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START-UP OF ANAEROBIC REACTORS FOR SLAUGHTERHOUSE WASTEWATER TREATMENT

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ABSTRACT: This study aimed to evaluate the start-up of a horizontal anaerobic fixed bed reactor (HAFBR) followed by an upflow anaerobic sludge blanket (UASB) for the slaughterhouse wastewater treatment. HAFBR was filled with bamboo rings and had 1.2 m in length, 0.10 m in diameter and volume of 7.5 L. The UASB had the volume of 15 L. The HAFBR and UASB operated at organic loading rate and hydraulic retention time average of 8.46 and 3.77 kg m^{-3} d^{-1} of COD and 0.53 and 0.98 days, respectively. During 150 days of monitoring system it was found pH 6.8, relatively high values of bicarbonate alkalinity (> 1000 mg L^{-1}) and reduced values of volatile acids (70 to 150 mg L^{-1}), which afforded average removal efficiencies of COD total and total suspended solids of the order of 31 and 23% in HAFBR and 79% and 63% in UASB. It can be concluded that the generation and consumption of bicarbonate alkalinity and total volatile acids, thereby maintaining the pH during the study indicated stable operation of the reactors. The COD removal in the reactors was satisfactory especially when it considers that the assessment was conducted in a period of adaptation of organisms to the effluent and also the high organic load applied during this period.

KEYWORDS: UASB, anaerobic filter, slaughterhouse, organic matter.

PARTIDA DE REATORES ANAERÓBIOS PARA TRATAMENTO DE EFLUENTES DE ABATEDOURO

RESUMO: Este trabalho teve por objetivo avaliar o período de partida de um reator anaeróbio horizontal de leito fixo (RAHLF), seguido de um reator anaeróbio de manta de lodo (UASB), para o tratamento de águas residuárias de abatedouro. O RAHLF, preenchido com anéis de bambu, teve 1,2 m de comprimento, 0,10 m de diâmetro e volume útil de 7,5 L. O UASB teve volume útil de 15 L. O RAHLF e o UASB operaram com carga orgânica volumétrica e tempo de detenção hidráulica médios de 8,46 e 3,77 kg m^{-3} d^{-1} de DQO e 0,53 e 0,98 dias, respectivamente. Durante 150 dias de monitoramento do sistema, verificaram-se pH de 6,8, valores relativamente elevados de alcalinidade bicarbonato (> 1.000 mg L^{-1}) e reduzidos valores de ácidos voláteis totais (70 a 150 mg L^{-1}), o que proporcionou eficiências médias de remoção de DQO total e sólidos suspensos da ordem de 31 e 23% no RAHLF e de 79 e 63% no UASB. Pode-se concluir que a geração de alcalinidade bicarbonato e consumo de ácidos voláteis totais e consequente manutenção do pH durante o estudo indicaram operação estável dos reatores. A remoção de DQO nos reatores foi satisfatória, principalmente quando se considera que a avaliação foi realizada em período de adaptação dos microrganismos ao efluente e também à elevada carga orgânica aplicada durante este período.

PALAVRAS-CHAVE: UASB, filtro anaeróbio, matadouro, matéria orgânica.

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INTRODUCTION

Brazil is among the largest producers and exporters of beef in the world (ABIPECS, 2012). As a result the generation of large volumes of wastewater in slaughterhouses operations and cold storage chamber has become an environmental concern (KIST et al., 2009; NARDI et al., 2011; PARK et al., 2012). The total amount of water used per animal varies between slaughterhouses and depends on the type of slaughtered animal and the procedure adopted in the slaughter. Different units are used to express the water consumption which complicates the comparison between slaughterhouses units. In slaughterhouses with meat processing and rendering plant, consumption could reach 8.2 m^3 for each ton of pig's carcass (BUGALLO et al., 2003). In Brazil it is reported by PACHECO & YAMANAKA (2006) the consumption of 0.4 to 1.2 m^3 for each pig carcass and could reach 1.5 m^3 for each animal when industrialization of the meat is taken.

The polluter potential of wastewater in slaughterhouse (ARA) is due to the high content of organic matter (BEUX et al., 2007; KIST et al., 2009; CAO & MEHRVAR, 2011), reflecting the presence in this type of effluent of pieces of meat, entrails, fat, fur and especially large volume of blood (PALATSI et al., 2011; BARANA et al., 2013). This fact leads to the search for effective treatment systems, in order to comply with the requirements and standards set by environmental legislation.

In this sense, an effective way of treating ARA consists of the anaerobic biodegradation system. Anaerobic systems have been studied for the treatment of effluent from slaughterhouses due to high removal efficiencies of organic matter with low cost, when compared to aerobic processes. Due to increasing knowledge for the treatment of domestic sewage, anaerobic processes have gained greater prominence, especially in tropical countries such as Brazil, where environmental conditions favor this type of treatment (CHERNICHARO et al., 2012).

Among anaerobic systems are the anaerobic sludge blanket reactor (UASB) and horizontal anaerobic fixed-bed reactor (HAFBR). Horizontal anaerobic fixed bed reactors (HAFBR) have been studied for treatment of different effluents, among which stand out: wastewater from the processing of the fruit from the coffee tree (BORGES et al., 2009), and effluent with the presence of hydrocarbon – BTEX (RIBEIRO et al., 2012) and pentachlorophenol (DAMIANOVIC et al., 2009). This system has the advantage of being built on supported soil, which reduces the construction cost when compared to up flow filter which require a false bottom (suspended) with structure to support the weight of the liquid and support means generally crushed stone (FIA et al., 2012).

Anaerobic systems have been tested with success in removing organic matter of slaughterhouse effluent (DEBIK & COSKUN, 2009; MÉNDEZ-ROMERO et al., 2011; RAJAKUMAR et al., 2012; PARK et al., 2012), reaching DQO removal efficiencies greater than 90% with the application of volumetric organic loads of up to 12 kg m^{-3} d^{-1}. However, the limitations of the anaerobic process in UASB reactors are related to the hydrolysis of organic suspended solids of the affluent, considered detrimental to development of granular sludge. So, to treat wastewater with high shares of organic particulate fraction, such as slaughterhouse, it may be advantageous to apply the two-stage anaerobic process, which consists of two reactors in series, one for partial hydrolysis of complex organic material and the other to digest the soluble compounds formed in the first reactor (BRUNO & OLIVEIRA, 2008; HUSSEYMICHAEL et al., 2013; STOYANOVA et al., 2013). Some studies have reported the improvement in the removal of organic matter when used anaerobic hybrid reactors or sequentially wherein in the first case happens the acidogenic stage and anaerobic degradation; in the second reactor the methanogenic phase which demands great care (IAMAMOTO et al, 2002; BEUX et al, 2007; SADDOUD & SAYADI, 2007).

The objective of this study was to evaluate the stability of the starting period of a horizontal anaerobic fixed bed reactor (HAFBR) followed by an up flow anaerobic sludge blanket (UASB) used in the treatment of slaughterhouse wastewater (ARA) by monitoring alkalinity, volatile acids and organic matter removal efficiency.

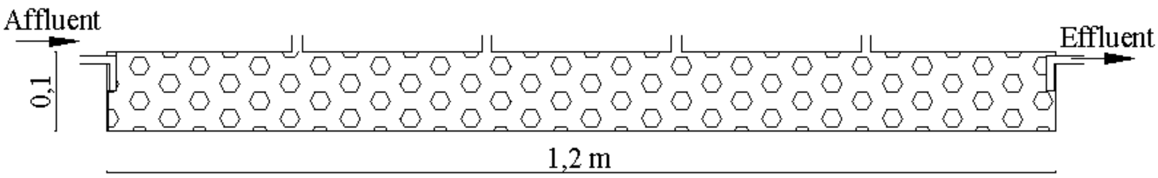
MATERIAL AND METHODS

The treatment system mounted on a laboratory scale consisted of a horizontal anaerobic fixed bed reactor (HAFBR) followed by an upflow anaerobic sludge blanket reactor (UASB).

The HAFBR was built in polyvinyl chloride (PVC) with 1.2 m in length and 0.1 m in diameter (Figure A). As support material were used bamboo rings with average dimensions of 0.020 m of diameter, 0.035 m tall and 0.005 m thick ring wall. The porosity of the support material was 0.80 m^{-3} m^{-3}, resulting in a HAFBR volume of 0.0075 m^3. In the upper part were installed on equidistant manner, four tubes of 0.025 m in diameter to the output of the biogas.

The UASB was built in fiberglass with 1.12 m height (Figure 1B) and volume of 0.015 m^3. The lower part of the reactor (body) had 0.10 m in diameter and 0.72 m height while the upper part of the reactor (head) presented 0.20 m in diameter and 0.31 m height.

(A)



(B)

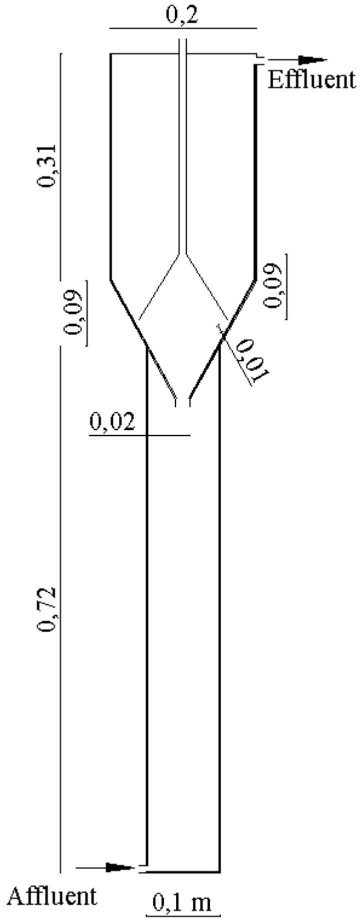


FIGURE 1. Schematic diagram: (A) horizontal anaerobic fixed bed reactor (HAFBR) and (B) upflow anaerobic sludge blanket reactor (UASB).

The reactors were inoculated with sludge from a UASB reactor from effluent treatment station of Federal University of Lavras pig farming in order to obtain initial biological organic load (COB) equal to 0.2 kg kg^{-1} d^{-1} expressed in terms of [DQO] $[SSV]^{-1}$ $[d]^{-1}$ (CHERNICHARO, 2007), totaling 0.0026 m^3 of sludge in the HAFBR and 0.0051 m^3 of sludge in the UASB.

Wastewater of slaughterhouse (ARA), coming from the NUTRILI slaughterhouse located near the town of Lavras-MG was collected weekly in large containers and stored for the experiment under refrigeration and presented during the leaving period that lasted 150 days. Medium characteristics presented in Table 1. The main features of the operating reactors are presented in Table 2.

TABLE 1. Mean values and standard deviation of the main characteristics of slaughterhouse wastewater (ARA) used during the start-up system.

Variables	ARA
pH	6.8 ± 0.4$^{(n = 23)}$
Total chemical oxygen demand (mg L^{-1})	4,294 ± 2,028$^{(n = 23)}$
Total solids (mg L^{-1})	2,368 ± 1,366$^{(n = 18)}$
Total suspended solids (mg L^{-1})	1,017 ± 1,071 $^{(n = 18)}$
Total Kjeldahl nitrogen (mg L^{-1})	262 ± 160$^{(n = 22)}$
Total phosphorus (mg L^{-1})	24.9 ± 23.2 $^{(n = 22)}$

TABLE 2. Mean and standard deviation of the operational characteristics of the horizontal anaerobic fixed bed reactor (HAFBR) and the upflow anaerobic sludge blanket reactor (UASB).

Variables	HAFBR	UASB
Influent flow (m^3 d^{-1})	0.014 ± 0.001	0.014 ± 0.001
Hydraulic detention time (d)	0.53 ± 0.05	0.98 ± 0.09
Volumetric organic load (kg m^{-3} d^{-1} of DQO)	8.46± 3.81	3.77 ± 3.00
Average temperature of the liquid (ºC)	21.3 ± 0.6	21.3 ± 0.6

The monitoring during the period of the startup system was made by affluent and effluent samples of each reactor, weekly during 150 days, totaling 21 samples. The variables were quantified in triplicate partial, intermediate and total alkalinity and total volatile acids by titrations (RIPLEY et al., 1986); hydrogen potential (pH) by potentiometer (4500B); total chemical oxygen demand (DQO_T) by closed reflux method and Colorimetric (5220D), soluble chemical oxygen demand (DQO_S) by closed reflux method and Colorimetric (5220D) after sample filtration in 0.45 µm membrane; and total suspended solids (SST), by gravimetric method (2540D) (APHA et al., 2005).

The means of the variables pH, alkalinity, and volatile fatty acids in addition to the removal rates of DQO_T, DQO_S and SST obtained for each experimental unit were subjected to analysis of variance using the Statistical Programmer SISVAR® (FERREIRA, 2011) and means were compared by Tukey test at 5% probability.

RESULTS AND DISCUSSION

The reactors operated under room temperature. Extremes temperature observed in the liquid during the experiment were 14.8 and 26.6 °C with an average of 21.3 °C. Although microbial activity be greater with increasing temperature, BEUX et al. (2007) found that the removal of organic matter by anaerobic degradation of effluent from the slaughterhouse did not suffer significant variation when the systems were operated at room temperature (22ºC) and in mesophilic temperature of 32°C.

In this study was not necessary maintaining alkalinity supplementation of pH values as noted by VALLADÃO et al. (2011) in the treatment of effluent from the slaughterhouse. The maintenance of pH in anaerobic reactors ($p > 0.05$) within appropriate anaerobic degradation values (Table 3) may be regarded as indicative of the system stability.

TABLE 3. Mean values of pH, bicarbonate alkalinity (AB), volatile fatty acids (AVT), and relationship between intermediate and partial alkalinity (AI/AP) obtained in the influent and effluent from anaerobic fixed bed horizontal reactor (HAFBR) and anaerobic sludge blanket reactor (UASB).

	pH	AB (mg L^{-1} de $CaCO_3$)	AVT (mg L^{-1} acetic acid)	AI/AP
ARA	6.8a	540a	282 a	-
HAFBR	6.8a	1,278 b	131 b	1.50
UASB	6.9a	1,403 b	60 c	1.41

Medium followed by the same letter in the column did not differ among them by Tukey test at 5% probability.

The AB values fluctuated throughout the experimental period, though relatively satisfactory values were observed throughout the follow-up process, as noted by PADILLA-GASCA et al. (2011). There was no difference between the values observed in HAFBR and in UASB ($p > 0.05$). Is evidenced in the literature that there is strong correlation between alkalinity and partial acid buildup with the composition of the wastewater. Protein-rich effluents, such as those from slaughterhouses, the acids accumulate in the same proportion, but pH and AB tend to increase due, probably, to the formation of ammonia during anaerobic degradation of proteins (RAJAKUMAR et al., 2012; PADILLA-GASCA et al., 2011). In this study HAFBR seems to have worked as an acidogenic reactor and UASB as metanogenic. BEUX et al. (2007) observed in two sequential anaerobic reactors used in the treatment of a slaughterhouse effluent with TDH from 1 day each, and AVT concentrations and AB equal to 391 and 530 mg L^{-1} at first, and 173 and 769 mg L^{-1} at the second, respectively, as observed in this study.

Although the HAFBR have worked with an acidogenic reactor, favoring the degradation of organic matter in the UASB reactor, the effluent of the HAFBR were lower than AVT affluent ($p <0.05$) showing the consumption of AVT in the first reactor, probably by the inoculated biomass characteristics in HAFBR. This result differs from that observed by JIA et al. (2012), which after 7 days on pre-fermentation effluent from slaughterhouse without inoculums, observed increase in the average values of AVT from 200 mg L^{-1} to 620 mg L^{-1}.

AB associated with the high values was observed reduced values for AVT. This combination of the maintenance of pH values near neutrality, AB high values and low values of AVT provided favorable conditions for the occurrence of anaerobic degradation. PADILLA-GASCA et al. (2011) and RAJAKUMAR et al. (2012) found maximum concentrations of AVT between 285 and 448 mg L^{-1} without observing any change in the stability of an anaerobic system used in the treatment of a slaughterhouse effluent. RAJAKUMAR et al. (2012) applied a COV of 2.74 kg m^{-3} d^{-1} of DQO. PADILLA-GASCA et al. (2011) observed AVT values in the stable phase of the reactor that was less than 100 mg L^{-1} while AB values ranged from about 2.000 mg L^{-1}.

Although it has been observed high values of AB and reduced values of AVT, the relationship between the intermediate and partial alkalinity (AI/AP) was superior to 0.3 which may indicate a disturbance in the process of anaerobic digestion (RIPLEY et al., 1986). DEBIK & COSKUN (2009) observed in anaerobic reactors used in effluents treatment of slaughterhouse, alkalinity values near to 1,500 mg L^{-1} and AI/AP ratio inferior than 0.3 to an average of COV of 2.73 kg m^{-3} d^{-1}. However, the affluent alkalinity to the reactor was 1.315 mg L^{-1}, almost three times that observed in this study.

It is possible that the stability of the process occurs for different values of 0.3 being wise the verification for each particular case (CHERNICHARO, 2007). According to Ripley et al. (1986) the inhibition of the metanogenic phase only occurs in AI/AP values above 0.8. It has been reported in the literature, especially in agro-industrial wastewater treatment, AI/AP ratio values between 0.53 and 2.2, even for systems considered stable. However, removal efficiencies for DQO were inferior to 50% for COVs between 0.5 and 5.3 kg m^{-3} d^{-1} of DQO (IAMAMOTO et al., 2002; PEREIRA et al., 2011; LEE et al., 2011; FIA et al., 2011).

Although they were obtained high values of AI/AP ratio, the average removal efficiencies of DQO in HAFBR and UASB (Table 4) can be considered satisfactory. The UASB-HAFBR set removed an average of 84% of DQO_T and 86% of the DQO_S .

The experimental set-up of HAFBR followed by UASB probably favored the two-stage of anaerobic degradation, given the values of AVT in UASB below HAFBR ($p < 0.05$). PALATSI et al. (2011), in biodegradability tests for slaughterhouse waste countertops it was verified the accumulation of AVT in the first days being about 100 times greater than the values observed in the final stages of degradation.

The use of anaerobic treatment systems in two stages can improve stability, reduce problems with excessive duplication of acidogenic bacteria and consequently the reduction of methanogenic archaea, and increase the removal efficiency of organic matter (BRUNO & OLIVEIRA, 2008; COLUSSIA et al., 2013; URBINATI et al., 2013).

TABLE 4. Removal efficiency (E) of total suspended solids (SST) and chemical oxygen demand total and soluble (DQO_T and DQO_S), and removal rate (TR) of SST and DQO in anaerobic fixed bed horizontal reactor (HAFBR) and anaerobic sludge blanket reactor (UASB).

Units	SST		DQO			
	E (%)	TR_{SS} (kg m^{-3} d^{-1})	E_{DQOT} (%)	TR_{DQOT} (kg m^{-3} d^{-1})	E_{DQOS} (%)	TR_{DQOS} (kg m^{-3} d^{-1})
HAFBR	23	0.33a	31	2.77a	74	2.40a
UASB	63	0.93b	79	2.95a	82	0.46b
HAFBR- UASB	67	-	84	-	86	-

Medium followed by the same letter in the column did not differ among them by Tukey test at 5% probability.

The dragging of solids (sludge) HAFBR during the monitoring period of experimental units reduced the SST removed load in HAFBR (Table 4).

RAJAKUMAR et al. (2012) verified that the gradual increase in the concentration of affluent SST favored the removal of solids (93%) in the poultry slaughterhouse effluent treatment in UASB hybrid reactor (partially filled with media support). BEUX et al. (2007) had lower solids removal efficiencies as verified in this study and when evaluate sequential anaerobic reactors with removal of 15% and 28% of solids for the first and for the second, considering a TDH at 1 day each.

The UASB showed higher removal rate of SST ($p <0.05$) compared to HAFBR what appears to be reflected in increased removal efficiency DQO_T. Moreover, the biggest solid drag occurred in HAFBR contributed to lower removal efficiencies of DQO_T . This can be justified because the DQO_S removal efficiency values were superior to DQO_T in HAFBR, equating to DQO_S removal efficiencies in the UASB (Table 4).

Another factor that probably differ from the removal efficiencies of organic matter between HAFBR and UASB ($p <0.05$) was that the first worked as an acidification reactor favoring anaerobic degradation in the UASB. In HAFBR there was a higher concentration of AVT while in UASB there was a higher concentration of AB. This was also confirmed by SADDOUD & SAYADI (2007) and BEUX et al. (2007).

SADDOUD & SAYADI (2007) reported that the use of an anaerobic membrane reactor as a single treatment unit of slaughterhouse effluents, the maximum COV applied without destabilizing the system was 8.23 kg m^{-3} d^{-1} of DQO reaching 94% of DQO_T removal efficiency. By inserting an anaerobic fixed bed reactor before the anaerobic membrane reactor was observed that the COV applied in the system (two reactors) would be 12.7 kg m^{-3} d^{-1} DQO, achieving a DQO removal of 98 %.

BEUX et al. (2007) have observed similar removal efficiencies in two sequential anaerobic reactors evaluated in this study. With TDH of 1 day each at an affluent concentration of about 2.300 mg L^{-1}, the efficiencies obtained for the first, and the second reactor were 54% and 51%.

TORKIAN et al. (2003) applied COVs between 13 and 39 kg $m^{-3}d^{-1}$ of DQO of slaughterhouse effluent in UASB reactor. The maximum COV applied without destabilization of the system was 30 kg m^{-3} d^{-1} DQO reaching 83% of DQO_T removal efficiency. To raise the COV to 39 kg m^{-3} d^{-1} of DQO the average removal efficiency was reduced to 68%.

Comparing the removal efficiency of organic matter in the DQO form, obtained in this study, they can be considered satisfactory in the anaerobic reactors evaluated mainly because is an initial period of adaptation of the system and also by organic loads applied that were superior to many studies reported in the literature.

CONCLUSIONS

The generation of bicarbonate alkalinity and total volatile acid consumption and consequent maintenance of pH during the study indicated stable operation of the reactors. As a result of stability, DQO removal efficiency in the reactors was especially satisfying when considering that the evaluation was conducted in a period of adaptation of the microorganisms to the degradation of slaughterhouse wastewater (system start-up period), and also to the high organic volume applied during this period.

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