EFFECT OF MEDIA ON TREATMENT OF SETTLED DOMESTIC SEWAGE USING HYBRIDIZED ANAEROBIC BAFFLED REACTORS

تأثير الوسط على معالجة مياه الصرف الصحى باستخدام المفاعلات اللاهوائية ذات الحواجز

Kamal Radwan*, Ahmed Fadel and Khalid Hassan*****

* Assistant Prof. of Sanitary Engineering, Faculty of Engineering, University of Mansoura.
** Prof. of Sanitary Engineering, Faculty of Engineering, University of Mansoura.
***Assistant Prof. of Sanitary Engineering, Higher Institute of Eng., Shorouk Academy

الملخص: يهدف هذا البحث الحصول على تكنولوجيا منخفضة التكاليف لمعالجة مياه الصرف الصحى للتجمعات الصغيرة أو الريف المصرى٠ و تم استخدام المفاعلات اللاهوائية ذات الحواجز و الوسط حتى نحصل على أنسب نظام للمعالجة و ذلك باستخدام وسائط بلاستيكية و زلطية بمساحة سطحية نوعية ١٠٠ ، ٨٠ م٢/م٣ على الترتيب٠ و يتكون نظام المعالجة من خزان تغذية سعة ٢ م٣ يوزع على عدد (٤) مجموعات منها مجموعتان بهما وسط زلطى بأحجام مختلفة و المجموعة الثالثة بدون وسط و الأخيرة بها وسط بلاستيكي ٠ تركيز المياه الداخلة لمجموعات المعالجة حوالى ٣٠٠ مجم /لتر من الأكجسين الكيميائى الممتص٠ و زمن المكث الهيدروليكى يتراوح من ٠,٥الى ٣,٥ يوم و الحمل العضوى ٠,٠٥ الى ٠,٢٥ كجم/م٣/يوم من الأكجسين الحيوى الممتص٠ و قد وجد أن أفضل نتائج إزالة للمواد العضوية كانت لمجموعة الوسط البلاستيكى يليها الوسط الزلطى ثم بدون وسط٠ نجد أن هذا النظام من المعالجة يكون مناسبا فنياو إقتصاديا للتجمعات الصغيرة و التى يقل تعداد سكانها عن ٥٠٠٠ نسمة٠

ABSTRACT

This research work aimed at obtaining a low cost sustainable technology for domestic wastewater treatment for Egyptian rural areas. To make this come through, a high rate hybirdized anaerobic baffled reactor (HABR) was pilot tested for a period of about 18 months in order to assess the state of art and the technical and economic efficiency of this system. This pilot reactor consisted of four reactors with different media (HABR1, HABR2, HABR3 and HABR4) were constructed and each reactor had a total volume of 800 liters and consists of four compartments. Plastic media and gravel were used and had specific surface area of 100 and 80 m^2/m^3 respectively. The average influent COD concentration was about 300 mg/l. The overall HRTs tested were 3.5, 2.5, 1.0 and 0.5 days with average influent organic loadings in the range from 0.05 to 0.25 Kg

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BOD_5/m^3.day. High substrate removal rates can be achieved in a HABR fed with low substrate levels of only 300 mg/lit of COD. At an HRT of 3.5 days, HABR1 with plastic media gave an average BOD_5 removal rate of 79% with an effluent of 25 mg/lit. This was the highest removal value recorded as the other reactors HABR2, HABR3 and HABR4 gave 60.5%, 71.5% and 75.6% respectively for the same HRT. In a likewise manner, the COD removal rates recorded at the same HRT were 85.7%, 80%, 83.3% and 85.7% respectively. Suspended solids removal rates were the highest and recorded a value of 90.3% for a HRT of 3.5 days for HABR1. At the same HRT the removal rates for HABR2, HABR3 and HABR4 were 76.8%, 86.5% and 89% respectively. For HABR1 the BOD_5 removal rates dropped from 79% at a HRT of 3.5 days to about 50.5% at a HRT of 0.5 days. This was also the case with the other three reactors and the lowest removal rate recorded was 33.7% for HABR2 at an HRT of 0.5 days. The highest COD value recorded was at a HRT of 0.5 days for HABR2 with a value of 101.2 mg/lit. While the highest SS value recorded was 72.4 mg/lit with a percentage removal of 58.8% for HABR3 at a HRT of 0.5 days. This system provides potential attractive possibilities for application in small communities with a population of less than 5000 capita.

KEYWORDS : Sustainable technology, hybirdized anaerobic baffled reactor (HABR), plastic media, compartment, organic loading, small communities.

1. INRODUCTION

Obviously, many small communities in Egypt need to be served with a sewerage system to a certain extent. Nonetheless, the extent to which this will be brought to practice needs reconsideration. In fact, an alternative wastewater treatment concept needs to be profitably integrated with an overall sewage master plan. This concept must lead to the treatment and reuse of wastewater from small communities with a population of about 5000 capita or less, as this small communities are not formatted in any future master plans within the Egyptian sanitation sector due to their high per capita costs with regards centralized conventional sewerage systems.

The start-up of anaerobic reactors can be satisfactorily achieved in very short times if adequate inoculum is available [1]. Nonetheless, inoculation with active biomass was not shown to be a prerequisite to start-up of anaerobic reactors for sewage treatment [2]. An adequate construction of the reactor and a proper operation can eliminate completely the problem of bad odors in anaerobic reactors [3]. The term 'high-rate' was once used for the later designs of sewage sludge digesters, but it is now widely used to refer to anaerobic treatment systems meeting at least the following two conditions: (a) the ability to separate hydraulic retention time (HRT) from solids retention time (SRT). It is this separation that allows relatively slow growing anaerobic micro-organisms to remain within the reactor independently of the flow of wastewater, (b) proper contact between incoming wastewater and retained sludge [4]. Anaerobic treatment in high-rate reactors is increasingly recognized as the core method of an advanced technology for environmental protection and resource preservation, and it represents, combined with other proper methods, a sustainable and appropriate wastewater treatment system for developing countries [4-6]. It is often questioned why aerobic treatment of sewage is not replaced more rapidly by the economically more attractive and conceptually more holistic direct anaerobic treatment [7]. Anaerobic treatment would provide tremendous advantage over conventional aerobic methods. The costs of aeration and sludge handling, the two largest costs associated with aerobic sewage treatment, would be reduced dramatically because (a) no oxygen is needed in the process and (b) the production of sludge is 3-20 times smaller than in aerobic treatment [8]. Moreover, the sludge (biomass) produced in aerobic processes has to be stabilized in classic anaerobic sludge digesters before it can be safely disposed of, but it was shown to be very resistant to anaerobic degradation [9].

The HABR has both objectives of high rate anaerobic reactors by means of a design which is both simple and inexpensive to construct, since there are no moving parts or mechanical mixing devices. High rates of hydraulic throughput are possible with very little loss of bacteria from the reactor. Attractive possibilities for application are hotels, restaurants, urban residential districts, apartment buildings, offices, schools, hospitals, small rural communities with population of 5000 capita or less, remote cluster of houses .... etc.

The objectives of the present work is to study the applicability of the high rate/low cost anaerobic baffled reactor technologies with different media in treating domestic settled wastewater in Egypt. Reactors were monitored with respect to BOD_5, COD, SS removal and pH according to Standard Methods [10].

2. MATERIALS AND METHODS

The pilot plant constructed for this research work was situated at the site of the Nawag wastewater treatment plant. Nawag is a village situated 10 kms away from Tanta city. The method of wastewater collection system adopted in the village is the small bore sewer system. The wastewater treatment system adopted for the Nawag plant is the extended aeration activated sludge process. The pilot treatment plant was operated using domestic settled low strength wastewater. The pilot plant was operated with a retention time of 7.0 days. Due to the absence of any high rate anaerobic large scale projects in Egypt, the reactor was seeded with sludge from a septic tank.

The pilot plant as shown in Fig. 1 was then operated with this initial hydraulic retention time (HRT) of 3.5 days. This retention time gave a discharge of 0.23 m^3/day (158.7 ml/min). This low discharge gave an initial low loading rate of about 0.083 kg COD/m^3.day so that slow growing micro-organisms are not overloaded. This low organic load gave a low liquid up flow velocity so as to encourage flocculent, granular and attached growth within the reactor compartments. After completing the start-up phase and the system reaching the steady state, tests were conducted on the different parameters and then the HRT was decreased and organic load increased in a step-wise manner. The overall HRTs tested were 3.5, 2.5, 1.0 and 0.5 days. The four reactor trains (HABR1, HABR2, HABR3 and HABR4) were configured to operate in four different manners, Fig.1 as follows:

HABR1

In this reactor plastic media was used for the attached biomass growth. This media was placed in the upper two thirds water depth of the reactor. The media had a depth of 0.6m and was rested on a steel meshwork placed in the bottom of the tank. The plastic media used had the following specifications: Specific surface area = 100 m^2/m^3 and void ratio = 97 %.

HABR2

This reactor was operated without media, it was operated as an anaerobic baffled reactor without media.

HABR3

This reactor was operated with gravel media. The gravel was placed in the upper third water depth of the reactor. The depth of the media in this reactor was 0.3 meters. The characteristics of the gravel used in this reactor were as following: - Specific surface area = 55 - 70 m^2/m^3 and void ratio = 40 - 50 % .

HABR4

This reactor was operated using gravel media with the same specifications as that of the third reactor but the only difference is the depth of the media. In this reactor the media depth is double that used in the previous reactor, 0.6m.

HABR was constructed with a total volume of 0.8 m^3. To achieve the baffling configuration (compartmentation), each reactor was constructed from four circular plastic tanks placed in series with a net volume of 0.2 m^3 per tank, each tank had an inner diameter of 55.0 cms and a total depth of 105.0 cms and a net water depth of 85.0 cms, as shown in Fig.1. The tanks were spaced 30 cms apart in series with a drop of 3 cms in each tank in order to obtain smooth gravity flow. The tanks were shallow so as to maintain acceptable liquid and gas up flow velocities. The experimental parameters measured were COD, BOD, pH and SS. Analyses were carried out by the methods given in the Standard Methods.

3. RESULTS AND DISCUSSIONS

The hybrid anaerobic baffled reactor (HABR) described earlier were pilot tested for a period of about 540 days during which many variables were examined. In the following sections the results obtained from the experimental running of the pilot project will be discussed .

3.1 Start up Operations

The reactor was filled with sullage wastewater then the inoculum was fed gradually into the four chambers. Due to the absence of any functioning high rate anaerobic treatment plant, the inoculant used was accumulated sludge from septic tanks. The inoculum was fed in the reactor from the first to last compartment as follows: 100, 75, 50 and 25 liters respectively. The inoculum filled 31.25% of the reactor volume. After that the reactors were operated at a low organic loading rate which was initially used to enable a suitably flocculent or granular biomass to develop before the loading rates were increased. The initial start up retention time was seven days with an organic loading of 0.043 kg COD/m^3.day.

After about 15 days of operation, it was noticed that biomass characteristics had developed and the loading rate was steadily but gradually increased until an operational loading rate of 0.084 kg COD/m^3.day was achieved. This loading rate reflected a 3.5 day retention time. The reactors were then operated for a period of 39 days with this loading rate after which the reactors reached their steady state and the operational period began; this amounted to an overall start up period of about 54 days.

3.2 Effect of Hydraulic Retention Time on Substrate Removal

The reactors were then subjected to different operational loads at different retentions periods starting from 3.5 days and dropping to 0.5 days and the flow rates vary from 0.23 m^3/day to 1.6 m^3/day. In the following parts of this section, the performance of the four reactors under study are demonstrated for each retention time.

3.2.1 3.5 days retention time (Run # 1)

The reactors were operated at this retention time with a flow rate of 0.23 m^3/day for 57 days during which ten samples were collected and analyzed.

3.2.1.1 pH variations (Run # 1)

Throughout this stage of the experiment, the pH values remained reasonably stable in the four reactors under study with an average value of about 7.5. Fig. 2 shows the variation of the pH profile within the four compartments in the four reactors for this HRT. From the figure it can be noticed that the pH slightly decreased in the first two compartments and then maintained its level or slightly higher in the third and fourth compartments.

3.2.1.2 BOD_5 removal rates (Run # 1)

At this stage of operation, the pilot system gave good results for the BOD_5 removal. Fig. 3 shows the BOD_5 values recorded for the 57 days operation of the pilot system at HRT=3.5 days. From the figure we can deduce that HABR1 with plastic media gave the best results with an average percentage removal of 79%. The average influent BOD_5 value recorded for this stage of work is 119.18 mg/lit yielding a load of 0.034 kg BOD_5/m^3.day. The minimum effluent BOD_5 value was 25 mg/lit and that was in HABR1. The percentage removal values recorded for HABR2, HABR3 and HABR4 were 60.5%, 71.5% and 75.6% respectively.

3.2.1.3 COD removal rates (Run # 1)

During this run that lasted for 57 days as mentioned earlier, COD removal rates were identical to those obtained in the previous section. The average influent COD value recorded for this run was 300 mg/lit yielding an average loading rate of 0.086 kg COD/m^3.day. From Fig. 4 we can deduce that HABR1 gave the best removal rates with a percentage of 85.7% followed by HABR4, HABR3 and HABR2 with removal percentages of 84.7%, 83.3% and 80% respectively. Again we can notice that the removal efficiencies of HABR3 and HABR4 are almost the same and are slightly lower than that recorded in HABR1. The average effluent COD value recorded was 43 mg/lit. A great portion of the removal was achieved in the first two compartments as mentioned in the previous section.

3.2.1.4 SS removal rates (Run # 1)

During this run, all four reactors gave promising effluent suspended solids (SS) values. Chronologically, in the same manner as discussed in the previous sections, HABR1 gave the best result with an average effluent value of 17 mg/lit yielding a percentage removal of 90.3%. The average influent SS value recorded for this run was 175 mg/lit. The average removal percentages recorded for HABR2, HABR3, and HABR4 are 76.8%, 86.5% and 89% respectively. Fig. 5 shows the influent and effluent values recorded for this run.

3.2.2 2.5 days retention time (Run # 2)

This run commenced directly after the first run. The system was adjusted for the second run with a flow of about 0.32 m^3/day. The system was allowed to run for about two weeks to reach its steady state, after that samples were collected. This run lasted for about 63 days.

3.2.2.1 BOD_5 removal rate (Run # 2)

BOD_5 removal rates recorded in this run were all promising as those obtained in the first run. The average influent BOD_5 recorded was 119.18 mg/lit yielding an organic load of 0.05 kgBOD_5/m^3.day. Fig. 6 shows the results obtained during operation of the system. The BOD_5 removal percentage dropped to 73%, recording a drop of about 6% from the first run. The average effluent BOD_5 recorded was 32 mg/lit while the recorded percentage removals of HABR2, HABR3 and HABR4 were 56.5%, 67.3% and 70.6% respectively. Again it can be noticed that the reactor with the plastic media gave the best results. This can be attributed to the fact that the plastic media with a high specific surface area (100 m^2/m^3) play a very important role in the substrate removal.

3.2.2.2 COD removal rate (Run # 2)

The COD removal rate during this run didn't exhibit marked difference from the sequence recorded during the pervious run. With the average value almost similar to that of the first run, the removal rates in the fourth reactor were slightly higher than those recorded by HABR1. An average effluent value of 49 mg/lit was recorded by HABR4 yielding an average removal percentage of 83.6%. HABR1 gave an average removal efficiency of 83%. While HABR3 and HABR2 gave an average removal efficiency of 81.3% and 77.6% respectively. Fig. 7 shows a profile of the COD values recorded during the run.

3.2.2.3 SS removal rate (Run # 2)

This run experienced good promising results as those obtained from the previous run. The highest average removal efficiency recorded was that of HABR1 with a value of 85%. While the average lowest recorded value was that of HABR2 with an average of 72.3%. The average influent value recorded for this run was 175 mg/lit with an average effluent of 26.2 mg/lit. HABR3 and HABR4 gave intermediate results of 79.3% and 82% respectively. Fig. 8 shows the influent and effluent suspended solids value recorded during this run.

3.2.4 1.0 day retention time (Run # 3)

This run lasted for about 28 days after reaching its steady state period. During this run, the discharge was adjusted to 0.8 m^3/day that gave an organic loading of 0.285 kg COD/m^3.day. The results obtained during this run were higher than those obtained in the previous runs and, generally, as the retention time decreases the removal percentages decrease with a proportional increase in the effluent values.

3.2.4.1 BOD_5 removal rates (Run # 3)

The BOD_5 removal rate during this run dropped by about 6.5% compared with the previous run. The reactor was operated at a loading rate of 0.12

kg BOD_5/m^3. day. The maximum removal efficiency attained was 60.5% and that was in the HABR1. This removal efficiency gave an average effluent value of 47 mg/lit. Other removal efficiencies were very low; HABR2 gave the lowest removal rate with an average of 38.7%. While HABR3 and HABR4 gave 45% and 50.5% respectively. Fig. 9 shows the influent and effluent values recorded during this run.

3.2.4.2 COD removal rates (Run # 3)

During this run, the reactors were operated at a loading rate of 0.285 kg COD/m^3.day. This run gave slightly high COD effluent values with the average lowest effluent value recorded being 69.8 mg/lit. The recorded COD removal rates during this run for the four reactors, HABR1, HABR2, HABR3 and HABR4, were 76.7%, 71.6%, 73.3% and 75% respectively. Fig. 10 shows the influent and effluent COD values recorded during this run.

3.2.4.3 SS removal rates (Run # 3)

During this run the water was clearly turbid in all the samples collected. The average lowest effluent value recorded was 40 mg/lit in HABR1 yielding a percentage removal of 77.5%, The other three reactors HABR2, HABR3 and HABR4 gave 70.2%, 70% and 74.4% respectively. Reactors two and three gave similar removal during this run. Fig. 11 shows the influent and effluent values recorded during this run.

3.2.5 0.5 day retention time (Run # 4)

This run was conducted after the fourth run directly with a time gap of about one week for the system to reach its steady state. Similar to the previous run, this run was operated for a period of 28 days. During this run, the flow was adjusted at 1.6 m^3/day that gave an organic loading of 0.6 kg COD/m^3.day. It was noticed that the effluent values recorded during this run were above those recommended by the Egyptian standards except for HABR1. Thus it was decided to stop the runs at this stage.

3.2.5.1 BOD_5 removal rates (Run # 4)

During this run, the BOD_5 values monitored gave unpromisingly high results. HABR1 with the best results gave a removal percentage of 50.5%. This low removal ratio gave an average effluent value of 59 mg/lit. The values recorded for HABR2, HABR3 and HABR4 were 33.7%, 38.7% and 44% respectively. The average influent value recorded during this run was 119.18 mg/lit yielding an organic load of

0.24 kg BOD_5/m^3.day. Fig. 12 shows the influent and effluent BOD_5 values recorded during this run.

3.2.5.2 COD removal rates (Run # 4)

At this low hydraulic retention time coupled with the increased organic loading, the system gave high effluent COD values. The average recorded effluent values for the four reactors were 78.72 mg/lit, 101.2 mg/lit, 85 mg/lit and 85 mg/lit respectively. It can be seen that both HABR3 and HABR4 gave the same values. The average influent COD value recorded was 300 mg/lit yielding an organic load of 0.6 kg COD/m^3.day. Fig. 13 shows the influent and effluent COD values recorded during this run.

3.2.5.3 SS removal rates (Run # 4)

The average influent suspended solids value recorded for this stage was 175 mg/lit. While the removal percentages recorded for the four reactors were 73.3%, 61.5%, 58.8% and 70.3% respectively. Fig. 14 shows the influent and effluent SS values recorded during this stage of operation.

3.3 Summary of BOD_5 and COD Removal

It was visible during the five runs conducted that the hydraulic retention time was directly proportional with the reactors efficiency. However, the overall total BOD_5 and COD removal from the wastewater was generally fair (50-79 % BOD_5 removal and 74-86 % COD removal with regards HABR1). The best performance was observed in HABR1 with a HRT of 3.5 days or a loading of 0.09 kg COD/m^3.day. The following tables and figures show the different correlations of the BOD_5 and COD within the four reactors at different HRTs. From the figures and tables it can be seen that when the retention time was decreased to 0.5 days the efficiency of the HABR dropped and the removal rates were comparatively poor. The relatively high BOD/COD ratio shown in Tables 1-4 of the treated effluent from the four reactors is indicative of the biodegradable nature of the residual BOD and COD. Fig. 15 shows the relation effluent BOD_5 and the organic loading rates while Fig. 16 shows the relation between the effluent COD and organic loading rates. From the figures it is clear that as the loading rate increases the effluent values increase in a directly proportional manner. This is similar to the results reported by [11-18].

Table 1: Overall COD and BOD_5 removal with varying HRT for HABR1

HRT (days)	Influent COD (mg/lit)	Influent BOD_5 (mg/lit)	Influent BOD/COD	Effluent COD (mg/lit)	Effluent BOD_5 (mg/lit)	Effluent BOD/COD	% COD Removal	% BOD_5 Removal
3.5	300	120.0	0.4	43	25	0.58	85.7	79
2.5	300	120.0	0.4	51	32	0.62	83	73
1.0	300	120.0	0.4	69.8	47	0.67	76.7	60.5
0.5	300	120.0	0.4	78.52	59	0.75	73.7	50.5

Table 2: Overall COD and BOD_5 removal with varying HRT for HABR2

HRT (days)	Influent COD (mg/lit)	Influent BOD (mg/lit)	Influent BOD/COD	Effluent COD (mg/lit)	Effluent BOD_5 (mg/lit)	Effluent BOD/COD	% COD Removal	% BOD_5 Removal
3.5	300	120.0	0.4	60	47	0.78	80	60.5
2.5	300	120.0	0.4	67	52	0.77	77.6	56.5
1.0	300	120.0	0.4	85	73	0.86	71.6	38.7
0.5	300	120.0	0.4	101	79	0.78	66.3	33.7

Table 3: Overall COD and BOD_5 removal with varying HRT for HABR3

HRT (days)	Influent COD (mg/lit)	Influent BOD_5 (mg/lit)	Influent BOD/COD	Effluent COD (mg/lit)	Effluent BOD_5 (mg/lit)	Effluent BOD/COD	% COD Removal	% BOD_5 Removal
3.5	300	120.0	0.4	50	34	0.68	83.3	71.5
2.5	300	120.0	0.4	56	39	0.70	81.3	67.3
1.0	300	120.0	0.4	80	65	0.81	73.3	45
0.5	300	120.0	0.4	85	73	0.86	71.6	38.7

Table 4: Overall COD and BOD_5 removal with varying HRT for HABR4

HRT (days)	Influent COD (mg/lit)	Influent BOD_5 (mg/lit)	Influent BOD/COD	Effluent COD (mg/lit)	Effluent BOD_5 (mg/lit)	Effluent BOD/COD	% COD Removal	% BOD_5 Removal
3.5	300	120.0	0.4	43	29	0.67	85.7	75.6
2.5	300	120.0	0.4	49	35	0.71	83.6	70.6
1.0	300	120.0	0.4	75	59	0.79	75.0	50.5
0.5	300	120.0	0.4	85	67	0.79	71.6	44

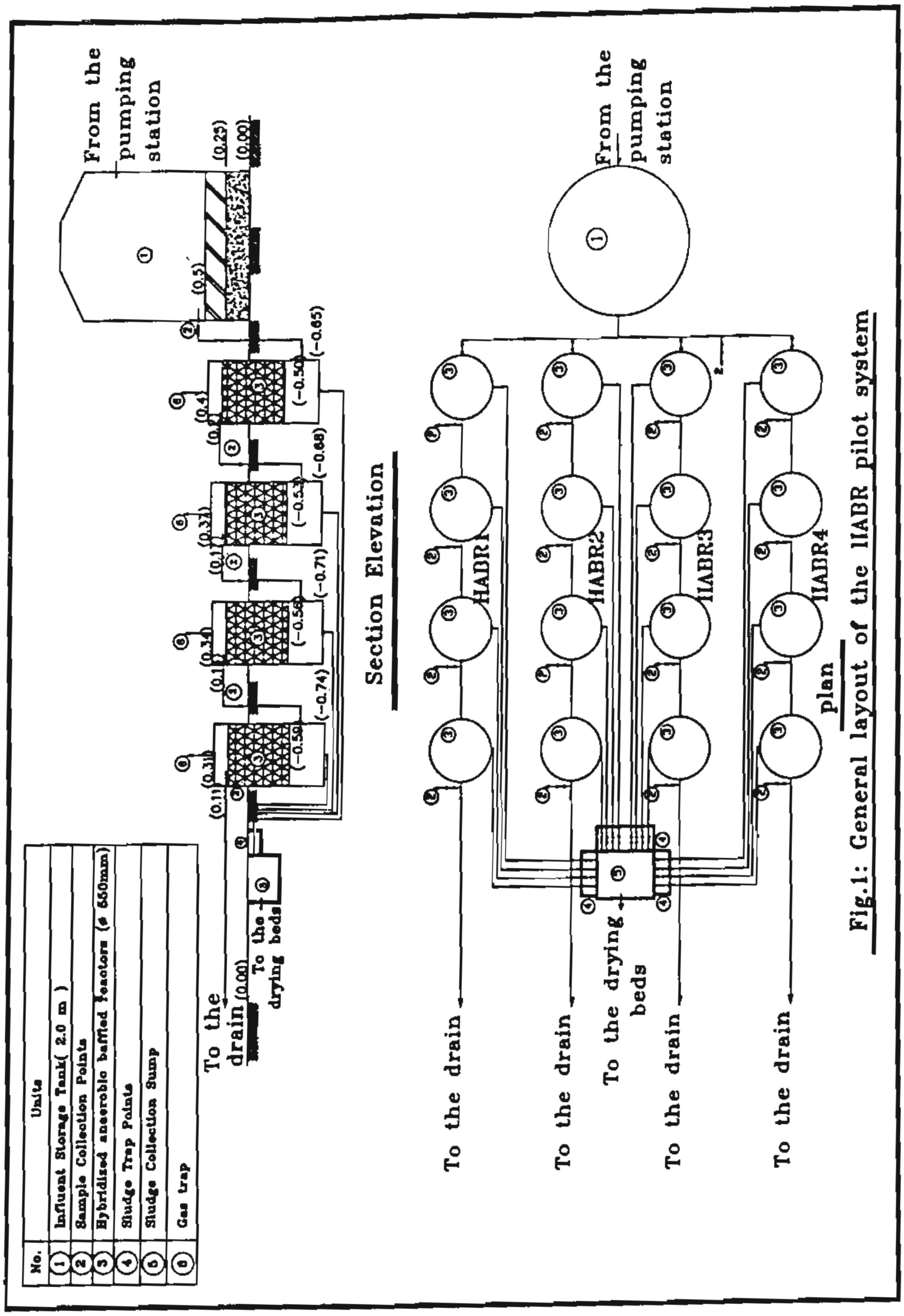

Fig.1: General layout of the HABR pilot system

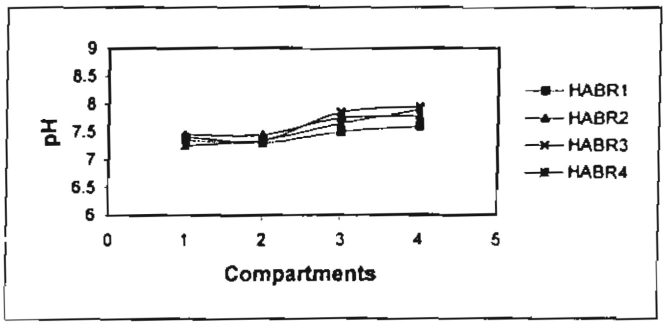

Fig. 2. Variation of the pH profile within the four compartments of the four reactors Run#1 (HRT = 3.5 days)

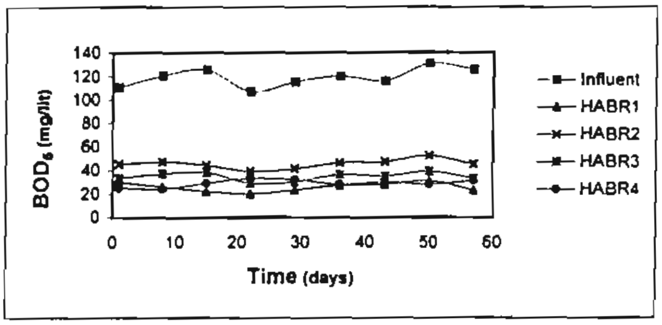

Fig. 3. BOD_5 Influent and effluent values recorded for Run#1 (HRT = 3.5 days)

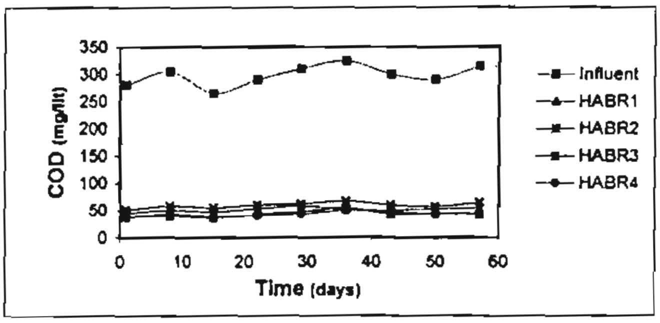

Fig. 4. COD Influent and effluent values recorded for Run#1 (HRT = 3.5 days)

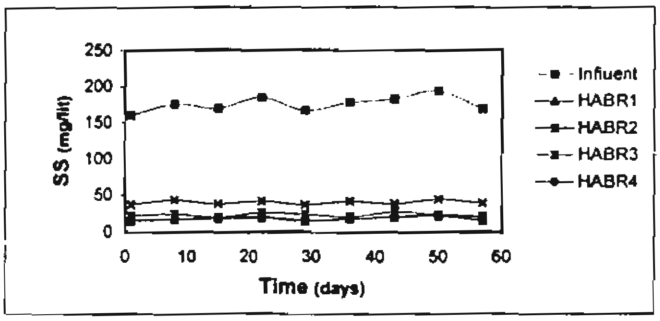

Fig. 5. SS influent and effluent values recorded for Run#1 (HRT = 3.5 days)

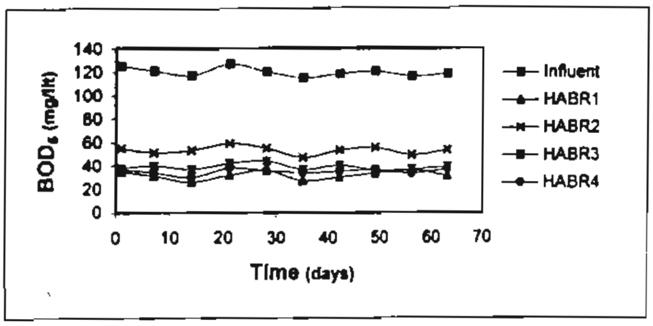

Fig. 6 Variation of the BOD_5 influent and values for Run#2 (HRT = 2.5 days)

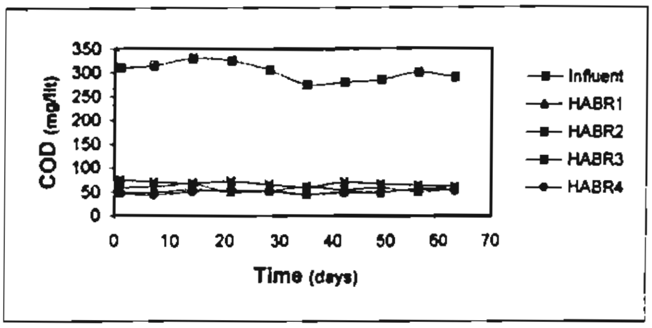

Fig. 7. Variation of the COD influent and effluent values within the four reactors for Run#2 (HRT = 2.5 days)

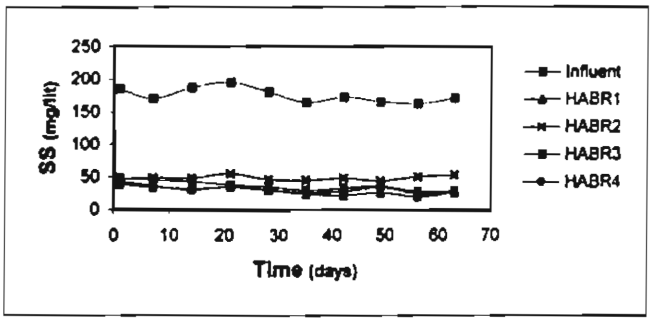

Fig.8. SS influent and effluent values recorded during Run#2 (HRT = 2.5 days)

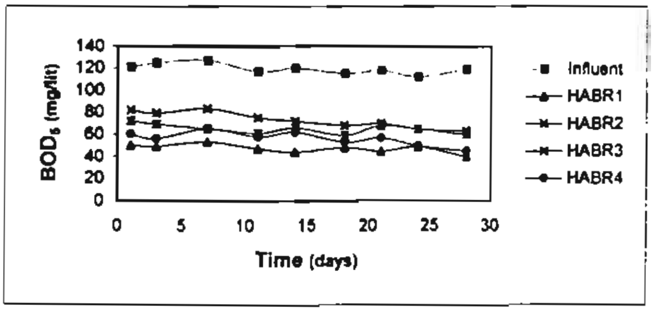

Fig. 9. Variation of the BOD_5 influent and effluent values for Run#4 (HRT = 1.0 days)

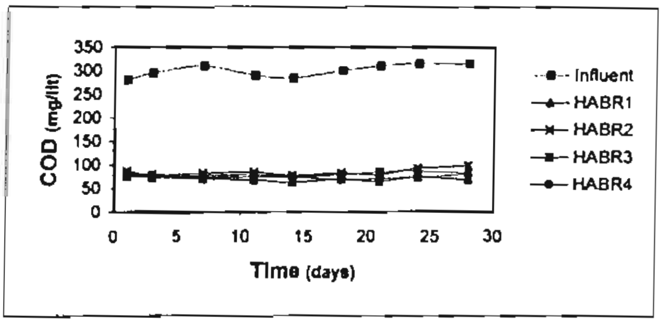

Fig. 10. Variation of the COD influent and effluent values for Run#4 (HRT = 1.0 days)

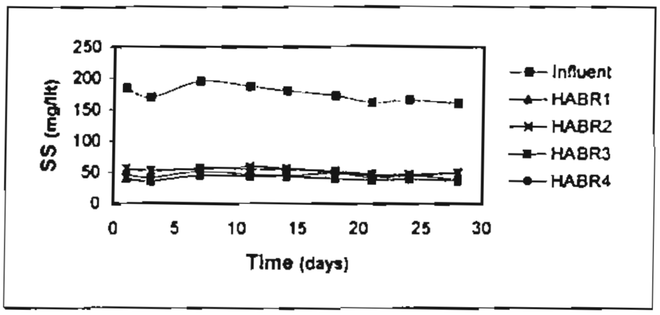

Fig. 11. Variation of the SS influent and effluent values for Run#4 (HRT = 1.0 days)

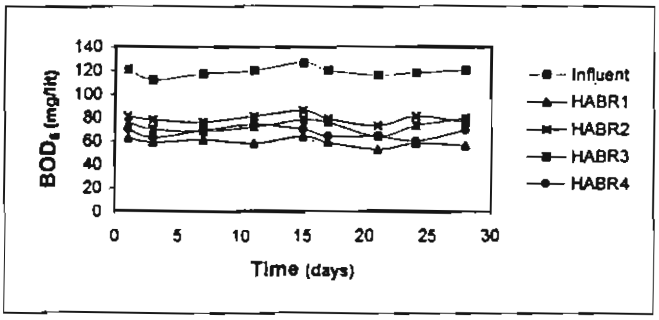

Fig. 12. Variation of the BOD_5 influent and effluent values for Run#5 (HRT = 0.5 days)

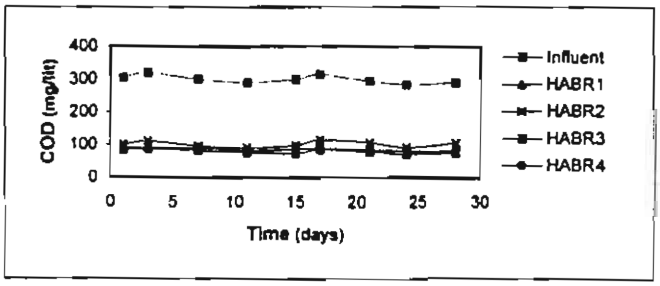

Fig. 13. Variation of the COD influent and effluent values for Run#5 (HRT = 0.5 days)

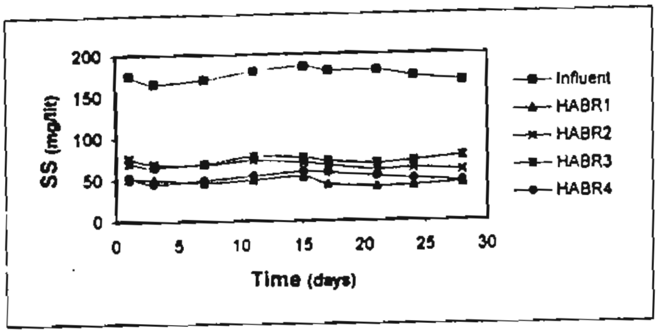

Fig. 14. Variation of the SS influent and effluent values for Run#4 (HRT = 0.5 days)

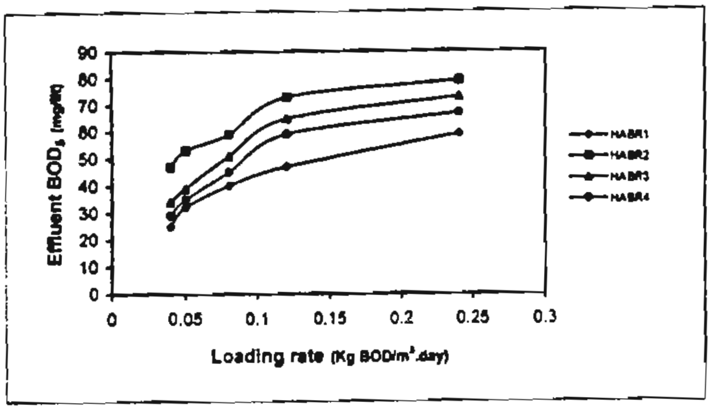

Fig. 15. Effluent BOD_5 Vs organic loading rate for the four reactors

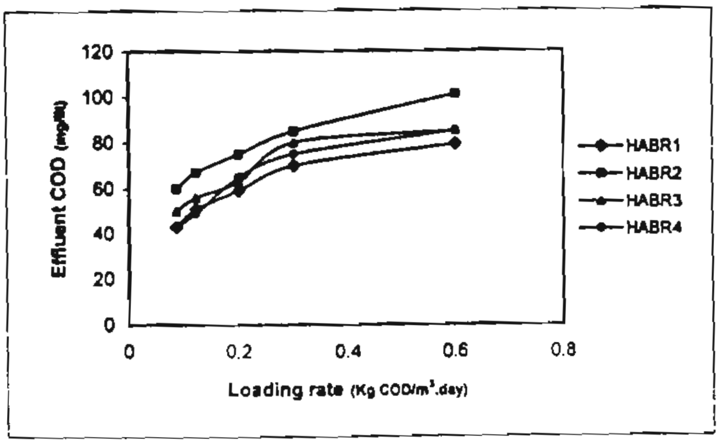

Fig. 16. Effluent COD Vs organic loading rate for the four reactors

4. CONCLUSIONS

Based on the experimental results obtained in this study, the following conclusions were drawn out:

1- High substrate removal rates can be achieved in a HABR fed with low substrate levels of only 300 mg/lit of COD.

2- HRT was found to have a direct effect on the subsrate removal rates.

3- At an HRT of 3.5 days, HABR1 with plastic media gave an average BOD_5 removal rate of 79% with an effluent of 25 mg/lit. This was the highest removal value recorded as the other reactors HABR2, HABR3 and HABR4 gave 60.5%, 71.5% and 75.6% respectively for the same HRT. In a likewise manner, the COD removal rates recorded at the same HRT were 85.7%, 80%, 83.3% and 85.7% respectively.

4- SS removal rates were the highest and recorded a value of 90.3% for a HRT of 3.5 days for HABR1. At the same HRT the removal rates for HABR2, HABR3 and HABR4 were 76.8%, 86.5% and 89% respectively. The lowest average effluent SS value recorded was 17 mg/lit.

5- For HABR1 the BOD_5 removal rates dropped from 79% at a HRT of 3.5 days to about 50.5% at a HRT of 0.5 days. This was also the case with the other three reactors and the lowest removal rate recorded was 33.7% for HABR2 at an HRT of 0.5 days.

6- The highest COD value recorded was at a HRT of 0.5 days for HABR2 with a value of 101.2 mg/lit. While the highest SS value recorded was 72.4 mg/lit with a percentage removal of 58.8% for HABR3 at a HRT of 0.5 days.

7- The influent values recorded were almost constant with no any sharp vagaries and this is attributed to the presence of the septic tanks upstream each connection. The septic tanks act as pretreatment units which stabilize any sudden rise in substrate concentrations.

8- The high BOD/COD ratio of the effluent is an indicative figure of the high biodegradable nature of the effluent. This is due to the presence of some BOD_5 and COD fractions that cannot be removed by anaerobic digestion.

RFFERENCES

1. de Zeeum, W., "Acclimatization of anaerobic sludge for UASB-reactor start-up", *Ph.D thesis*, Wageningen Agricultural University, Wageningen, The Netherlands, 1984.
2. Louwe Kooijmans, J. and van Velsen, E. M., Application of the UASB process for treatment of domestic sewage under sub-tropical

conditions, the Cali case, Anaerobic Treatment: a grown up technology. Conference papers *(Aquatech , 1986)* , pp. 423-436, 1986.

3. Conil, P., "El control de olores en las plantas anaerobias de tratamiento de aguas residuales: estudios de casos, *Proceedings IV Seminario - Taller Larinoamericano Sobre Tratamiento Anaerobio de Aguas Residuales*, Bucaramanga, Colombia, pp. 143-158 (In Spanish); 1996.
4. Lettinga, G., de Man, A., Grin, P. and Hulshoff Pol, L., "Anaerobic wastewater treatment is an appropriate technology for developing countries", *Trib. Cebedeau*, **40**(514),pp. 21-32, 1987.
5. Lettinga, G., de Man, A., van der Last, A. R. M., Wiegant, W., van Knippenberg, K., Frijns andss van Buuren, J. C. L., "Anaerobic treatment of domestic sewage and wastewater", *Water Science and Technology*, **27**(9),pp. 67-73, 1993.
6. Lettinga, G., Hulshoff Pol, L. W., Zeeman, G., Field, J., van Lier, J. B., van Buuren, J. C. L., Janssen, A. J. H. and Lens, P., Anaerobic treatment in sustainable environmental pollution concepts, *Proceeding of the 8th International Conference on Anaerobic Digestion*, Sendui, Japan, Vol. 1, pp. 32-39, 1997.
7. Mergaert, K., Vanderhaegen, B. and Verstraete, W., "Applicability and trends of anaerobic pretreatment of municipal wastewater", *Water Research*, **26**(8), pp.1025-1033, 1992.
8. Rittmann, B. E and Baskin, D. E., Theoretical aspects of anaerobic treatment of sewage, Proceedings of the seminar / workshop on Anaerobic Treatment of Sewage, Amherst, USA , eds. M. S. Switzenbaum, pp. 55-44, 1985.
9. Sanders, W., van Bergen, D., Buijs, S., Corstonje, R., Gerrits, M., Hoogerwerf, T., Kanwar, S., Zeeman, G., van Groenestijn, J. and Lettinga, G., "Treatment of waste activated sludge in an anaerobic hydrolysis upflow sludge bed reactor", EWPCA-Symposium, sludge treatment and reuse, 1996 .
10. APHA, AWWA and WPCF, "Standard Methods: for the examination of water and wastewater", 18th edition, 1992.
11. Witthauer D. and Stuckey D. C., "Laboratory studies on anaerobic processes to treat dilute organic waster in developing countries", Study by IRCWD, EAWAG Dübendorf, Switzerland, 1982.
12. Bachmann A., Beard V. L. and McCarty P. L., "Performance characteristics of the anaerobic baffled reactor", Wat. Res. 19(1), pp.99-106, 1985.

13. Yang P. Y. and Moengangongo T. H., "Operational stability of a horizontally baffled anaerobic reactor for diluted Seine wastewater in the tropics", Trans. ASAE. 30(4), pp.1105-1110, 1987.
14. Yang X., Garuti G., Farina R., Parisi V. and Tilche A., "Process differences between a sludge bed filter and an anaerobic baffled reactor treating soluble wastes", 5th International Symposium on Anaerobic Digestion, Bologna, Italy, pp. 355-360, 1988.
15. Boopathy R. and Tilche A., "Anaerobic-digestion of high-strength molasses wastewater using a hybrid anaerobic baffled reactor", Wat. Res. 25(7), pp.785-790, 1991.
16. Garuti G., Dohanyos M. and Tilche A., "Anaerobic-aerobic combined process for the treatment of sewage with nutrient removal": the Ananox® process, Wat. Sci. Technol. 25(7), pp.383-394, 1992.
17. Nachaiyasit S. and Stuckey D.C., "Microbial response to environmental changes in an anaerobic baffled reactor (ABR)", Antonie van Leeuwenhoek, 67, pp. 111-1233, 1995.
18. Bae J. H., Song K. B. and Cho K. M., "Comparison of operational characteristics of UASB and ABR: organic removal efficiency and the variations of PH2 and PCO", Proceedings Digestion, Vol. 1, Sendai, Japan, pp. 164-171, 1997.