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Start-up and Steady-State Conditions of an Anaerobic Hybrid Reactor (AHR) Using Mini-Filters Composed with Two Types of Support Medium Operating Under Low Loading Rates

Vivian Galdino da Silva[1], **Cláudio Milton Montenegro Campos**[2], **Erlon Lopes Pereira**[3*] and **Júlia Ferreira da Silva**[4]

[1]Unidade de Ciências Exatas e Tecnológicas; Universidade Estadual de Goiás; C. P.:459; Goiânia - GO - Brasil. [2]Departamento de Engenharia; Setor Recursos Hídricos e Meio Ambiente; Universidade Federal de Lavras; C. P.: 3037; Lavras - MG - Brasil. [3]Departamento de Biotecnologia; Escola de Engenharia de Lorena; Universidade de São Paulo; Lorena – SP - Brasil. [4]Instituto de Ciências Ambientais e Desenvolvimento Sustentável; Universidade Federal da Bahia; Barreiras - BA – Brasil

ABSTRACT

The present work aimed at studying the operational parameters of an Anaerobic Hybrid Reactor (AHR) removing organic matter of coffee wastewater with low concentration. The AHR was built similar to an UASB reactor, however the interior was filled with mini-filters composed by two types of support materials: expanded clay and rolled pebble. Three start-ups were accomplished in order to achieve the stationary state (steady-state). Three hydraulic retention times were appraised: 28.5; 24.0 and 18.0 h, obtaining a volumetric loading rate (VLR) of 0.70; 0.56; 0.54 kg COD m^{-3} d^{-1} *and a biological organic loading rate (BOLR) of 0.0156; 0.0103 and 0.01213 kg* BOD_5 *kg* TVS^{-1} d^{-1}*. Due to the decrease in the concentration of organic matter in the influent, the endogen process started to occur on the biomass lowering the methanogenic process.*

Key words: *environmental chemistry, coffee wastewater, biodegradation, optimization process*

INTRODUCTION

Issues concerning energy economy, environmental conscience and conformity with the safety's rules have been lifted up in order to reach the best solution for each one of the specific cases. In order to take care of the environment that surrounds us, one must consider to treat the wastewaters that can pollute the rivers and soils, and, mainly, to produce appropriate alternatives, as reduction, reutilization and recycle (Chaiprasert et al., 2003; Pereira et al., 2011). The trend is that the productive sector takes the responsibility for the problems of the environmental degradation, and therefore the governmental organizations must exercise a great pressure on the non-governmental organizations (NGOs) and also on the society. This issue has a great importance in Brazil, mainly after the approval of the law concerning the Environmental Crimes, which is in agreement with the law n° 9605 of February 1998 (Pereira et al., 2010a; Pereira et al., 2010b; Pereira et al., 2011).

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[*] Author for correspondence: erlonlopes@gmail.com

Besides preserving the springs of water, the treatment of liquid effluents is directly inserted in the context of the above-mentioned maintainable development, satisfying the current needs without reducing the perspectives of the future generations (Pereira et al., 2009; Pereira et al., 2010a).

The anaerobic systems applied to wastewater treatment have frequently been used with the purpose of optimizing and minimize the costs (Pereira et al., 2010). However, to be used as a unique treatment, it has certain limitation with relationship to its efficiency, normally being necessary to be polished using other treatment unit (Metcalf and Eddy, 2003).

The anaerobic system should be low energy consuming process (Chernicharo, 2007).

Among many post-treatment alternatives, one option is the anaerobic filters. These filters are characterized by the presence of a packing material to which the sludge (bacterial material) can stick and grow, forming the biofilm, or even it can grow in void places among the medium forming the interstitial biofilm. These anaerobic filters have the capability to remove the organic matter (Colin et al., 2007). Campos et al. (2010), studying the UASB reactors in laboratory scale found that the biological processes of organic matter removing depended on the microorganisms activity which in turn depended on the acclimatization with the food source, pH, alkalinity and other parameters. The efficiency of this degradation was linked to the operational parameters applied to the reactors. Fia et al. (2010), treating the coffee wastewater with a COD concentration varying from 812 to 5,320 mg L^{-1} evaluated anaerobic reactors of fixed bed using as support high-oven scum, polyurethane foam and pebble no. 2. The authors got a COD removal average efficiency of 80%, observing a variety of microorganisms in the biofilm, such as bacilli, curved bacilli, filaments, and similar morphologies as the *Methanosaeta* sp. and *Methanosarcina* sp. However, since the coffee is an annual culture it is common that at the end of the crop the concentration of the effluent decreases, demanding more care with relationship to the operational parameters applied to the reactor. It is still an unknown situation, because the researchers of the area commonly work with effluents of high concentration (Campos et al., 2010).

The present work aimed at studying the operational parameters for optimizing the hybrid anaerobic reactor (AHR) as part of an effluent treatment system operating with low organic loads.

MATERIAL AND METHODS

The experiment was carried out in the Pilot Station built for treating the coffee wastewater and it was located in the Coffee Research Center (CEPECAFE), of the Department of Agriculture of the Federal University of Lavras, MG, Brazil. The system was composed with preliminary treatment (PT), with two screens, sand sedimentation tank, secondary treatment composed by a stabilization pond (SP), two concentric UASB reactors working in series with pressurized equalization tank, an anaerobic hybrid reactor (AHR), three filters for H_2S removing, three gas-meters, two aerobic batch reactors (ABR), a drainage bed sludge (DBS), six reservoirs and a pumping system composed with six pumps (Fig. 1).

The anaerobic hybrid reactor (AHR) was built using orthoftalic polyester resin of Merk and later covered with reinforced blanket fiber roving reinforced with steel plate rings and wrapped with orthoftalic gel-coat. The unit had a diameter of 1.0 m, height of 4.0 m and liquid volume of 3,107 L. It also had a three-phase separator (TPS) with height of 1.37 m, built with fiberglass. The AHR, contained 54 PVC mini-filters (1.0 m of length and 0.1 m of diameter). The mini-filters contained two types of support material: expanded clay and rolled pebble (Fig. 2).

The AHR was seeded using the domestic sludge. The sludge was discharged in the digestion compartment, close to the three-phase separator (TPS), until the height of 4 meters.

The mini-filters were placed in the AHR and the proportion between the rolled pebble and expanded clay was defined through the experimental tests. A nylon screen was adapted to the TPS so that the mini-filters did not occupy its interior (Fig. 3).

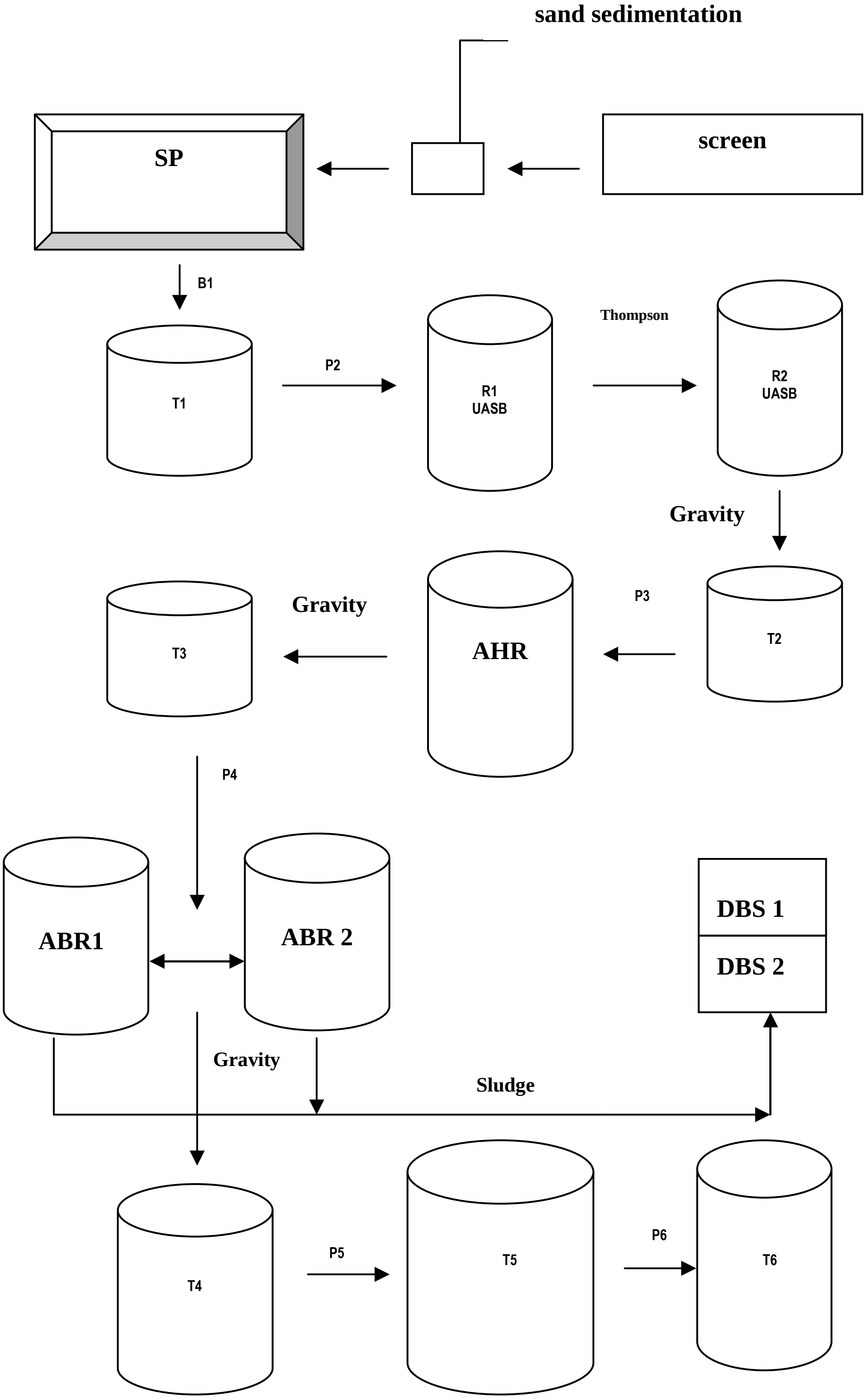


Figure 1 - Operational flowchart of the pilot system treating coffee wastewater, where: SP (stabilization pond); P (pump); R1 and R2 (reactors); AHR (anaerobic hybrid reactor); (ABR (aerobic batch reactor); T (reservoir).

Figure 2 - (a) Mini-filters with expanded clay balls and rolled pebble (round quartz stone) (b) AHR illustration.

Figure 3- Three-Phase Separator (TPS).

The reactor was submitted to three start-ups after inoculation. Before each start-up, the concentration of total volatile solids (TVS) of the biomass and the COD concentration of the influent were evaluated. The temperature of the treatment units was monitored by the thermo-resistors and the data were registered using two computerized registers, Eurotherm mark. The pH was measured using a Hach according to the hydrogenionic potential methodology 4500-H-B (APHA et al., 2005). The alkalinity was measured using also hydrogenionic potential methodology, according to Ripley et al. (1986). The NTK, COD, BOD, total solids (TS), total fixed solids (TFS), total volatile solids (TVS) analyzed followed the Standard Methods for Examination of Water and Wastewater (APHA et al., 2005). The following parameters were monitored daily, temperature of the liquid influent and of the environment, humidity, pH analyses, electric conductivity, salinity and total dissolved solids (TDS). Besides these, total and partial alkalinity and total acidity were also tested. Periodically, the samples from the AHR were collected in order to determine the total fixed and volatile solids concentrations. The experiment was monitored during a period of 136 days.

RESULTS AND DISCUSSION

Start-up of the system

The first start-up was carried out 13 days after the inoculation. The whole system worked automated using a logic programmable controller (LPC), which controlled several solenoid valves and level controller sensors installed inside the reactors and containers. During the experiment, the automated system failed two times, and it was necessary to start up again after each failure. The parameters concerning the inoculation and the three start-ups are present in Table 1. These values corresponded to the samples analyzed during each start-up.

It was noted that the values for the majority of the observed parameters were quite close, except BOD_5 that presented an increase, probably due to the washing of solids outside of the reactor (wash out). There was a reduction in BOLR in consequence of the smallest concentration of BOD_5, in the first start-up, which was 310 mg L^{-1} and in the second start-up fell to 280 mg.L^{-1}. In the third start-up, the BOLR increased to 18%, proportionate to the addition of coffee peel in the pond with the purpose to increase the organic matter.

Table1 - Observed parameters in the inoculation and in the three started-ups of the pilot system referred to the AHR treating coffee wastewater.

Parameter	**Inoculation**	**1st startup**	**2nd startup**	**3rd startup**
COD (mg L^{-1})	-	828	665	645
BOD_5 (mg L^{-1})	-	310	280	380
BORL (Kg BOD_5 Kg TVS^{-1} d^{-1})	-	0,0156	0,0103	0,01213
Xvt (kg TVS)	-	51,926	71,25	82,09
HRT (hour)	-	28,5	28,5	28,5
Q (m^3 d^{-1})	-	2,62	2,62	2,62
VLR (Kg $BOD_{5\ m}^{-3}$ d^{-1})	-	0,26	0,236	0,32
VLR (Kg $COD_{5\ m}^{-3}$ d^{-1})	-	0,70	0,56	0,54
pH	5,34	7,34	7,06	6,73
TEMPERATURE (°C)	19,05	19,06	22,3	22,6
EC (dS m^{-1})	0,63	0,83	0,82	1,15
TDS (Mg L^{-1})	507	645	640	903

Obs.: The operational parameters as HRT and VLR were based on the total volume of reactor.

Evaluation of the system in the stationary state (steady-state)

Considering all the experimental period, it was observed that the reactor worked in the mesophilic temperature, quite appropriate for anaerobic processes, with an average of effluent temperature of 23.7^{o}C. The average concentrations of alkalinity and total acidity were 450 mg $CaCO_3$ L^{-1} and 46 mg L^{-1}, respectively. The pH did not change greatly, demonstrating high buffer conditions. After three successive start-ups and after the transient period, the system was monitored daily in order to improve the stability and growth of the biomass. When the BOD_5 of the effluent was 23, 22 and 25 mg L^{-1} and the variations were lesser than 10% (Metcalf and Eddy, 2003), (which was after the 77th day), it was assumed that the AHR reached the steady-state condition. It was observed that the concentration of organic matter in the AHR affluent was decreasing, therefore, the flow rate was increased, in order to increase the VLR, even decreasing the HRT. Although the flow rate was increased, the BOD_5 went on decreasing (Fig. 4).

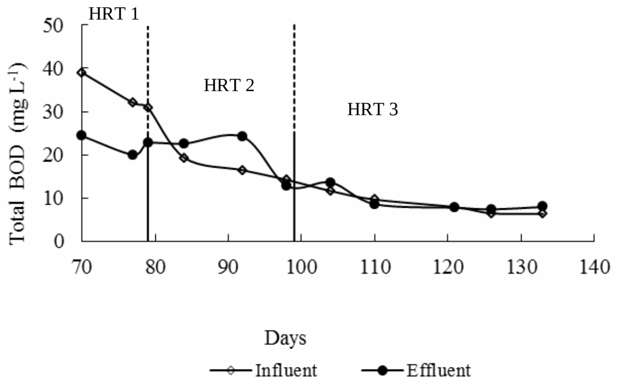


Figure 4 - Behavior of BOD_{total} during the system monitoring.

Due to the low concentration of organic matter, after 106 days, the filtered BOD was monitored (Fig. 5), with the purpose of knowing the dissolved matter concentration capable to degrade the BOD_{total} measures the dissolved and also the suspended solids, which can happen due to the wash-out of the sludge, causing negative efficiency, even when the system operates at ideal conditions. Therefore, it was necessary to analyze the filtered BOD, considering only the dissolved solids, minimizing the wash-out of the sludge.

Comparing the values of total BOD and the filtered BOD, it was observed that the two had similar values, about 6 mg L^{-1}, indicating that there was no washout of the solids and dissolved solids that made up most of the BOD, and the values of suspended solids were negligible. The observed concentration of TVS for HRT of 28.5 hwas about 23,930 mg L^{-1}, for HRT of 23.73 h it was about 17,84 mg L^{-1} and for HRT of 18.03 h, it was 12,037 mg L^{-1}. Although there was increased flow rate in AHR a decrease was observed in the concentration of TVS in the sludge. This phenomena was associated with the decreased VLR (Fig. 6), which was due to the dilution of the effluent. This led to decrease availability of substrate for the microorganisms, possibly caused by the endogenia.

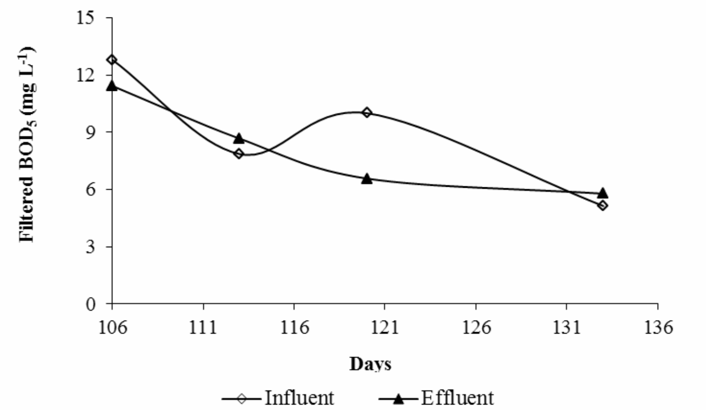


Figure 5 - Behavior of filtered BOD during the 18 h HRT.

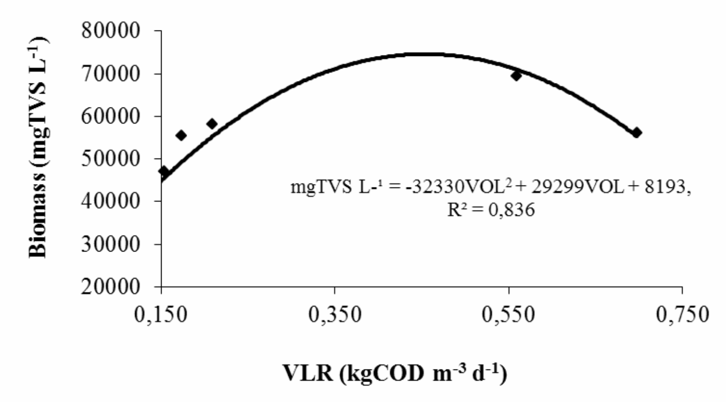


Figure 6 – Relationship between the sludge development and the observed volumetric loading rate (VLR) in the AHR.

Even reducing the HRT the decrease was not enough in order to get a mass increase of TVS, since the shortest time used was 18.03 h (Fig. 7). This meant that this time should be reduced below 12 h, whereas AHR might operate with a very low biological organic loading rate (BOLR). The lack of organic matter provoked low sludge production.

It was observed that the operational parameters had a limited interference in the process, in other words, the increase or decrease of the flowrate to attempt the maintenance of loads were just applicable when there was favorable concentrations.

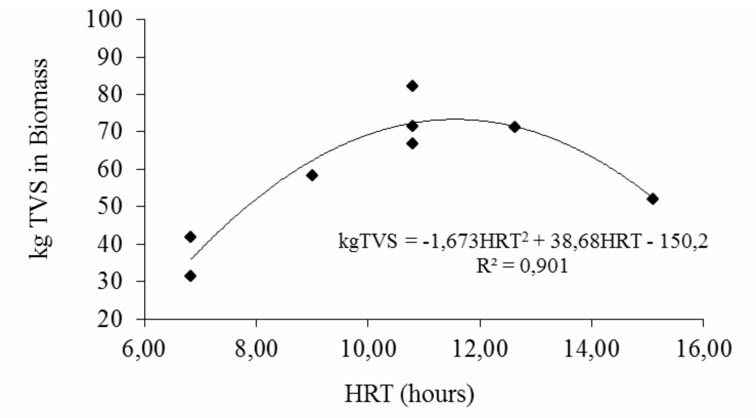


Figure 7 - Mass variation concerning TVS for different HRT.

The model equaton observed in the Figure 7 was obtained by regression:

$y = -1{,}6734x^2 + 38{,}681x – 150{,}21$

Deriving the cited equation, one can obtain the following expression:

$$\frac{dy}{dx} = \frac{d\,(-1{,}6734\,x^2 + 38{,}681x - 150{,}21)}{dx}$$

Equaling the first term to zero in order to find the maximum of the function, one can obtain the following expression:

$$\frac{dy}{dx} = 0$$

$– 3.3468x + 38.681 = 0$

$x = 11.6$ hours

Since the result was x=11.6, according to the model, the HRT must be more than 11.6 h in the AHR, or therefore would not have any effect on the biomass due to its low BOLR applied in the reactor.

Figures 8a, b and c show the curves obtained from the TVS for HRT of 28.5; 23.7 and 18.0 h, respectively. The concentration of solids in three HRT was very homogeneous along the strata, corresponding to the ports 1 (h=350 cm), 2 (h=310 cm), 3 (h=230 cm), 4 (h=190 cm) and 5 (h=150 cm). The average values for each stratum was 239; 251; 656; 437; 7.006; 44.603; 42.720 and 47.476 mg L^{-1} for the ports 1, 2, 3, 4, 5, 6, 7 and 8, respectively. Another factor that got the attention was that there was a larger concentration of TVS of the sludge in the last three strata of AHR (h = 0 to 110 cm). As the flow of AHR was in ascending order, the eighth extract presented, in all the situations, a smaller concentration than the seventh stratum, possibly due to the flotation phenomenon caused by the biogas production.

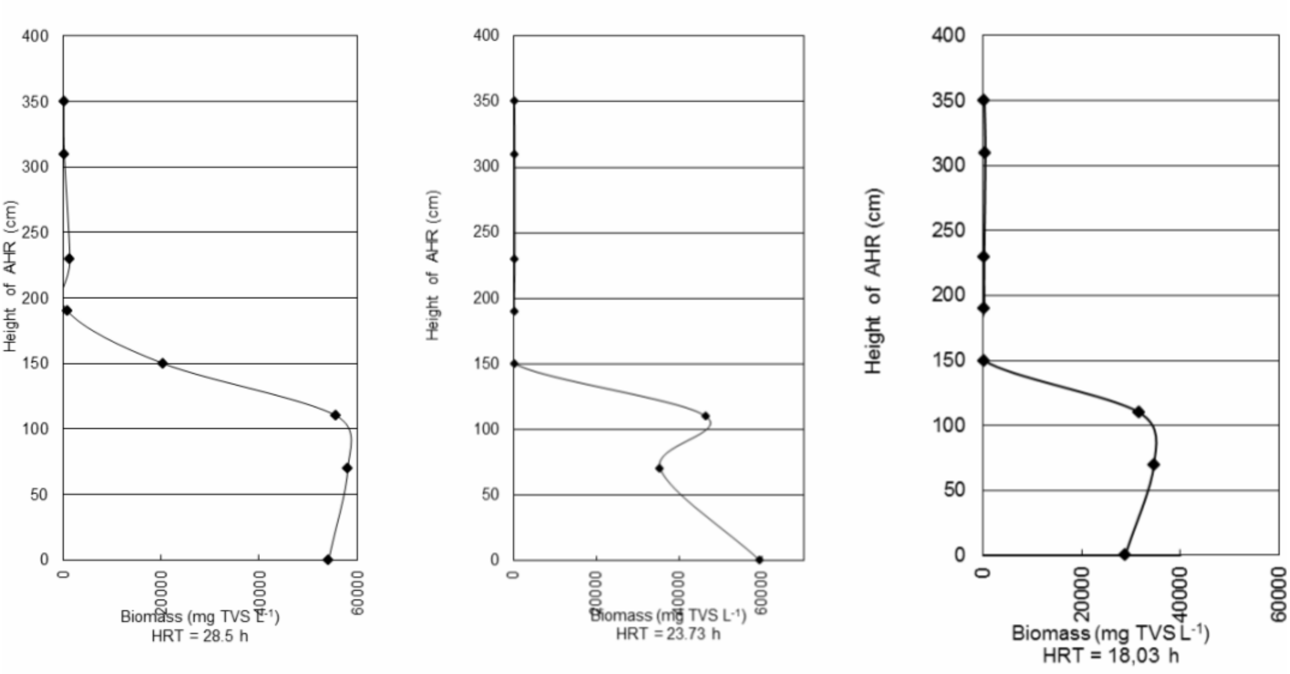
The average concentration of TVS for HRT=28.5 h was about 23,930 mg L^{-1}, for HRT=23,73 h about 17,841 mg L^{-1} and for HRT=18,03 h about 12,037 mg L^{-1}. There was a lowering in the concentration of TVS of the sludge, associated with the lowering of the biological organic loading due to the decreasing concentration of the effluent. This possibly decreased the substratum readiness to the microorganisms, causing endogen.

Nitrogen and Phosphorus

For the biological treatment the phosphorus concentration should reach compatible levels to improve the biochemical processes of oxidation of the organic matter, and the proportion of phosphorus needed for removing the biodegradable organic matter should have the rate of BOD/P < 100 (Metcalf and Eddy, 2003). The largest concentration of P_{total} was during the first HRT (28.5 h), reaching 0.4 mg L^{-1} in the effluent of the AHR. The value of P in the effluent for the last HRT (18.03 h) was of 0.11 mg L^{-1}, value below the maximum concentration allowed by the legislation, i.e., 0.15 mg L^{-1}, for class 3 (CONAMA, 2005). With such low concentrations of phosphorus, the ratio of BOD_5 / P was very high in the AHR, about 1732, showing that there was a lack of this nutrient for the microorganisms, and also contributed to the phenomenon of endogen. Concerning the nitrogen, close values were observed for the two collected points, showing that the removal was very low and that the amount of nitrogen was stable in the influent and in the effluent of the AHR. The analyses of nitrogen were accomplished after the third start-up, when the system already worked with low concentrations of organic matter and the activity of the biomass was quite small (Table 2).

Evaluation of the organic loading rate and biogas production

The evaluation of the removal efficiency of organic matter was made in function of the parameter of the total COD and also BOD5 (Table 3)



(a) (b) (c)

Figure 8 - Concentration of solids in the profile of AHR for: (a) HRT=28.5 h; (b) HRT=23.7 h; (c) HRT=18.03 h.

Table 2 - Concentration of NTK and P in the influent and effluent of AHR.

	NTK (mg L^{-1})		P (mg L^{-1})	
	Influent	Effluent	Influent	Effluent
HRT I	70	75	0,25	0,16
HRT II	35	35	0,22	0,16
HRT III	55	53	0,12	0,11

Table 3 - Average values of the removal efficiency of the COD and BOD_5 of the anaerobic hybrid reactor (AHR) at different hydraulic retention times (HRT).

	COD (mg L^{-1})			BOD_5 (mg L^{-1})		
	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)
HRT I	484.0	344.51	28.8	39.0	24,33	37.61
HRT II	168.0	159.33	0.5	20.17	20.53	0
HRT III	92.0	90.75	0.1	6.3	7.9	0

AHR was operated in a quite stable manner during the first HRT and with reasonable BOD_5 removal efficiency; it presented an influent average concentration to the AHR of 17.6 mg BOD_5 L^{-1}. Initially, the reactor operated with the influent of 39 mg BOD_5 L^{-1} and in the end of the experiment, the influent BOD $_5$ was only 6 mg BOD$_5$ L^{-1} mainly due to the excessive dilution of the wastewater and consequently low concentration of organic matter, which was virtually removed from the units prior to the AHR. Initially, the reactor was operated with an influent with 827 mg COD$_{total}$ L^{-1} and at the end of the experiment, the influent concentration of COD$_{total}$ was only 64.67 mg L^{-1}, showing that in the end, caused by the endogen, there was washout of the of dead cells from the AHR.

The low values were due to the low solid concentration present in the influent of the AHR, therefore, the biodegradable part was practically removed in the previous units and the AHR presented low efficiency concerning the removal of dissolved material.

During the monitoring, the AHR was operated with average efficiency of 11.58% for COD$_{total}$ removal. Figures 4 and 5 show the parameters related to the HRT and VLR influencing the concentration of the volatile solids of the sludge.

The removal efficiencies of organic material were considered very low when compared with other works (Campos et al., 2010; Fia et al., 2010 Pereira et al., 2010) since this reactor is considered of high loading, as the upflow anaerobic sludge blanket reactor (UASB) and anaerobic filter, the AHR could have had efficiency ranging from 75 to 80%. The biogas production from the AHR obtained in the 136 days can be seen in Figure 9. This was well below the accumulated volume of methane, calculated theoretically for each experimental stage using the equations described by Prado and Campos (2009) that was 23.8; 0.40 and 0.40 m^3, respectively for the three periods evaluated, considering the three HRT applied in the reactor.

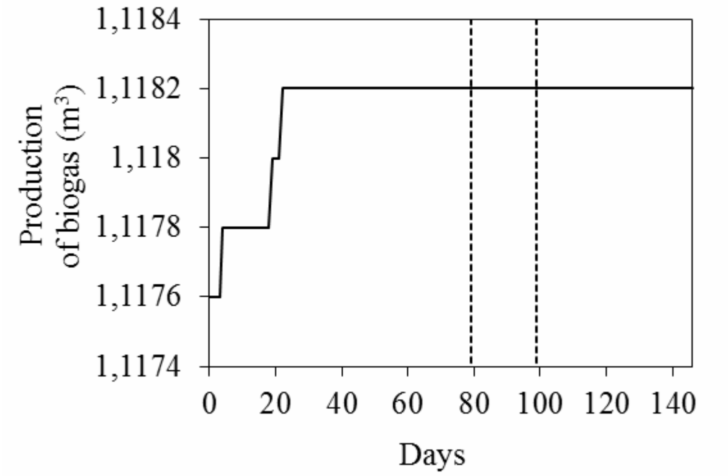


Figure 9 - Reading of the production of biogas of the anaerobic hybrid reactor (AHR).

It was possible that the biogas was exhausted through the TPS from the upper part of AHR due to the increase of the head loss caused by the equalization pressure tank. Therefore, the readings of the gas meter were quite low when compared with the theoretical values. Using the production of methane calculated from the total amount of biomass of the unit, estimated by the sum up of the TVS profile collected from each sampler port of the reactor`s profile, it was possible to estimate and the calculated values of the theoretical methanogenic activity (TMA) in the AHR, were: 4.5; 0.36 and 0.38 L CH$_4$ kg TVS^{-1} d^{-1} for HRT of 28.5; 23.7 and 18.0 h, respectively. The average daily production of CH$_4$ related to the removed COD, along the experiment, was: 0.19 m^3 CH$_4$ kg DQO$_{rem}^{-1}$ d^{-1}.

CONCLUSION

The efficiency of the reactor in removing organic matter was hampered by the low biological and volumetric organic loading rates applied, and therefore the AHR worked well below its capacity. A decrease was observed in the concentration of the sludge (TVS), associated with biological reduction of organic load, although the flow was increased. This explained process reduced the availability of substrate for microorganisms causing endogen. Organic matter was a limiting factor for the development of biomass, because there was lack of influent organic matter and consequently lack of nutrients, particularly phosphorus, causing low sludge production, irrelevant biomass growth in the support media (biofilm), and no flocculation or granulation. Even so, the unit demonstrated physical-chemical stability, even when operated with low loads.

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