281	34	0.8	67	29.7	6	33	64	23	53
	180	6.6	178	5.1	17	270	19	0.9	46	28.9	7	25	52	25	52

1 - HDT: hydraulic retention time, A: average, *Units: $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, TN (mg L^{-1} of N), DO (mg L^{-1} of O_2) and cv (%)

Therefore, the operating conditions adopted in the SBR were not efficient for the marked reduction of the concentration de Nam in the effluent via nitrification. The increased volume of injected air and the improvement of oxygen transfer to the liquid phase, changing the coarse bubble diffusers for fine bubble diffusers, could improve the results. The minimum concentration within the liquid to keep the aerobic environment for the microorganisms depends on several factors: size of the flake, mixing intensity, temperature and especially the rate of oxygen consumption. The sufficient DO concentration in order to occur nitrification without inhibition is 2 mg L^{-1} of O_2, according to VAN HAANDEL & MARAIS (1999) METCALF & EDDY (2003) and WEF & ASCE (2005); a value that was not reached in any of the assays and condition that must have been limiting to obtain higher rates of nitrification in the SBR.

In the treatment system (R1 + R2 + SBR) the average values of removal efficiencies of KN ranged from 57 to 73% and the highest decreases of KN concentration occurred in the two-stage UASB reactors (Table 6). Similar behavior was verified by OLIVEIRA et al. (2008) and the removals of KN reached 78%. With strong assistance from the SBR, OLIVEIRA & SANTANA (2011) reached higher values in the range of 70 to 90%, confirming that the operating conditions of the SBR can be further optimized for the removal of the KN of the final effluent.

The average concentrations of Ptotal in the affluent were high and ranged from 442 to 887 mg L^{-1} (Table 8). The removal efficiencies in the anaerobic treatment system, sets I and II, ranged from 58 to 64% (Table 8) and had a higher contribution from the UASB reactor from the first stage, which was also observed in other studies with two-stage anaerobic reactors (ABREU & OLIVEIRA NETO, 2009; DUDA & OLIVEIRA, 2009 and 2011, OLIVEIRA & SANTANA, 2011). The removal efficiencies of Ptotal followed the variations of TSS removals, indicating that physical removal was the most important process in the reduction of the Ptotal concentrations. However, as done by OLIVEIRA et al. (1997), DENG et al. (2008), OLIVEIRA & SANTANA (2011), the removal of phosphorus should be attributed not only to the sedimentation of suspended solids but also to the precipitation with aluminum, calcium, iron or magnesium and to the phosphine formation under anaerobic conditions.

In the SBR, the maximum removals of Ptotal, 58 and 51% (Table 8), occurred in assay 3, when the average air temperature was the highest (24.5 °C). These average values are found in the range of the highest removal efficiencies of Ptotal, from 45 to 66%, obtained by OLIVEIRA et al. (2008) and OLIVEIRA & SANTANA (2011) in SBR treating anaerobic effluent, which were also higher when the average air temperature was the highest, from 23.7 to 24.5 ^{o}C.

The research results on the effect of the temperature on the biological phosphorus removal were contradictory. Thus, it is concluded that the process is practically indifferent to temperature changes when compared to other biological processes (WEF & ASCE, 2005). However, the temperature has a marked effect on the sedimentation characteristics of biological solids (METCALF & EDDY, 2003). As the temperature increases, the viscosity and the density of the liquid in the reactor decrease and the solids settle faster (WEF & ASCE, 1998b). Thus, increasing the temperature may have caused a more intense biological sedimentation of immobilized P, which may be confirmed by the higher removal efficiencies of VSS in the SBR, of 73 and 64% (Table 5), in the assay 3.

PEREIRA-RAMIREZ et al. (2003) obtained a lower removal of Ptotal, only 26% in biological reactor with continuous aeration with HDT of 4 d, fed with effluent of the system with UASB reactor and anaerobic filter treating swine wastewater. Thus, with the SBR as it has been operated in this work and by OLIVEIRA et al. (2008) and OLIVEIRA & SANTANA (2011), it is possible to obtain higher removals of Ptotal, with less energy use, considering that the aeration in the SBR was intermittent.

In the treatment system (R1 + R2 + SBR), the average values of the removal efficiencies of Ptotal ranged from 61 to 82% (Table 8) and were higher in the two-stage UASB reactors. Only in the assays 2 and 3 there was the contribution of the SBR to the reduction of the average values of the Ptotal concentration in the final effluent and their coefficients of variation. These Ptotal removal values were similar to those obtained by DENG et al. (2008), from 49 to 71%, OLIVEIRA et al. (2008), from 74 to 83%, and OLIVEIRA & SANTANA (2011), from 57 to 74%, who also used the SBR fed with the effluent of the UASB reactors treating swine wastewater.

Affluent concentrations of coliforms were high, with average values of total coliforms that ranged from 1.6×10^{6} to 2.6×10^{7} MPN $(100 \text{ mL})^{-1}$ and thermotolerant coliforms from 1.5×10^{6} to 2.5×10^{7} MPN $(100 \text{ mL})^{-1}$ (Table 8). In the R1 effluent, the total coliform count decreased and was lower in set II, in assay 3, with average of 7.9×10^{5} MPN $(100 \text{ mL})^{-1}$. In the R2 effluent it continued to decrease, reaching the lowest value of 2.7×10^{5} MPN $(100 \text{ mL})^{-1}$ in assays 1 and 3, in the sets I and II.

TABLE 8. Average values and coefficients of variation (cv) of the total coliforms (TC) and thermotolerant coliforms (TeC) and of total phosphorus (Ptotal), and their removal efficiencies (E) obtained during the operation of two-stage UASB reactors (R1 and R2) and the sequential batch reactor fed constinuously (SBR) of the sets I and II, in the assays 1 to 3.

Assay	Set	Sample	HDT[1] (h)	Colimetry				Ptotal (mg L^{-1})		Ptotal E[2]	
				TC[2]	E[2]	TeC[2]	E[2]	A[1]	cv[2]	A[1]	cv[2]
1	I	Affl.	---	6.2 10^6	---	6.2 10^6	---	781	39	---	---
		R1	72	1.7 10^6	62.7	1.7 10^6	62.7	303	21	58	19
		R2	28	2.7 10^5	66.1	2.7 10^5	66.1	287	19	14	83
		R1+R2	100	---	87.3	---	87.3	---	---	59	23
	II	Affl.	---	2.8 10^6	---	2.8 10^6	---	552	51	---	---
		R1	72	2.4 10^6	85.7	1.3 10^6	53.6	236	45	54	29
		R2	15	1.2 10^6	50.0	1.2 10^6	7.7	204	31	16	79
		R1+R2	87	---	57.1	---	57.1	---	---	59	21
		SBR	240	2.3 10^5	80.8	2.3 10^5	80.8	200	19	13	147
		R1+R2+ SBR	---	---	91.8	---	91.8	---	---	61	16
2	I	Affl.	---	2.6 10^7	---	2.5 10^7	---	478	55	---	---
		R1	54	1.9 10^6	85.6	1.8 10^6	78.5	165	40	61	33
		R2	21	1.2 10^6	41.6	1.2 10^6	36.9	155	39	30	77
		R1+R2	75	---	92.4	---	88.6	---	---	64	26
	II	Affl.	---	3.3 10^6	---	3.3 10^6	---	442	62	---	---
		R1	54	1.2 10^6	67.3	9.4 10^5	73.8	164	52	60	38
		R2	11	3.3 10^5	59.7	2.8 10^5	67.7	155	62	36	67
		R1+R2	65	---	77.9	---	89.5	---	---	60	38
		SBR	240	---	---	---	---	89	34	27	74
			180	5.4 10^4	90.4	2.0 10^4	91.9	132	35	31	78
		R1+R2+ SBR	240	---	---	---	---	---	---	74	67
			180	---	98.1	---	99.3	---	---	70	22
3	I	Affl.	---	5.9 10^6	---	1.5 10^6	---	767	67	---	---
		R1	42	5.7 10^6	3.4	5.6 10^5	62.7	294	48	58	30
		R2	16	1.2 10^6	78.9	1.9 10^5	66.1	275	41	13	83
		R1+R2	58	---	79.6	---	87.3	---	---	58	33
	II	Affl.	---	1.6 10^6	---	1.6 10^6	---	887	83	---	---
		R1	42	7.9 10^5	52.2	7.9 10^5	52.2	414	65	54	33
		R2	9	2.7 10^5	65.3	2.5 10^5	68.4	327	67	31	86
		R1+R2	51	---	83.4	---	84.9	---	---	61	34
		SBR	240	---	---	---	---	154	35	58	34
			180	4.6 10^4	83.4	3.1 10^4	87.9	163	25	51	29
		R1+R2+ SBR	240	---	---	---	---	---	---	82	12
			180	---	97.2	---	98.2	---	---	79	53

[1]HDT: hydraulic detention time, E: removal efficiency. A: average, [2]Units: TC and TeC: most probable number per 100 mL (MPN $(100\ mL)^{-1}$), E (%), c v (%)

In assay 2, with HDT of 75 h in the anaerobic treatment system (R1 + R2) of the set I and with VOL of 9.4 g total COD $(L\ d)^{-1}$ in R1, the highest removal efficiency of total coliforms was observed, of 92.4%. For thermotolerant coliforms the largest removal, of 89.5%, occurred in the same assay, but in set II, with HDT of 65 h in R1 + R2.

The lowest concentration of thermotolerant coliforms of 2.0 x 10^4 NMP $(100\ mL)^{-1}$ was reached in the effluent from the SBR in the assay 2 with HDT of 180 h, when the removal efficiencies in the SBR and in the treatment system (R1 + R2 + SBR) showed the highest values, of 91.9 and 99.3%, respectively. OLIVEIRA et al. (2008) and OLIVEIRA & SANTANA(2011) obtained better results in two-stage UASB reactors followed by the SBR for the treatment of swine wastewater, even with the highest counts of thermotolerant coliforms in the affluent, from 1.5 x 10^7 to 4.6 x 10^8 NMP (100 mL)$^{-1}$. The authors achieved removals of up to 99.999% and minimum concentrations of thermotolerant coliforms, of 2.0 x 10^3; 2.4 x 10^3; 9.3 x 10^3 and 9.3 x 10^3 MPN (100mL)$^{-1}$, in effluent of the SBR with HDT of 240, 160, 56 and 28 h, respectively.

PEREIRA-RAMIREZ et al. (2003) were able to obtain even lower levels of thermotolerant coliforms, of 1.8 x 10^3 MPN (100 mL)$^{-1}$, in the effluent from the biological reactor with continuous aeration operated at HDT of 96 h. Therefore, the highest HDT, 240 and 180 h, used in the SBR in assays 1, 2 and 3 did not determine better microbiological quality of the effluent, indicating that the frequency and the greater proportion of the aerobic reaction step in the SBR cycle may be more effective for coliform removal, as observed by OLIVEIRA & SANTANA (2011) and PEREIRA-RAMIREZ et al. (2003).

The inclusion of the SBR was important to significantly increase the removal of thermotolerant coliforms and reach values under 10^5 MPN (100 mL)$^{-1}$ in the final effluent, so that its use is allowed in the irrigation of larger cultivations through drip irrigation, according to the guidelines for reuse of the World Health Organization (WHO, 2006).

CONCLUSIONS

The highest volumetric production of methane, total COD, CODdiss, TSS, VSS, KN, Norg and Ptotal removals occurred in the UASB reactor of the first stage.

The inclusion of the UASB reactor of the second stage contributes to the effluent quality improvement and the increase of the volumetric production of methane, with greater stability of the two-stage anaerobic treatment system. Consequently, increases occur in the removal efficiencies of total COD, CODdiss, TSS, VSS, Ptotal, total coliforms and thermotolerant coliforms.

In the two-stage anaerobic treatment system the various volumes of the UASB reactor of the second stage and the HDT and VOL values used, do not cause great differences in total COD, TSS, VSS, KN, Norg and Ptotal removals. This allows it to halve the volume of the two-stage UASB reactors and to maintain high removal efficiencies of total COD, TSS and VSS in the range of 91 to 94%, and KN and Ptotal, around 60%. Also, the shortest HDT, increasing the VOL, promotes increases in the CODdiss and in the volumetric production of methane.

The post-treatment of the anaerobic effluent in the SBR improves the quality of the final effluent by means of marked decreases in the values of total COD, CODdiss, TSS, VSS, Ptotal, total coliforms and thermotolerant coliforms and increases the stability of the treatment system. The largest increases are in the removal efficiencies for the total coliforms and the thermotolerant coliforms, which typically have lower reduction of concentration in the anaerobic treatment system.

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