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ANAEROBIC-AEROBIC BAFFLED REACTOR TREATING REAL MUNICIPAL WASTEWATER IN A LOW INCOME COMMUNITY

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Abstract

Inadequate sanitation and poor infrastructure for waterborne sanitation are common in many developing countries. The anaerobic/aerobic baffled reactor (AABR) is a sustainable option for water sanitation in developing countries. In the present study, a 2.50 m^3 AABR reactor working with real municipal wastewater was monitored. Four sequenced chambers, the first three being anaerobic and the fourth aerobic composed the AABR reactor. AABR efficiency and performance were examined during four different periods. Organic and hydraulic load increases were adequately absorbed, provoking no instability in the system and demonstrating good configuration for absorbing organic impacts. The AABR had a promising effect on COD removal, which led removal values of total COD up to 74%, and total suspended solid (TSS) removal up to 79%. Regardless of the value on entering, the pH from the reactor effluent remained close to 7 during the four periods, indicating good stability in the reactor.

Key words: aerobic treatment, anaerobic treatment, anaerobic-aerobic baffled reactor, municipal wastewater, reactor stability

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1. Introduction

With the great increase in world population, especially in metropolitan areas, the construction of sewage treatment plants has become a matter of growing concern and a massive challenge. In developing countries, there is a direct need to develop reliable technologies with low-cost implementation and simple operation (Gopala-Krishna et al., 2008). In view of the urgent need to build municipal sewage treatment plants, it is essential to have on hand various technological tailor-made options suited for local conditions.

These options should offer low-cost implementation, simple operation and produce final effluents that meet established standards. No single technological solution will be universally applicable.

One option for on-site primary sanitation in low-income countries is the Anaerobic Baffled Reactor (ABR). McCarty and coworkers at Stanford University (McCarty, 1981) developed the ABR. The reactor system consists of a series of vertical baffles. These baffles form a number of up flow and downflow compartments to make wastewater flow under and over them as it passes from the inlet to outlet. During up flow, wastewater flows through an anaerobic sludge blanket, which, because of the design, is retained within the reactor. The ABR is a high-rate bioreactor with many advantages over other municipal wastewater reactor systems: longer biomass retention times, lower sludge yields, better resilience to hydraulic and organic shock loadings, very low concentration of Volatile Fatty Acids (VFA) in the effluent, low HRT, intermittent operation possible,

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simple design and minimal maintenance, low capital and operational costs. A significant advantage of the ABR is the separation of acidogenesis and methanogenesis longitudinally down the reactor, allowing the different bacterial groups to develop under favorable conditions (Barber and Stuckey, 1999; Jianzheng et al. 2012; Qi et al., 2013; Wang et al., 2004). Many publications have revealed the potential of ABR for municipal wastewater treatment (Baloch, 2011; Bodkhe et al. 2009; Cao et al., 2011, Gopala Krishna et al., 2008; Liu et al., 2010; Qi et al., 2013; Sabry, 2010). However, the lack of a further polishing step makes it usually not suitable for real applications.

The combination of anaerobic and aerobic processes in the same unit has been already studied in order to reach better process stability and performance efficiency. Some examples of anaerobic-aerobic treatment of municipal wastewater already studied are: UASB followed by biofilm airlift suspension reactor (Zhou et al., 2006) UASB followed by aerated solids contact chamber and a clarifier (La Motta et al., 2007), membrane coupled anaerobic baffled reactor (Liu et al., 2016; Pillay et al., 2008) or hybrid aerating membrane-anaerobic baffled reactor (Hu et al., 2009).

The anaerobic/aerobic baffled reactor (AABR) was designed in an attempt to ensure stable effluent characteristics and optimize advantages present in ABR, (Seghezzo et al., 1998). The AABR combines anaerobic processes, with low sludge production and a high degree of stabilization, with a final aerobic process, which fosters good quality of treated effluent (Seghezzo et al., 1998; Von Sperling et al., 2006).

The main objective of this study was to examine the AABR applicability as on-site primary sanitation in a low-income community treating real municipal wastewater, focusing in on the effect of hydraulic residence time (HRT) on reactor performance and stability.

2. Material and methods

2.1. Reactor set-up

A 2.5 m^3 concrete reactor with four sequenced chambers was built, the first three anaerobic chambers and the fourth aerobic with an effective volume of 1.0, 0.50, 0.50 and 0.50 m^3, respectively (Fig. 1). The external dimensions were 3.06 m length, 1.30 m height, and 1.50 width. Right after the aerobic chamber, a laminar settling tank of 0.5 m^3 completes the treatment system. The laminar system tank was composed of polypropylene blades, 2mm thick, set 50mm apart, leaning at 60° horizontally. The sludge captured in the laminar settling tank is lead taken to the aerobic chamber in the reactor in order to stabilize the sludge and retain high active biomass quality in the system. The reactor anaerobic chambers are a series of UASBs. They consist of three vertical baffles to force the wastewater to flow under and over them as it passes from the inlet to the outlet. The wastewater can then come into close contact with a large amount of active biomass, while the effluent remains relatively free of biological solids (Liu et al 2010). A system comprised of an air diffuser placed at the bottom of the aerobic chamber, with two tubes (PVC), 64 mm in diameter and 980 mm long, arranged parallel at a distance of 100 mm between each other, aerated the aerobic chamber. A compressor with a reservoir, for commercial use of 175 liters and maximum pressure of 120 lbf/pol^2 supplied the air

The AABR was installed and operated at Graminha wastewater treatment plant (WWTP) in the city of Limeira, Sao Paulo, Brazil, receiving municipal wastewater (Table 1). The AABR had an ambient temperature that varied during the year from 15 to 29°C, the working temperature in the reactor. One of Limeira main economic activities is the production of handmade faux jewelry, frequently in small home shops.

Chemical products used are partially disposed in the sewage collecting system without pre-treatment. According to measurements taken prior to the present study, there have been sporadic sharp drops in pH, up to 1.7, in this sewage. During this study similar situations did not occur due to correction in pH levels of wastewater before entering the WWTP. The pH influent was randomly male corrected with calcium oxide by the WWTP operator. The pH influent of the studied reactor ranged values from 3.1 to 5.9, still outside the range considered ideal for methanogenic arqueas, but without extreme values such as 1.7. All those data indicate that the chemical product discharges are random and unpredictable.

2.2. Reactor operation

The AABR was operated at various hydraulic retention times (HRTs) by varying the flow rate of influent wastewater (I), thereby varying the organic loading rate (OLR). During the total period of AABR operation (444 days), the performance evaluation of AABR was carried out at 5 different HRTs. A by-pass in the third anaerobic chamber was built to study different HRTs in anaerobic and aerobic chambers separately. The different periods of the study were characterized by HRT variations used in the anaerobic and aerobic phases described in Table 2. Clogging problems occur in period 2, a period not used for discussion in the present study.

Five sample points were selected: Influent (I); chamber 1 exit (C1), chamber 2 exit (C2), chamber 3 exit (C3), the three located 1.0 m from the bottom of the reactor; and treated effluent (E) (Fig. 1). Samples were taken once a week. pH, total alkalinity, VFA, COD, and total suspended solids (TSS) were monitored for I, C3 and E sample points. VFA and pH were monitored for C1 and C2 sample points.

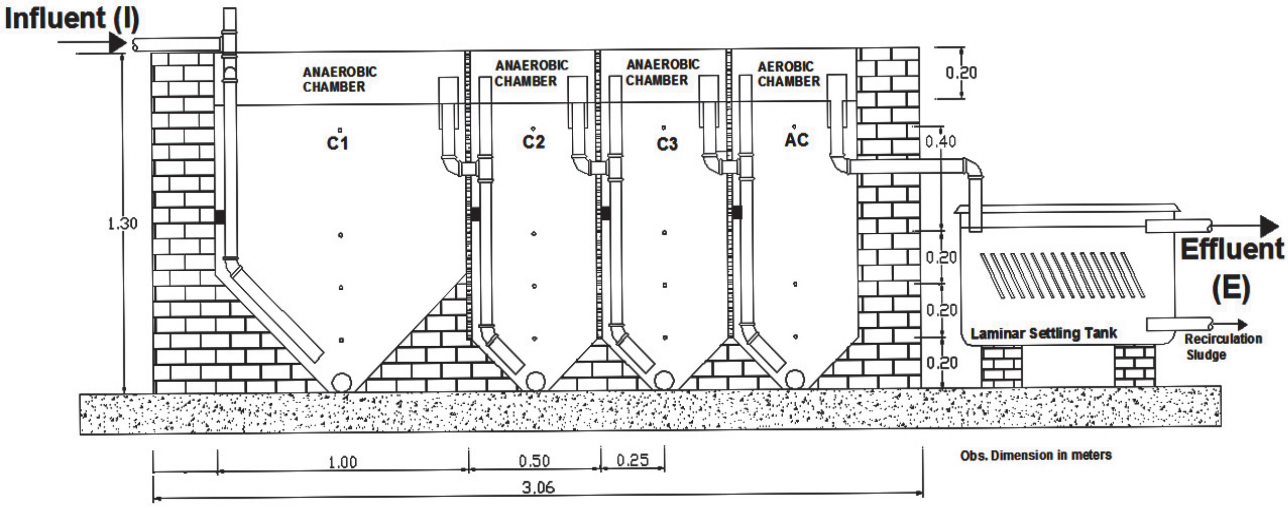

Fig. 1. Anaerobic-Aerobic Baffled Reactor profile

Table 1. Physical-chemical characteristics of municipal wastewater

Parameters	*Ranges*
Temperature (ºC)	18 – 30
pH	5.4 – 8.3
BOD_5 (mg L^{-1})	187 – 967
BOD_5/COD	0.20 – 0.65
COD (mg L^{-1})	455 – 1523
Alkalinity (mg L^{-1} as $CaCO_3$)	27 – 354
VFA (mg HAc L^{-1})	41 – 219
TSS (mg L^{-1})	178 – 398
VSS (mg L^{-1})	153 – 346

2.3. Analytical methods

Methodologies applied to determine pH, total alkalinity, COD, and total suspended solids (TSS) are presented in Standard Methods (2005). Partial alkalinity (pH 5.75) and VFA, were determined following Ripley (1986) and DiLallo (1961), respectively.

3. Results and discussion

3.1. Organic matter removal

3.1.1. COD removal percentage

The average COD removal percentage during the whole study in the 3rd chamber, i.e. partial removal in the anaerobic phase, and in the effluent, i.e. total removal, was 54 ± 14% and 68 ± 13%, respectively (Table 3). After the anaerobic chambers in period 1, with 8 hours HRT in the anaerobic phase, the average removal percentage was 56 ± 13% (Table 3). During the first 21 days of period 3 operation, with the same HRT, the average removal percentage after the anaerobic chambers was much lower, i.e. 27 ± 11%. This reduction is more likely due to the failure of period 2 operation. The average removal percentage increased to 54 ± 12% from those 21 days of period 3 operation till the end of period 3. A further reduction in HRT of the anaerobic phase was done in period 4, i.e. after 315 days of operation (Fig. 2). This HRT reduction was from 8 to 4 hours. During period 4, the removal percentage was a little higher than the previous period, i.e. 58 ± 15%.

This behavior agreed with Barber & Stuckey (1998), even with low HRT in ABR they obtained high removal efficiencies at low hydraulic retention times (2-6h). Foxon (2006) who studied an ABR treating municipal wastewater in Kingsburgh WWTP – South Africa also observed that effluent COD concentration decreased with less hydraulic retention time, this behavior can be explained by the improving reactor performance as a result of establishing sludge populations, rather than a function of loading. According to Boopathy and Sievers (1991), an ABR with two compartments provided a shorter solids retention time and lower performance than an ABR with three chambers. This was in contrast to findings of Sievers, 1988, when no difference was found in treatment efficiency compared with compartment number of an ABR system.

According to these papers found in the literature there is no consensus about the increase in the reactor efficiency with increasing number of baffles. Langenhoff et al. (2000) and Sarathai et al (2010) obtained removal efficiency of COD higher than 75%, in an ABR system, however these authors had worked with diluted colloidal wastewater and synthetic wastewater.

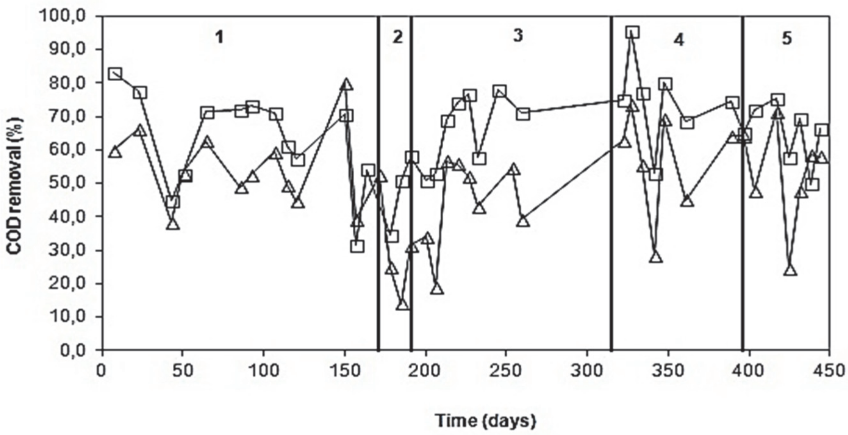

Fig. 2. COD removal (%) over time: (Δ) C3 and (□) Effluent

Table 2. Periods in anaerobic/aerobic baffled reactor operation during the study

Period	*HRT (h)*			*Operation time (days)*	*Accumulated operation time (days)*
	Anaerobic chambers	*Aerobic chambers*	*Total*		
Total	-	-	-	444	
1 – HRT_1	8	2	10	171	171
2 – HRT_2	12	4	16	20	191
3 – HRT_3	8	4	12	124	315
4 – HRT_4	4	4	8	81	396
5 - HRT_5	4	3	7	48	444

Table 3. Average values for COD removal percentage in the 3rd chamber (partial removal) and in the effluent (total removal) of the treatment system in periods 1, 3, 4, 5 and whole study.

Collection Point	*Period*				
	1 – HRT_1	*3 - HRT_3*	*4 - HRT_4*	*5 - HRT_5*	*Whole study*
C3	56 ± 13%	48 ± 16%	58 ± 15%	52 ± 7%	54 ± 14%
Effluent	65 ± 15%	68 ± 11%	74 ± 12%	65 ± 10%	68 ± 13%

After the Aerobic chamber in period 1, with 2 hours HRT in the aerobic phase, the average COD removal percentage was 65 ± 15% (Table 3). The increase of HRT in the aerobic chamber from 2 to 4 hours, i.e. from period 1 to 3 and 4, caused little change in average efficiency of total COD removal in relation to average values, i.e. 68 ± 11% and 74± 12%, respectively (Table 3). When HRT was altered from 4 to 3 hours, i.e. from period 4 to 5, there was a small decrease in average efficiency of total COD removal (Table 3).

The AABR was not able to treat municipal wastewater to an acceptable chemical standard, which for Brazilian standards is 80% BOD removal. Nevertheless 74% COD removal was obtained in period 4. The low partial COD removal after the anaerobic phase compared to other studies has to be improved in order to reach the final 80% COD removal. The reduction of COD in the aerobic phase, i.e. 13-16%, was comparable to the reduction in anaerobic/aerobic systems reported in the literature ranged between 9-22 % (Tandukar et al., 2006; Tawfik et al., 2006a; 2006b; Von Sperling et al., 2001).

3.1.2. Total Suspended Solids (TSS)

The influent of TSS concentration ranged from 178 to 398 mg L^{-1}. Average removal values of total TSS were 79, 71, 85, 80%, for period 1, 3, 4 and 5, respectively (Fig. 3). TSS concentrations in the treated effluent were in the range of 53–67 mg L^{-1}. TSS concentrations in the treated effluent were observed to be unaffected by the varying TSS concentrations in influent wastewater. Sarathai et al (2010) used an ABR with one settling chamber and three up-flow chambers to treat synthetic wastewater (sucrose) with TSS influent concentration of 568 ± 84 mgL^{-1} achieving a TSS removal efficiency of 90 %. This 90% TSS removal was obtained with 48 hours HRT. In the present study, with an HRT as low as 8 hours, a similar TSS removal was obtained.

3.1.3. Reactor operation stability

The stability of reactor operation has been evaluated by VFA, pH and alkalinity profiles over time.

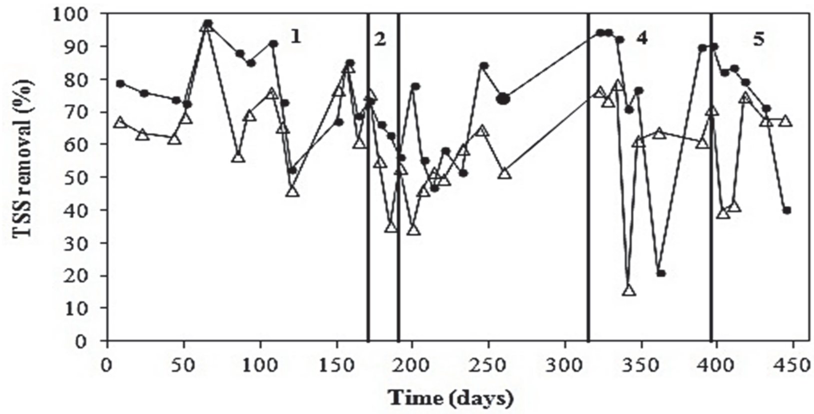

Fig. 3. TSS removal over time. (Δ) C3 and (•) effluent

3.1.3.1. Volatile Fatty Acids (VFA)

VFA concentration is a good indicator of proper anaerobic reactor functioning. Higher VFA values were observed in C2 and C1 compared to those in C3 (Table 4). The VFA values indicate that hydrolysis and acidogenesis were the main biochemical activities occurring in C1 and C2, as also observed by Baloch and Akunna (2003) and Bodkhe (2009) in a similar ABR. From period 1 (8 hours for anaerobic chambers and 2 hours for aerobic chamber) to period 3 (8 hours for anaerobic chambers and 4 hours for aerobic chamber) and period 4 (4 hours for anaerobic chamber and 4 hours for aerobic chamber) there was practically no change in VFA values.

In period 5, a VFA concentration increase was observed both in chamber 3 and at the system output due to a high concentration increase in the influent (Table 4). Nevertheless, the VFA value at the output was close to those found in previous periods, suggesting high stability in the system.

The aerobic chamber played a key role in VFA removal, as indicated by the concentration values at the output of both C3 and the effluent, 68 ± 26 mg HAc L^{-1} and 43 ± 19 mg HAc L^{-1} respectively. The aerobic treatment has strongly contributed to improve the quality of this effluent.

3.1.3.2. pH

Influent pH values during the whole reactor operation were in the range of 5.4-8.3, indicating that chemical product discharges in the sewage system were random and unpredictable. The effluent pH values were in the range of 6.5-7.5. It was observed that, in spite of variations in the effluent pH, the pH values for the treated effluent were quite stable. Stable pH values of C1, C2 and C3 implied the effective consumption of volatile fatty acids by methanogens in anaerobic chambers (Fig. 4). During the five monitoring periods and throughout the major part of the operations, most pH values ranged from 6.7 to 7.0, excellent measurements for the anaerobic process, and far from levels harmful to methanogenic arqueas activity (Fig. 4). The pH values observed in the present study indicate good stability and shock absorption in the system, supporting research done by Nachaiyasit and Stuckey (1997a, 1997b). This testifies to the considerable capacity of AABR to absorb pH variations in raw effluents, which is important in maintaining optimal metabolism conditions of anaerobic organisms, especially those involved in the methanogenic phase of the process.

3.1.3.3. Total alkalinity

Alkalinity levels indicate a potential anaerobic process failure. Low values of effluent alkalinity may warn about reactor failure. The data presented in Fig. 5 indicate a significantly high buffer capacity in the system so that pH variations, which occur in the influent, were more easily withstood.

The VFA/alkalinity ratio can be used as a measure of process stability (Björnsson et al., 2000; Bodkhe, 2009): when this ratio is less than 0.3–0.4 (equiv. acetic acid/equiv. $CaCO_3$) the process is considered to be operating favorably without acidification risk. The VFA/alkalinity ratio values in the present study were lower than the suggested limit value, showing the high stability of the AABR for all operating conditions assessed.

Table 4. Average values, standard deviations for volatile fatty acids (mg HAc L^{-1}) at the influent, C1, C2, C3, and effluent in periods 1, 3, 4 and 5

Collection Point	*Total Operation*	*1 – HRT_1*	*3 - HRT_3*	*4 - HRT_4*	*5 - HRT_5*
	A ±sd	*A ±sd*	*A ±sd*	*A ±sd*	*A ±sd*
Influent	81 ± 37	80 ± 14	57 ± 10	79 ± 31	134 ± 56
C1	86 ± 32	51 ± 2	79 ± 20	79 ± 33	125 ± 25
C2	79 ± 32	51 ± 21	80 ± 22	70 ± 27	117 ± 1
C3	68 ± 26	56 ± 20	68 ± 31	68 ± 28	93 ± 13
Effluent	43 ± 19	46 ± 24	37 ± 10	34 ± 16	57 ± 21

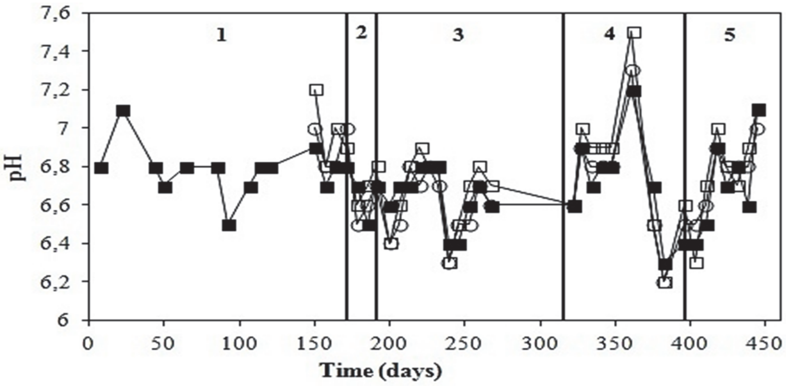

Fig. 4. pH values over time. (□) C1, (o) C2 and (■) C3

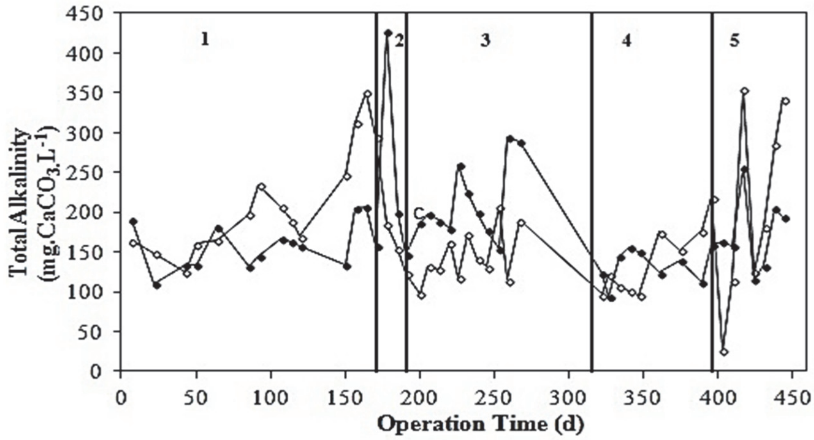

Fig. 5. Total Alkalinity over time: (◊) Influent and (♦) effluent

3.1.3.4. Reactor evaluation

- AABR is simple to operate and with considerably reduced installation, operation and maintenance costs compared to aerobic or centralized systems.

- AABR used in this study was not able to treat real municipal wastewater to an acceptable chemical standard. There must be an improvement in the anaerobic phase to achieve appropriate standard reuse.

- Regardless of the value on entering, the pH on emerging from the reactor remained close to 7 during the five periods, indicating good stability in the reactor.

- Increases occurring in organic and hydraulic loads were adequately absorbed, provoking no instability in the system and demonstrating good configuration for absorbing hydraulic and organic impacts.

- The reactor presents good flexibility in relation to HRT changes, which refer to removal efficiency of COD and TSS.

- The viability of this reactor configuration in promoting tertiary treatment is very promising.

- AABR can be useful as an economical solution for wastewater treatment in small communities. Further studies should be conducted to scale-up configuration and testing on a pilot scale reactor for wastewater treatment.

4. Conclusions

The reactor volume, its compactness and economy of operation depend upon the minimum HRT at which the reactor yields the designed treatment efficiency. To ensure cost-effectiveness of the reactor operation, selection of the most suitable minimum possible HRT is important.

In the present study an 8-hour HRT yields even better effluent quality than an HRT of 12 hours, most probably due to sludge acclimation, a decrease to 7 hours reduces the yield obtained at 8 hours. This indicated that an HRT of 4 hours for anaerobic chambers and 4 hours for the aerobic chamber was the most suitable minimum HRT for economic operation of the AABR.

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