TREATMENT OF SETTLED DOMESTIC SEWAGE USING A HYBRIDIZED ANAEROBIC BAFFLED REACTOR (HABR)

معالجة مياه الصرف الصحي باستخدام المفاعلات اللاهوائية ذات الحواجز و الوسط

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الملخص: الغرض الرئيسي من البحث هو اختيار نظام منخفض التكاليف لمعالجة مياه الصرف الصحي للتجمعات الصغيرة أو الريف المصرى، و تم استخدام المفاعلات اللاهوائية ذات الحواجز و الوسط حتى نصل إلى أفضل الأسس التصميمية لهذا النظام فنيا و إقتصاديا. يتكون نظام المعالجة من خزان للتغذية سعة ٢ م٣ و يتغذى من مياه الصرف الصحي الخارج من خزانات تحليل و عدد (٤) خزانات بسعة ٢٠٠ لتر لكل منهم و تم استخدام وسط بلاستيكي بمساحة سطحية نوعية ١٠٠ م٢ /م٣ . و كان متوسط تركيز مياه المجارى الخام حوالي ٣٠٠ مجم/ لتر من الأكجسين الكيميائي الممتص، و زمن المكث الهيدروليكي يتراوح من ٠,٥ الى ٣,٥ يوم . و كانت نسبة إزالة المواد العضوية (كمية الأكجسين الحيوي الممتص) ٧٩% و بتقليل زمن المكث الهيدروليكي الى ٠,٥ يوم نجد تناقص نسبة الإزالة الى ٥٠,٥%. و نجد أن هذا النظام مناسب إقتصاديا للتجمعات الصغيرة و التى يقل تعداد سكانها عن ٥٠٠٠ نسمة.

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 hybridized 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. The reactor (HABR) was constructed with a total volume of 800 liters and consists of four compartments. The plastic media used had specific surface area = 100 m^2/m^3 . The average influent COD concentration was about 300 mg/l. The overall HRTs tested were 3.5, 2.5, 1.5, 1.0 and 0.5 days with average influent organic loadings in the range from 0.05 to 0.25 Kg BOD_5/m^3.day. At a HRT of 3.5 days, the

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HABR gave an average BOD_5 removal rate of 79% with an effluent of 25 mg/lit. In a likewise manner, the COD removal rate recorded at the same HRT was 85.7%. 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 system provided attractive possibilities for large-scale application within small communities with population less than 5000 capita in Egypt.

KEYWORDS : Sustainable technology, hybridized anaerobic baffled reactor, plastic media, sewage treatment, in small areas.

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 these 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.

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 (Lettinga, *et al.*, 1987, 1993, 1997). 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 (Mergaert *et al.*, 1992). 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 (Rittmann & Baskin, 1985). 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 (Sanders *et al.*, 1996).

The start-up of anaerobic reactors can be satisfactorily achieved in very short times if adequate inoculum is available (de Zeeum,1984). Nonetheless, inoculation with active biomass was not shown to be a prerequisite to start-up of anaerobic reactors for sewage treatment (Louwe Kooijmans & van Velsen, 1986). An adequate construction of the reactor and a proper operation can eliminate completely the problem of bad odors in anaerobic reactors (Conil, 1996). 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 (Lettinga *et al.*, 1987).

The HABR has both objectives of high rate anaerobic reactors by means of a design which is both simple and in expensive 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, hospital, 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 in treating domestic wastewater in Egypt and also to study the effect of stages/compartmentation on the removal of BOD_5, COD and SS.

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 wastewater treatment plant is situated 2 km away from the village in the southern direction. Nawag has a total population of about 17000 capita and the method of wastewater collection system adopted in the village is the small bore sewer system. This system is the first of its type in Egypt. Wastewater (settled) is collected from the septic tanks in the village via a network of small diameter gravity sewers. This sewers drain into one collector main which leads to the pump station. Settled wastewater collected in the pump station is conveyed via a 250 mm force main to the wastewater treatment plant. The wastewater treatment system adopted for the Nawag plant is the extended aeration activated sludge process. The pilot treatment plant under study was constructed on an area of about 25 m^2 within the premises of the wastewater treatment plant.

The pilot treatment plant was operated using settled domestic wastewater with negligible variable organic strength. This type of wastewater has undergone primary treatment within the septic tanks, thus the wastewater has low strength. The pilot plant was first put into operation on the 20th of June, 1999, with a retention time of 7.0 days. The pilot plant as shown in Fig. 1 was then operated with this initial hydraulic retention time (HRT) of 84 hours (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, 1.5, 1.0 and 0.5 days.

The reactor (HABR) was constructed with a total volume of 800 liters (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. 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, void ratio = 97 %. The experimental parameters measured were COD, BOD, pH and SS. Analyses were carried out by the methods given in the Standard Methods', 1992.

3. RESULTS AND DISCUSSIONS

The hybrid anaerobic baffled reactor (HABR) was 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 are discussed .

3.1 Start up Operations

The reactor was filled with settled 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 reactor was 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 was then operated for a period of 39 days with this loading rate after which the reactor reached its steady states 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 was then subjected to different operational loads at different retention periods starting from 3.5 days and dropping to 0.5 days and the flow rates varying from 0.23 m^3/day to 1.6 m^3/day. In the following parts of this section, the performance of the reactor under study is demonstrated for each retention time.

3.2.1 BOD_5 removal rates

At this stage of operation, the pilot system gave good results for the BOD_5 removal. Fig. 2 shows the BOD_5 values recorded for the pilot system operation under varying HRTs. From the figure we can deduce that HABR gave with an average percentage removal of 79% at HRT = 3.5 days whereas, the average percentage removal dropped to 50.5% at HRT = 0.5 day. 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 average effluent BOD_5 values were varied from 20 to 59 mg/lit.

3.2.2 COD removal rates

COD removal rates were identical to those obtained in the previous section as shown in Fig. 3. The average influent COD value was 300 mg/lit yielding an average loading rate of 0.086 Kg COD/m^3.day. From Fig. 3 we can deduce that HABR removal rates with a percentage of 85.7% at HRT = 3.5 days whereas, the average percentage removal dropped to 73.7% at HRT = 0.5 day . The average effluent COD values were varied from 43 to 78.5 mg/lit.

3.2.3 Suspended solids removal rates

The reactor gave promising effluent suspended solids (SS) values. Chronologically, in the same manner as discussed in the previous sections, HABR gave an average effluent value of 17 mg/lit yielding a percentage removal of 90.3% at HRT = 3.5 days whereas, the average percentage removal dropped to 75% at HRT = 0.5 day. The average effluent SS values were varied from 17 to 47 mg/l. Fig. 4 shows the influent and effluent values recorded.

3.3 Comparing the Different HRTs Together and with Other Studies

In this section, the discussion will be focused on the comparison between the different hydraulic retention periods that were previously discussed. Also the removal across the four different compartments of the reactor will be demonstrated, together with the comparison with other similar studies that were conducted in the same field.

3.3.1 pH variations

Throughout the experiment the pH values remained reasonably stable at around (7) within the reactor as shown in Fig. 5. It was found that there is a relation between the HRT and the pH value. The decrease in HRT decreases the pH in compartments one and two compared with other HRTs. This is clear from the figures and is attributed to the accumulation of volatile fatty acids (VFA) that were observed in the first two compartments at HRT = 0.5 day. These findings are similar to the observations reported by Ackunna and Clark, 2000.

3.3.2 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). The best performance was observed with a HRT of 3.5 days or a loading of 0.09 kg COD/m^3.day. The following table and figures show the different correlations of the BOD_5 and COD within the reactor at different HRTs. From the figures and table it can be seen that when the retention time was decreased to 0.5 days the efficiency of the reactor dropped and the removal rates were comparatively poor. The relatively high BOD/COD ratio shown in Table 1 of the treated effluent from the reactor is indicative of the biodegradable nature of the residual BOD and COD. Fig. 6 shows the relation between effluent BOD_5 and the organic loading rates while Fig. 7 shows the relation between the effluent COD and organic loading rates. From the figure 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 Bachmann *et al.*, 1985; Boopathy & Tilche, 1991; Nachaiyasit & Stuckey, 1995 and, finally, Bae *et al.*, 1997.

Table 1 : Overall COD and BOD_5 removal with varying HRT

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
1.5	300	120.0	0.4	59	40	0.68	80.3	66.4
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

Analysis of the removal rates within the four compartments of the reactor indicate that about (70-80)% of the total removal rates take place in the first two compartments. The BOD_5 and COD profile in the reactor was monitored during each run. BOD_5 and COD removal occurred through the entire length of the reactor as shown in Fig. 8, 9. From the figures it can be seen that better substrate removal percentages were obtained at low HRTs. This is due to the fact that at low retention time when treating dilute wastewaters, an decrease in hydraulic turbulence occurs which in turn lowers the apparent K_s values (Kato *et al.,* 1997) thus enhancing treatment efficiency. The removal percentages were also noticed to be high in the first two compartments at low HRTs in contrary to what was noticed at high HRTs. At low HRTs the thickness of the biomass layer was at its extent in the first two compartments and gradually reduced to an apparent minimum in the last two compartments a case that implied possible biomass starvation in the later compartments at longer retention times. On the other hand, at higher retention times the thickness of the biomass layer was found to be almost evenly distributed among the four compartments within the reactor.

3.3.3 TSS removal

Total suspended solids (TSS) were found to be markedly removed in hybridized anaerobic baffled reactors at lower retention times. As SS represents the major COD fraction in domestic sewage, high removal of SS will lead to high removal of COD. During the operation of the pilot plant, it was noticed that the removal of large particles in the SS fraction depended mainly on drag forces and settling characteristics of the particles. In general, in the HABR the removal of SS occurs by settling and by filtration through the sludge bed and/or filter media and biologically by the decomposition of substrate. Influent concentration was found to have a great effect on the sedimentation filtration rates in the reactor thus altering the overall SS removal and this was similar to what was stated by Man *et al.,* 1986, and Wang (1994). Hydraulic retention time was found to have both physical and biological effects on the removal of SS. Increasing the HRT was found to improve the settling and filtration, physically, and the anaerobic digestion biologically. This can be clearly seen in Fig. 10 in which at HRT = 3.5 days higher removal efficiencies were recorded in the reactor under study compared with the other descending HRTs. Upflow velocity which has a direct effect on SS removal and consequently an indirect effect on substrate removal was found to be affected by HRTs due to the fixed reactor depth and crosssectional area. The lowest upflow velocity recorded was 0.016 m/h at a HRT of 3.5 days while the highest upflow velocity recorded was 0.28 m/h at a HRT of 0.5 day. Man *et al.*, 1986, found that the application of an upflow velocity exceeding 0.5 m/h resulted in a significant decrease in SS removal. Fig. 11 shows the relation between upflows velocity and SS removal in the reactor under study.

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- At an HRT of 3.5 days, HABR with plastic media gave an average BOD_5 removal rate of 79% with an effluent of 25 mg/lit. In a likewise manner, the COD removal rates recorded at the same HRT were 85.7%.

3- SS removal rates were high and recorded a value of 90.3% for a HRT of 3.5 days for HABR. The lowest average effluent SS value recorded was 17 mg/lit.

4- 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.

5- 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.

6- The compartmentalized structure of the HABR together with the presence of media prevents much of the biomass being washed out.

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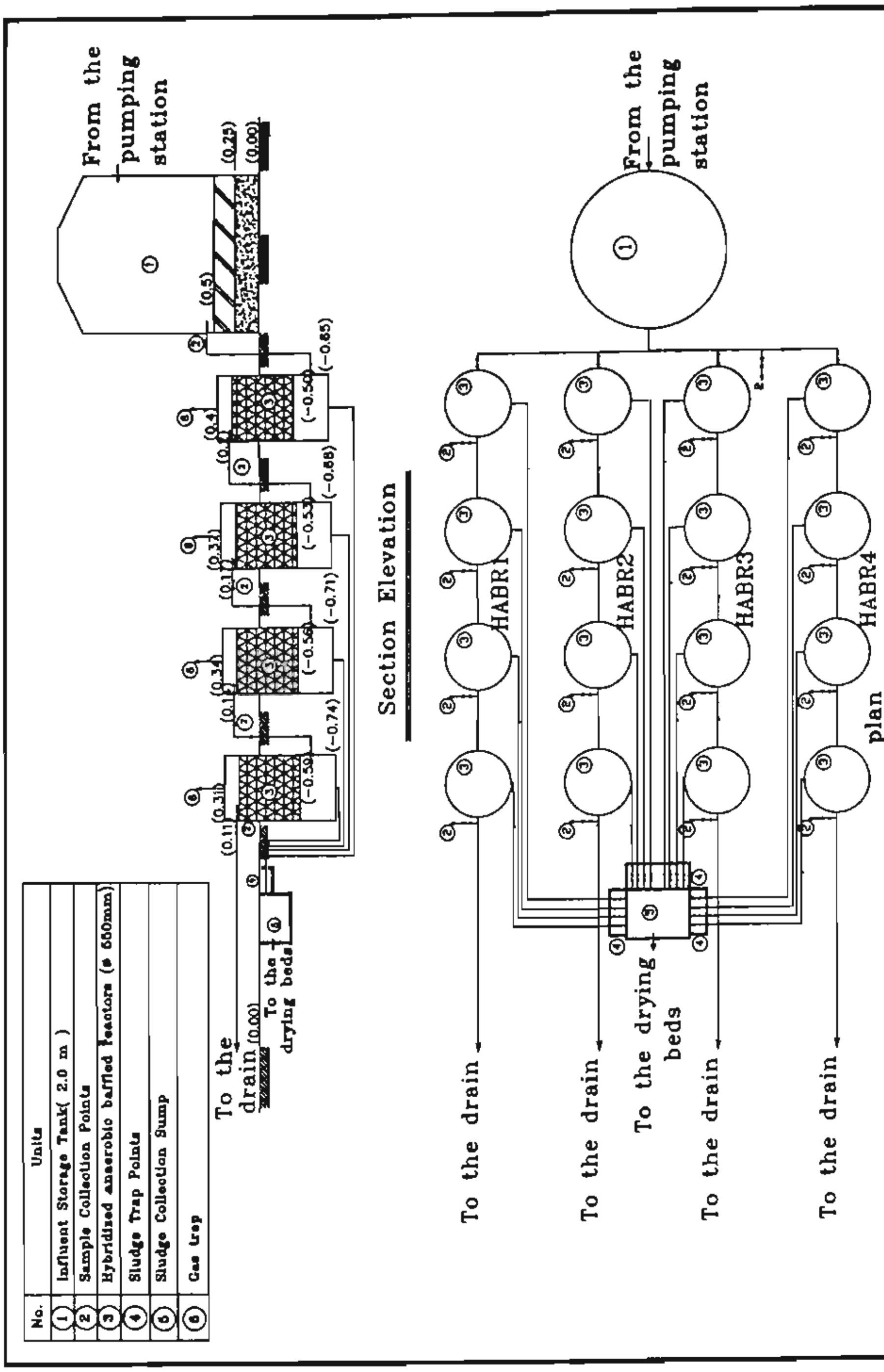

Fig.1: General layout of the HABR pilot system

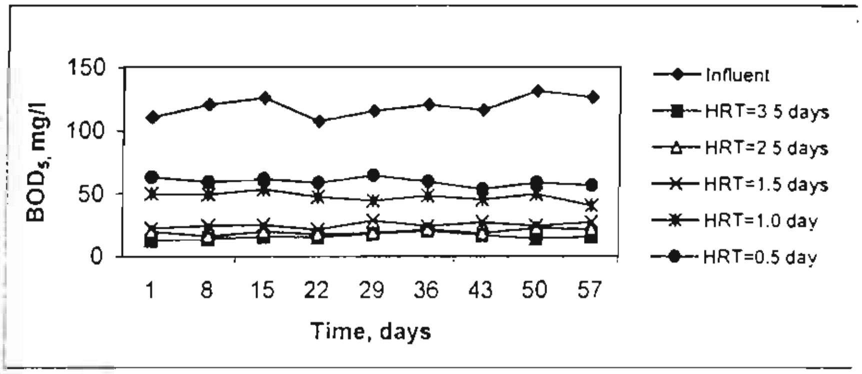

Fig.2: BOD_5 Influent and effluent values recorded for the HABR system

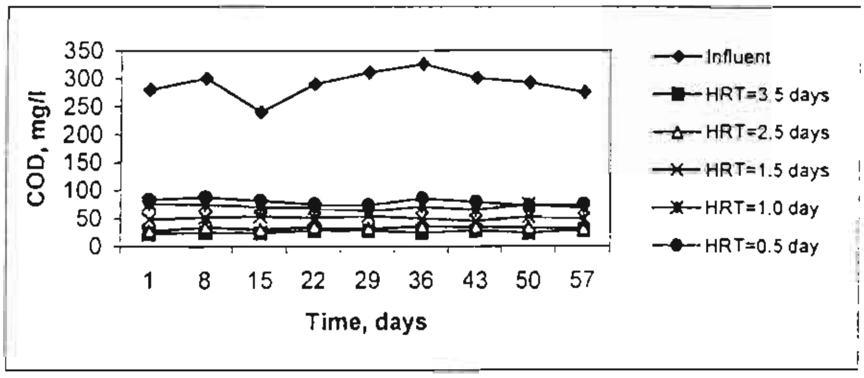

Fig.3: COD Influent and effluent values recorded for the HABR system

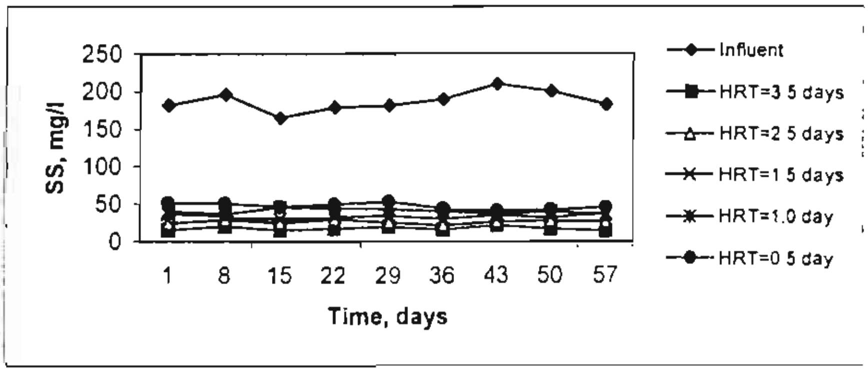

Fig 4: SS Influent and effluent values recorded for the HABR system

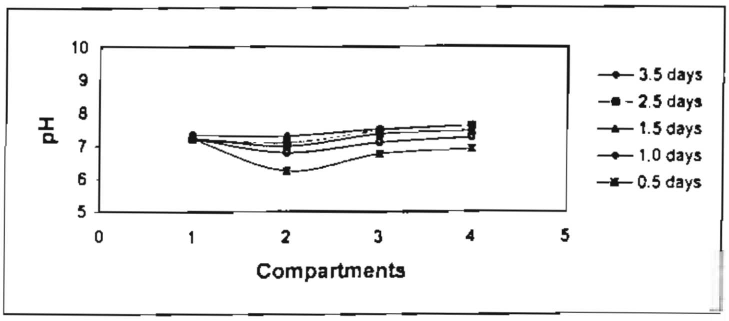

Fig.5: Variation of the pH profile within the four compartments with HRTs

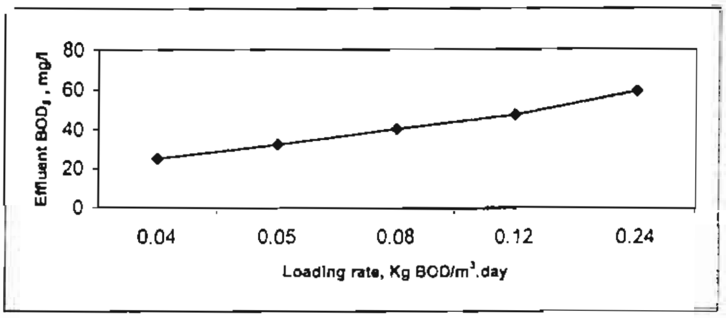

Fig.6: Effluent BOD_5 Vs organic loading rate for the reactor

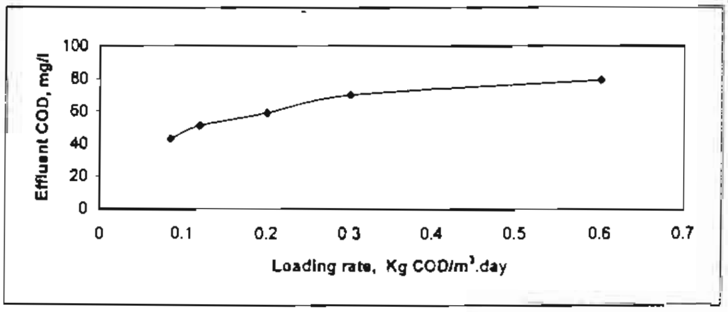

Fig.7: Effluent COD Vs organic loading rate for the reactor

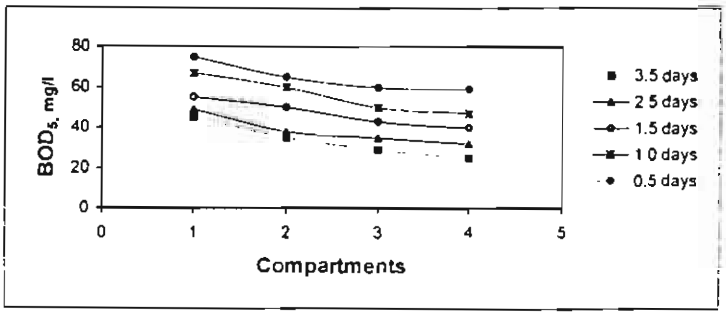

Fig.8: BOD_5 Variation with HRTs in the reactor compartments

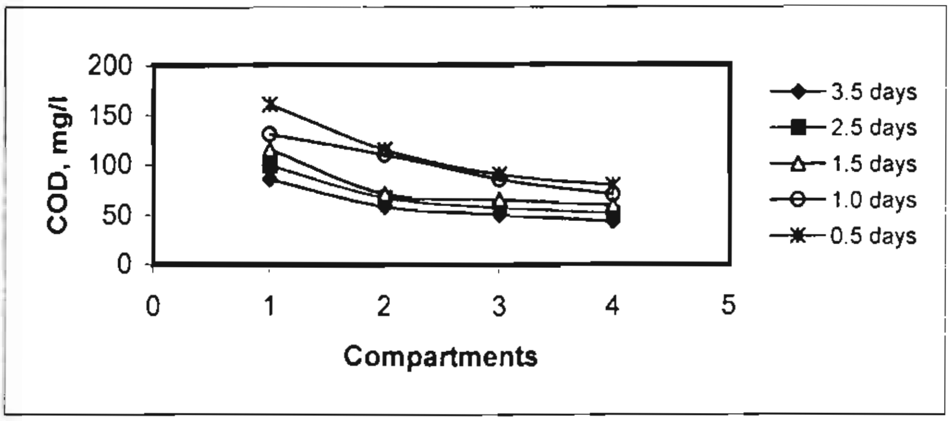

Fig.9: COD Variation with HRTs in the reactor compartments

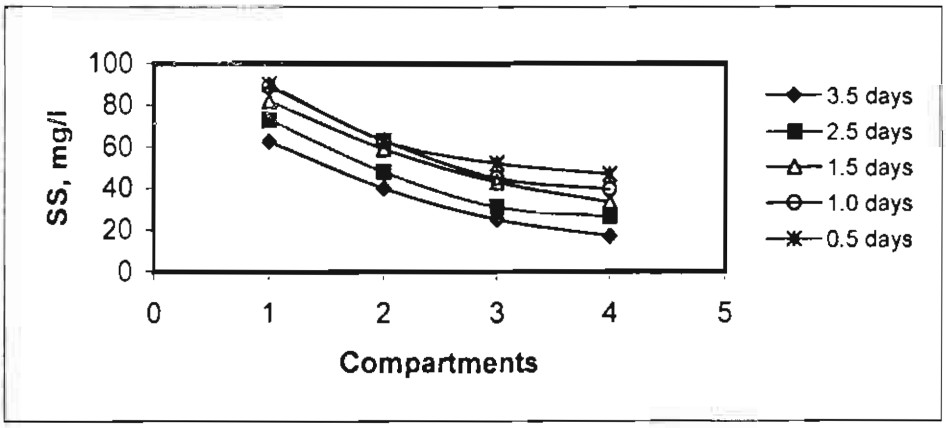

Fig.10: Variation of HRTs with SS in the reactor compartments

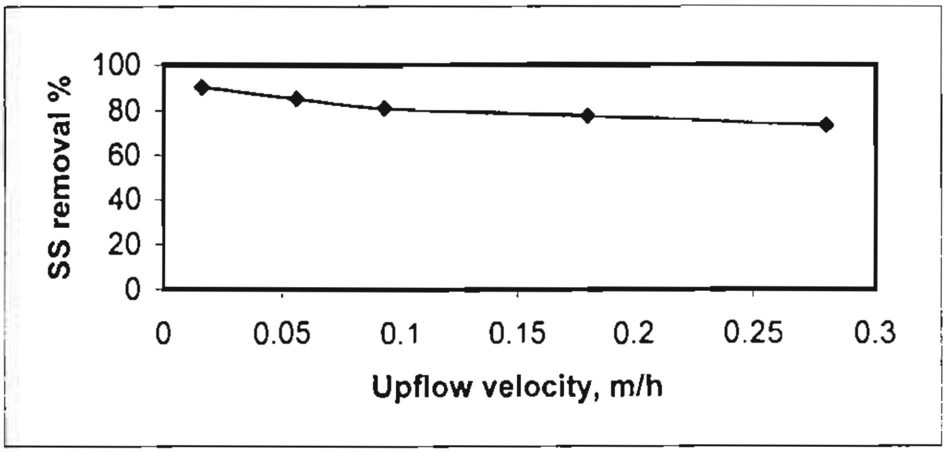

Fig.11: Upflow velocities Vs SS removal in the reactor