TREATMENT OF SETTELED DOMESTIC SEWAGE USING HYBRIDIZED ANAEROBIC BAFFLED REACTOR(HABR) UNDER HYDRAULIC SHOCK LOADS

معالجة مياه الصرف الصحي باستخدام المفاعلات اللاهوائية ذات الحواجز و الوسط تحت تأثير الأحمال الهيدروليكية المفاجئة

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

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

الملخـص: 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 علـــى الترتيب٠ و يتكون نظام المعالجة من خزان تغذية سعة ٢ م٣ و يتغذى من مياه الصـــرف الصحي الخارج من خزانات تحليل و يوزع هذا الخزان على عدد (٤) مجموعات مـــنها مجموعتان بهما وسط زلطى باحجام مختلفة و المجموعة الثالثة بدون وسط و الأخيرة بها وسط بلاستيكي٠تم اختبار هذه المحطة التجريبية على تحمل الأحمال الهيدروليكية المفاجئة و تـــم تعيين نسب الإزالة للمواد الصلبة العالقة و الأكجسين الكيميائى الممتص و درجة الأس الهيدروجيـــنى٠ و كـــان متوسط تركيز المواد العضوية حوالي ٣٠٠ مجم /لتر من الأكجسين الحـــيوي الممـــتص٠ و كان زمن المكث الهيدروليكي الرئيسى يتراوح من ١,٥ إلي ٣,٥ يوم وأمـــا زمـــن الحمـــل الهيدروليكـــي المفاجئ كان ٦ لمدة ساعات٠ خلال الحمل المفاجئ يتضـــاعف الحمل الهيدروليكي و بالتالي الحمل العضوي أيضا و يوجد عوامل كثيرة و معقدة تؤثـــر فـــي نسب الإزالة للمواد العضوية٠ و قد وجد أن هذه المفاعلات اللاهوائية تستطيع أن تـــتحمل هـــذه الأحمـــال الهيدروليكية المفاجئة و تستعيد كفاءتها الأصلية بدون تأثير خلال ٩ ســـاعات بعد إزالة هذه الأحمال٠ أيضا نجد أن وجود الوسط و الحواجز يمنع خروج البكتيريا نظرا لالتصاق هذه البكتيريا على الوسط٠ و كانت أفضل النتائج مع الوسط البلاستيكى٠

ABSTRACT

Four hybirdized anaerobic baffled reactors (HABRs) were constructed each with a total volume of 800 liters and consists of four compartments. The plastic media and gravel were used with the specific surface area of 100 and 80 m^2/m^3 respectively. All the reactors in the pilot plant were used to examine the effect of transient and step hydraulic shock loads on reactor performance in terms of PH and COD, SS removal responses to hydraulic shocks in each compartment. The average influent COD and SS

Accepted September 30, 2003.

concentrations were about 300 and 175 mg/l respectively. The reactors were operated at three baseline conditions, hydrulic retention time (HRT) = 3.5, 2.5 and 1.5 days. At each baseline condition the reactors were subjected to three shocks with a duration of six hours per shock. However, the effect of decreasing HRTs coupled with increasing the organic loading rates (OLR) is more severe and its effects are more complex.. The HABR was found to be stable when subjected to large transient hydraulic shock loads for 6 hours and while biomass loss was substantial, it recovered to baseline conditions and performance after about 9 hours. The best results was observed in the reactor with plactic media compared with with other reactors. The compartmentalized structure of the HABR together with the presence of media prevents much of the biomass being washed out or exposed to low pHs during step hydraulic shock loads.

KEYWORDS : Hybirdized anaerobic baffled reactor (HABR), plastic media, compartment, mass transfer, hydraulic shock loads.

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. In most cases it has been found that biological processes are more economic and efficient than physical and chemical treatment , especially anaerobic treatment (Roig *et al.* ,1993).

A number of studies have been carried out in the literature on the effect of HRT /shock loads on anaerobic digestion. Denac and Dunn (1988) compared the performance of a packed bed reactor with a fluidised bed biofilm reactor under vaying HRT conditions at a constant load of 10 kg-COD/m^3.d. COD removal decreased with decreasing HRT, and the results were comparable for both types of reactors. In the start up of a hybird anaerobic digester treating soluble synthetic wastes, guiot *et al.* (1989) found that the soluble COD content of the effluent increased with decreasing HRT, and this was composed essentially of volatile fatty acids (VFAs).

An increase in influent flow of 100 and 150% for 5 and 10 hrs was carried out in an anaerobic downflow filter treating slaughterhouse wastewater (Borja *et al.*, 1994). Effluent suspended solids increased, which was probably due to the increase of gas production brought about by the increase in the organic loading rate (OLR) and hydraulic shear. After the influent flow rates were returned to normal, all measured parameters retruned to their orginal values within 7 and 12 hrs. Zhang and Noike (1994) evaluated the influence of HRT on the performance and bacterial trophic populations in an anaerobic continous stirred tank reactor treating strach at 35 ^{0}C. The results demonstrated that methanogenesis occurred in the acidogenic phases, even with HRTs as short as 1.5 hrs, and that retention time was a significant factor in selecting for the predominant microbial species.

The objectives of the present work is to investigate the sability of the high rate anaerobic baffled reactor technologies in treating domestic wastewater under hydraulic shock loads. Reactors will be monitored with respect to pH variation, and COD and SS removal according to Standard Methods (1992).

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 pilot treatment plant was operated using domestic wastewater with variable organic strength. This type of wastewater has undergone pretreatment within the septic tanks, thus the wastewater has low strength. The pilot plant was operated with a retention time of 7.0 days. The reactor was seeded from anaerobic sludge from a septic tank. Each reactor was seeded with 5 liters of sludge at the beginning of operation. The hydraulic retention time was gradually reduced to 3.5 days in 15 days.

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. This low discharge gave an initial low loading rate of about 0.083 kg COD/m^3.day so that slow growing microorganisms 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 reactors were operated at three baseline conditions, hydrulic retention time (HRT) = 3.5, 2.5 and 1.5 days. At each baseline condition the reactors were subjected to three shocks with a duration of six hours per shock. The four reactor trains (HABR1, HABR2, HABR3 and HABR4) were configured to operate in four different manners and they are 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 m. 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, 0.6 m.

The reactor (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 in the previous were pilot tested for a period of about 100 days during which many variables were examined. In the following sections the results obtained from the experimental running of the pilot project were 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 states and the operational period began; this amounted to an overall start up period of about 54 days.

3.2 Effect of Hydraulic Shock Loads on Substrate Removal Rates

After the steady state operation of the pilot treatment plant at the different HRTs, which lasted for a period of about one year, the system was subjected to step and transient hydraulic shocks at constant feed strength. All the four reactors in the pilot plant were used to examine the effect of transient and step hydraulic shock loads on reactor performance in terms of pH, COD and SS removal responses to hydraulic shocks in each compartment. The reactors were operated at three baseline conditions, HRT = 3.5, 2.5 and 1.5 days. At each baseline condition the reactors were subjected to three shocks with a duration of six hours per shock. Samples were taken every 1.5 hours during the duration of the shock and every six hours after the cease of the shock till it reaches its original steady baseline conditions. The results obtained for the hydraulic shock loads for the three baseline conditions is as follows:-

3.2.1 First baseline conditions (HRT = 3.5 days)

This hydraulic shock load run at this baseline condition lasted for 21 days. During this period the system was subjected to three hydraulic shocks with an HRT of 2.0 days, 1.25 days and 0.75 day for a six hour period per shock.

Transient hydraulic shock for 6h at an HRT of 2.0 days

The reactors were stable to this perturbation and returned to normal operation within 9 to 12 hrs after the shock ended. This is only about a third of the time required under a similar situation in an earlier work by Grobicki and Stuckey, 1991, and almost equal to that obtained in a recent work by Nachaiyasit and Stuckey, 1997. HABR1 was found to be more stable compared with the other reactors. HABR2 gave more turbid effluent values compared with the other reactors. During this shock period, the COD removal rate dropped from 85.7% at baseline conditions to 80% during the shock period. The pH and SS values where found to increase during the first 1 to 3 hrs of the shock duration. After that it comes back to normal in about 9 hrs after returning to baseline conditions. Fig. 2 to 4 show the results recorded during this shock run.

Transient hydraulic shock for 6h at an HRT of 1.25 days

The reactors during this run where similar to those in the previous run; with the only exception that effluent wastewater here was more turbid and it took a slightly longer time to reach its baseline. The percentage drop in the removal rates during this run where slightly higher that those recorded during the previous shock run. The amount of biomass washed out during this shock run was noticeably higher than that noticed in the previous run. The pH and SS values where found to increase during the first (3-5) hours of the shock duration. After that it comes back to normal in about (20-30) hours after returning to original capacity Figures 5 ,6 show the results obtained during this run. It can be noticed from these figures that, the apparent slightly long recovery time. The results obtained during this run are similar to those obtained by Borja *et al.*, 1994, as they noticed quick recoveries in an anaerobic filter after the cessation of the shock, but the recovery took a slightly longer time than in the HABR under study.

Transient hydraulic shock for 6h at an HRT of 0.75 day

This run was conducted consequently after the previous run. No any abnormal readings were recorded during this run. However, the system was found to efficiently withstand hydraulic shock loads at this very low retention time. Even by reducing the hydraulic shock period to about three and a half times the baseline conditions, the system was found to recover quickly and attain its pre-shock state. However, more turbid effluents and longer recovery periods were also noticed during this run. The COD and SS removal rates dropped by about 22% and 20% respectively from that recorded during the steady state baseline conditions and returns back to original capacity within 40 hours. Figures 7, 8 show the results obtained during this run.

3-2-2 Second baseline conditions ***(HRT = 2.5 days)***

This hydraulic shock run was conducted consecutively after the first run and it lasted for a period of 21 days. The baseline conditions for this run was HRT = 2.5 days and the system was subjected to two hydraulic shocks with an HRT of 1.5 and 0.5 days respectively for a period of six hours per shock.

Transient hydraulic shock for 6h at an HRT of 1.5 days

During this shock run it was noticed that great turbulence occured to the biomass attached to the media and more biomass washout was noticed in comparison with the previous runs. The baseline removal percentage for both COD and SS was found to drop by about 24% and 26% respectively during the shock period. Figures 9, 10 show the profile of the effluent wastewater during the shock period. Twenty four hours after the transient hydraulic shock, the COD removal stabilized at pre-shock levels in reactor one and four. In reactors two and three the recovery period increased by about eighteen hours compared with the first and fourth reactor. The parameters analyzed during this work are fewer than those considered in similar earlier work by Grobicki and Stuckey, 1991, and Nachaiyasit and Stuckey, 1997, in which the results provided more insights into the fundamental physical and microbial responses of the HABR system; yet the results obtained in this study almost coincide with what was previously obtained with regards the common parameters monitored.

Transient hydraulic shock for 6h at an HRT of 0.5 day

This run didn't differ much from the previous run. Prolonged recovery periods were recorded compared with the previous run. A drop of about (40 – 50)% was recorded in the substrate removal rates. More biomass washout was noticed together with more turbulence to the system. Results obtained during this run are outlined in Fig. 11, 12 with regards the parameters measured.

3-2-3 Third baseline conditions *(HRT = 1.5 days)*

After the end of the previous run, the pilot plant was adjusted at an HRT of 1.5 days. The system was then subjected to a hydraulic shock load of HRT = 0.25 days for a period of 6 hrs and observations were taken.

Transient shock for 6h at an HRT of 0.25 day

At this shock load the reactors were unstable. It is likely that during this very low HRT, in order to minimize the pressure drop through the bed. Channeling occurred which resulted in minimal contact between the biomass and the substrate. This phenomenon was observed by Grobicki and Stuckey, 1991, with short HRTs, but in this work the walls of the reactors were opaque and buried in the ground, this made visual observation impossible. Figures 13, 14 show the variation of COD and SS in each of the four reactors under study over time during the hydraulic shock. During this transient hydraulic shock, substrate was simply washed through each compartment almost without being metabolized, probably because of channeling occurring in the biomass bed, or too short a contact time (retention time of 1.5 hrs in each compartment) between the microorganisms and substrate, or a combination of both.

3.3 Summary of Reactors Performance During and After the Shocks

For the three hydraulic step changes in the four reactors, HABR1, HABR2, HABR3 and HABR4, the efficiency of COD removal during the shock period declined as the HRT was reduced. Table 1 shows the summary of the results obtained during the shock periods. At the shortest

HRT the reactors faced a drastic shock and the performance was affected extensively. When comparing the data obtained in this study under different shock conditions (Table 1), it is apparent that the effect of decreasing HRT (at constant feed concentration), in the HABR is similar in terms of COD and SS removal. However, the effect of decreasing HRTs coupled with increasing the OLR is more severe and its effects are more complex.

Table 1 Overall Summery of Hydraulic Shock Loads

Baseline conditions / Reactors		HRT = 3.5 days $\%COD_{removed}$ = 80 -86 $\%SS_{removed}$ = 75 - 91			HRT = 2.5 days $\%COD_{removed}$ = 75 -83 $\%SS_{removed}$ = 70 – 85		HRT = 1.5days $\%COD_{removed}$ =70 - 80 $\%SS_{removed}$ = 70 - 82
		Shock HRT 2.0 days	Shock HRT 1.25 days	Shock HRT 0.75 day	Shock HRT 1.50 days	Shock HRT 0.50 day	Shock HRT 0.25 day
HABR1	$\%COD_{removed}$ during shock	77	74	70	69	60	17
	$\%SS_{removed}$ during shock	81	76	72	71	63	23
HABR2	$\%COD_{removed}$ during shock	70	69	65	63	52	7
	$\%SS_{removed}$ during shock	64	63	60	51	45	8
HABR3	$\%COD_{removed}$ during shock	73	72	69	67	58	18
	$\%SS_{removed}$ during shock	68	66	65	63	60	14
HABR4	$\%COD_{removed}$ during shock	76	74	69	68	53	10
	$\%SS_{removed}$ during shock	77	74	69	66	56	16

Ultimately, the COD removal rate at steady state in a HABR is a function of a number of factors, some of which are independent of each other, while some are highly dependent. These are: the concentration activity and kinetics of the biomass; the dead space in the reactor; the severity and type of channeling in each compartment; the substrate concentration in each compartment; driving mass transfer into the flocs; floc size; HRT and OLR.

The drop in COD over time after the shock ceased was simply the result of the glucose, amino acids and the long chain fatty acids formed in the hydrolysis stage of the anaerobic digestion being washed out. Since very low levels of volatile fatty acids were produced due to channeling (an indication of increased pH values during the shock runs), the recovery period was moderately quick. Removal rates during this shock run where found to drop to about 16% and 20% with regards COD and SS removal.

CONCLUSIONS

1- The HABR was found to be stable when subjected to large transient hydraulic shock loads for 6 hours and while biomass loss was substantial, it recovered to baseline conditions and performance after about 9 hours.
2- COD removal rate at steady state in a HABR is a function of a number of factors, some of which are independent of each other, while some are highly dependent. These are: the concentration activity and kinetics of the biomass; the dead space in the reactor; the severity and type of channeling in each compartment; the substrate concentration in each compartment; driving mass transfer into the flocs; floc size; HRT and OLR.
3- The compartmentalized structure of the HABR together with the presence of media prevents much of the biomass being washed out or exposed to low pHs during step hydraulic shock loads.
4- The best results were observed in the reactor with plactic media compared with other reactors.

RFFERENCES

- APHA, AWWA and WPCF (1992), Standard Methods: for the examination of water and wastewater, *18th edition* .
- Borja R., Banks C. J. and Wang Z. (1994), Sablitiy and performance of an anaerobic downflow filter treating slaughterhouse wastewater under transient changes in process parameters. *Biotech. Appl. Biochem.* 20, pp.371-383.
- Denac M. and Dunn I. J. (1988), Packed – and fluidized –bed biofilm reactor performance for anaerobic wastewater treatment . *Biotech. Bioengng.* 32,pp. 159-173.
- Grobicki A. and Stucky D. C. (1991), Performance of the anaerobic baffled reactor under steady-state and shock loading conditions. *Biotech. Bioengng.* 37,pp. 344-355.
- Guiot S. R., Podruzny M. F. and McLean D. D. (1989), Assessment of macroengertic parameters for anaerobic upflow biomass bed and filter (UBF) reactor . *Biotechlo. Bioengng.* 34, pp.1277-1288.
- Nachaiyasit S. and Stuckey D.C. (1997), The effect of shock loads on the performance of an anaerobic baffled reactor (ABR). 2. Step and transient hydraulic shocks at constant feed srength, *Water Research*, 31(11), pp.2747 - 2754.
- Roig M. G., Martin-Rodoguez M. J., Cachaza J. M., Mendoza-Sanchez L. and Kennedy J. F. (1993), Principals of biotechnoloical treatment of industrial wastes. *Crit. Rev. Biotechnol.* 13, pp. 99-116.
- Zhang T. C. and Noike (1994), Influence of retention time on reactor performance and bacterial trophic populations in anaerobic digestion processes *Water Research* 28, pp. 27-36.

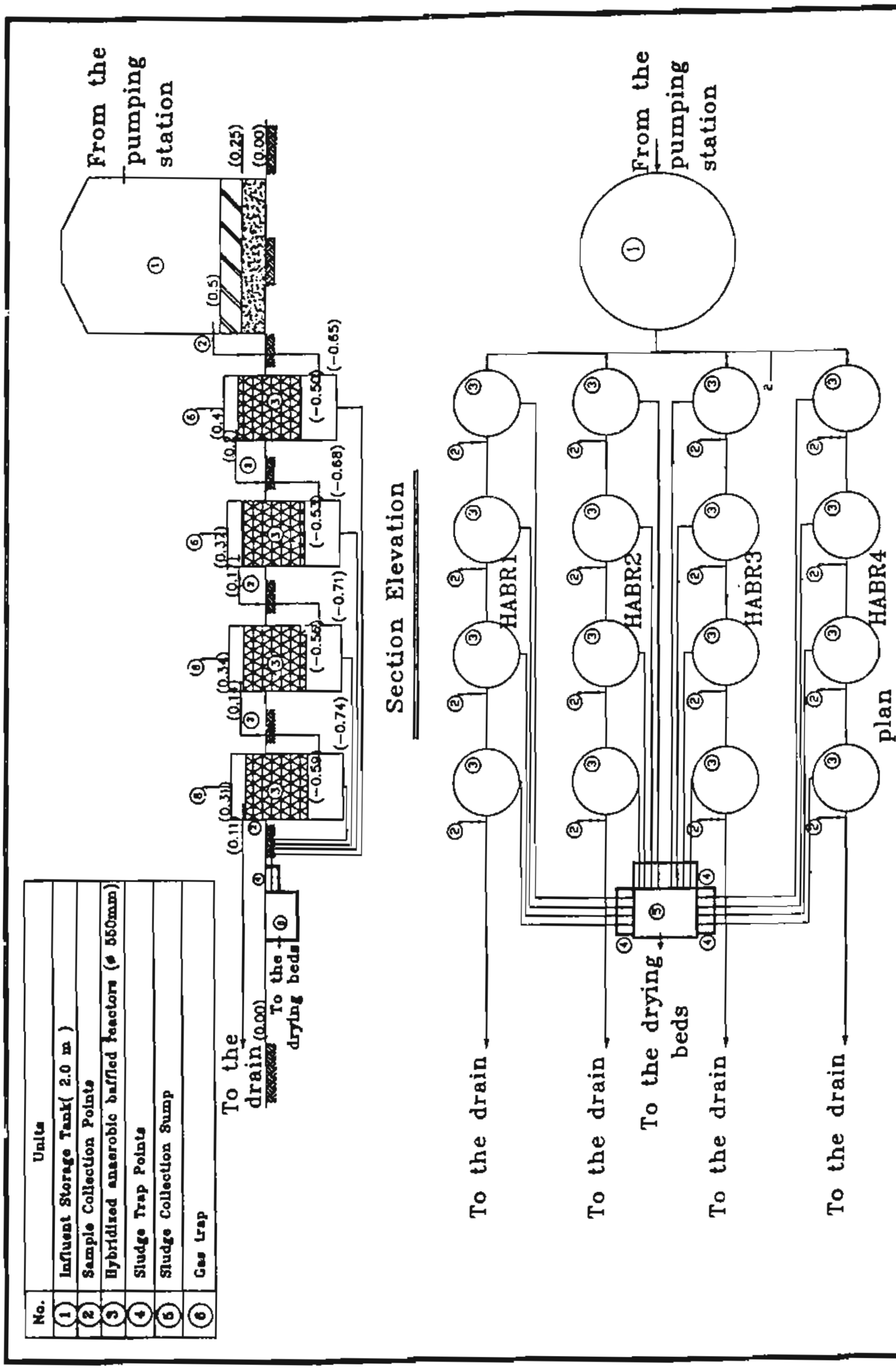

Fig.1: General layout of the HABR pilot system

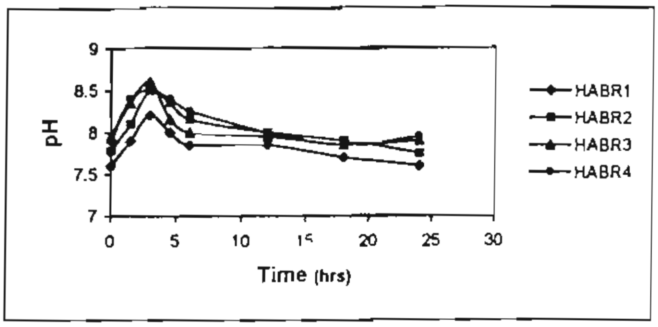

Fig. 2 pH profile over time in each reactor during the transient shock load of 2.0 days HRT for 6 hrs
(Baseline HRT = 3.5 days)

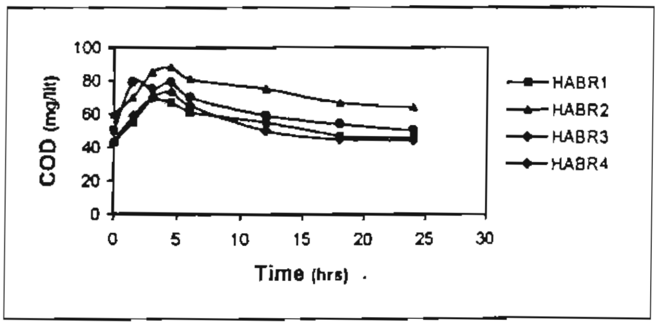

Fig. 3 COD profile over time in each reactor during the transient shock load of 2.0 days HRT for 6 hrs
(Baseline HRT = 3.5 days)

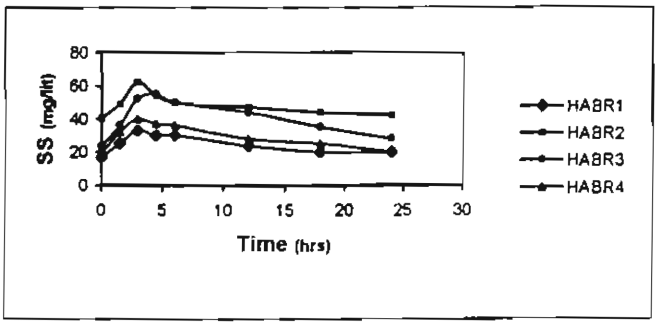

Fig. 4 SS profile over time in each reactor during the transient shock load of 2.0 days HRT for 6 hrs
(Baseline HRT = 3.5 days)

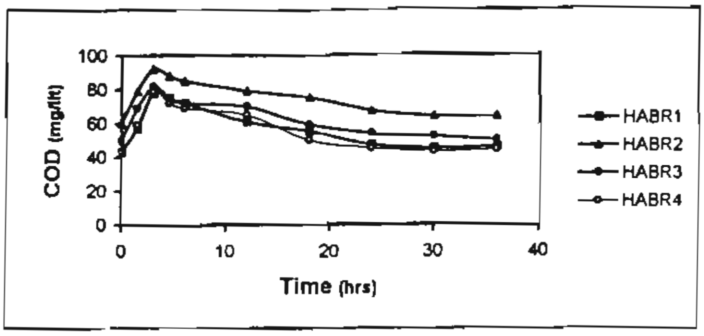

Fig. 5 COD profile over time in each reactor during the transient shock load of 1.25 days HRT for 6 hrs (Baseline HRT = 3.5 days)

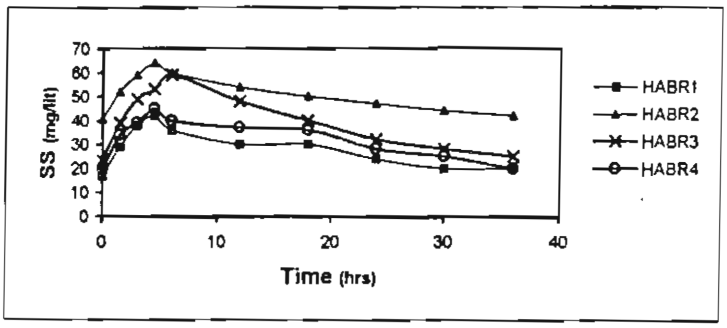

Fig. 6 SS profile over time in each reactor during the transient shock load of 1.25 days HRT for 6 hrs (Baseline HRT = 3.5 days)

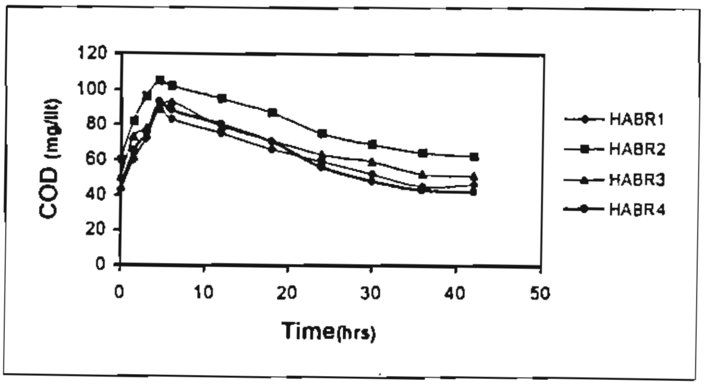

Fig. 7 COD profile over time in each reactor during the transient shock load of 0.75 day HRT for 6 hrs (Baseline HRT = 3.5 days)

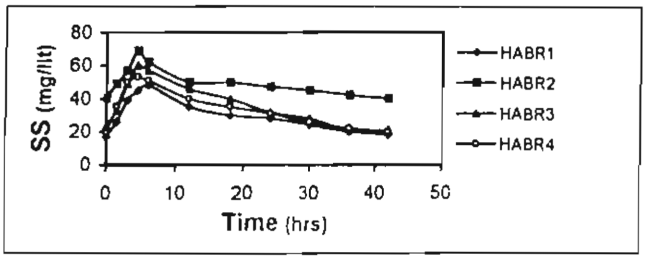

Fig. 8 SS profile over time in each reactor during the transient shock load of 0.75 day HRT for 6 hrs (Baseline HRT = 3.5 days)

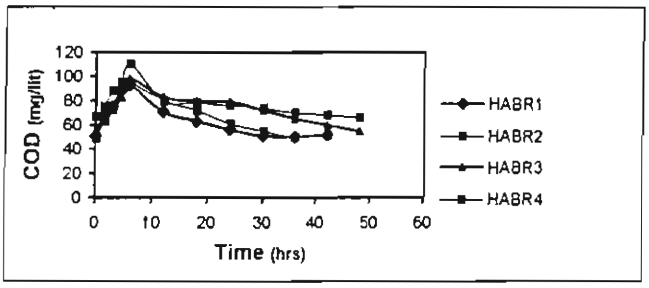

Fig. 9 COD profile over time in each reactor during the transient shock load of 1.5 days HRT for 6 hrs (Baseline HRT = 2.5 days)

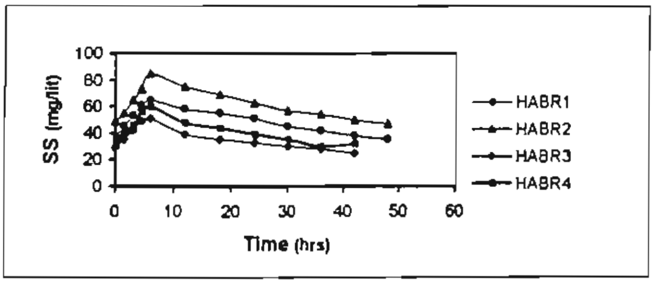

Fig. 10 SS profile over time in each reactor during the transient shock load of 1.5 days HRT for 6 hrs (Baseline HRT = 2.5 days)

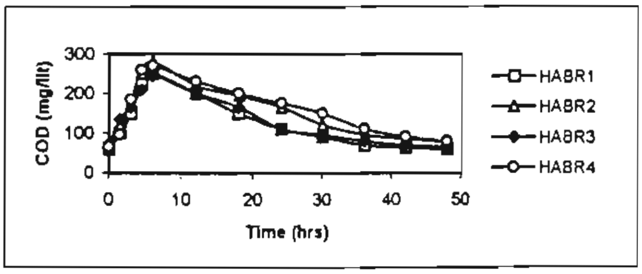

Fig. 11 COD profile over time in each reactor during the transient shock load of 0.5 day HRT for 6 hrs (Baseline HRT = 2.5 days)

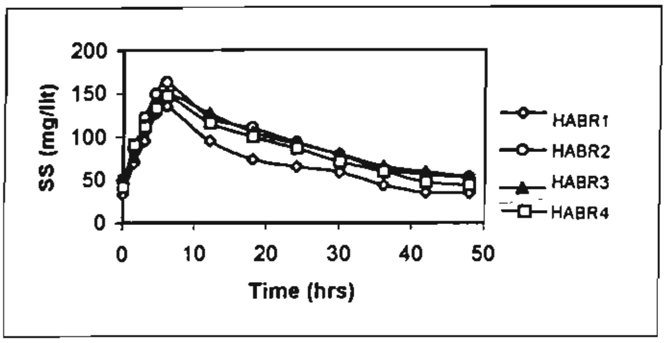

Fig. 12 SS profile over time in each reactor during the transient shock load of 0.5 day HRT for 6 hrs (Baseline HRT = 2.5 days)

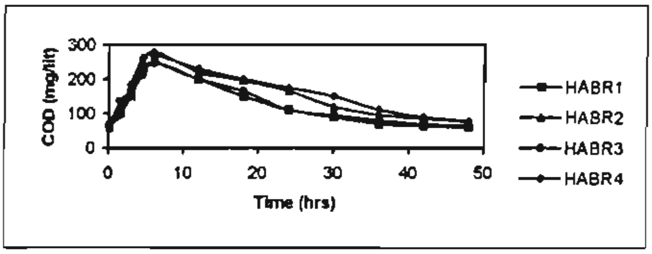

Fig. 13 COD profile over time in each reactor during the transient shock load of 0.25 day HRT for 6 hrs (Baseline HRT = 1.5 days)

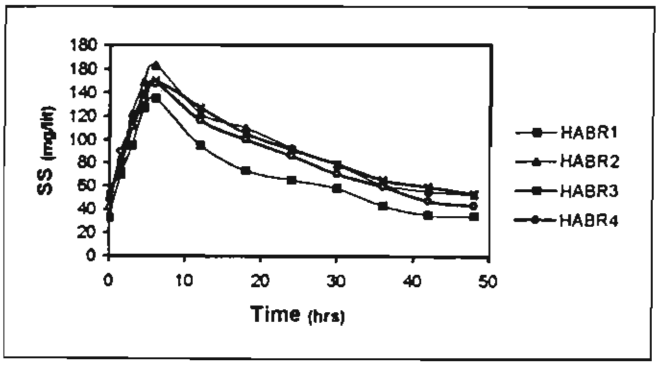

Fig. 14 SS profile over time in each reactor during the transient shock load of 0.25 day HRT for 6 hrs (Baseline HRT = 1.5 days)