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Hybridized Anaerobic Baffled Reactor For The Treatment Of Domestic Wastewater: Pilot and Prototype Scale

المفاعلات اللاهوائيه ذات الحواجز والوسط فى معالجة مياه الصرف الصحى من خلال محطة حقلية و تجريبية

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الخلاصة

المفاعلات اللاهوائيه ذات الحواجز والوسط تتميز على باقى المعالجات اللاهوائيه واعتمادا على ذلك تم تطبيق هذا النظام واستخدامة. ويتميز المفاعل اللاهوائي ذو الحواجز والوسط بقدرته علي الفصل بين عمليات تكوين الأحماض وعمليات تكوين غاز الميثان مما يجعل الخزان الواحد يعمل علي أنه ذو مرحلتين بدون زيادة فى التكاليف او حدوث اى مشاكل وتم تنفيذ اول محطة معالجة بنظام المفاعلات اللاهوائيه ذات الحواجز والوسط بقرية دمو على بعد ١٠ كم شرق مدينة الفيوم بتصرف ١٦٧٨ م٣ \ يوم وقد تم مراقبتها لمدة عام كامل من اجل تقيم النظم ذات التكلفة المنخفضة التى تلائم ظروف القرى المصرية المنعزلة او ذات الكثافات المنخفضة. واظهرت النتائج أن خواص المياه الناتجة من المحطة كانت اقل من الحدود التي حددها القانون ٤٨ لعام ١٩٨٢. ولكن كفاءتها في إزالة الملوثات العضوية والمواد العالقة أقل من كفاءة المحطة التجريبية بقرية نواج حيث كان متوسط نسب الإزالة للمواد العضوية والمواد العالقة حوالي ٥٠% مقارنة بنسب الإزالة التي حققتها المحطة التجريبية بقرية نواج عند زمن بقاء ٢,٥٠ يوم والتي أعطت متوسط إزالة للمواد العضوية مقداره ٨٣,١٢% وكان متوسط نسب إزالة المواد العالقة ٨٣,٨٥%. ويعزي هذا الفارق في كفاءة إزالة الملوثات إلي عدم ملائمة زمن البقاء المصمم عليه المحطة لخواص مياه الصرف الصحي بقرية دمو.

Abstract

Hybridized anaerobic baffled reactor has distinct advantages over many other anaerobic treatment processes. Recognition of these advantages has resulted in a broadening application and use of this system. The most significant advantage is, its ability to separate the acidogenes and methanogenes longitudinally down the reactor allowing the reactor to behave as a two phase system without the associated control problems and high cost (Weiland and Rozzi, 1991). The first full scale HABR in Egypt constructed at Demo, (10 Kms east of EL Fayoum city) to treat a wastewater discharge of about 1678 m^3/d, was monitored for about one year in order to investigate the applicability of this system as a low cost sanitation technology matches the Egyptian village circumstances. Results showed that the full scale HABR achieved an accepted effluent quality corresponds the Egyptian limitations, but the performance was lower than anticipated from the pilot scale HABR constructed at Nawag village. The most frequented removal ratios at HRT of 2.5 days for COD and SS were around 50% for the studied reactors, while the average removal ratios for the pilot plant were 83.12% and 83.58% for COD and suspended solids, respectively at the same HRT.

KEYWORDS

Hybridized Anaerobic Baffled Reactors (HABR), Chemical Oxygen Demand (COD), Suspended Solids (SS), Hydraulic retention time (HRT).

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INTRODUCTION

The successful application of anaerobic technology to the treatment of domestic wastewater depends on the development of high-rate bioreactors such as the upflow anaerobic sludge blanket reactor concepttion (Lettinga et al., 1980), which achieve a high reaction rate per unit reactor volume by retaining the biomass in the reactor for long periods of time. While there have been many high rate designs developed, the anaerobic baffled reactor has many advantages compared to these, such as better resilience to hydraulic and organic shock loads, the ability to partially separate the various phases of anaerobic catabolism and lower sludge yields than many other high rate anaerobic treatment systems. The differing populations of bacteria across the compartments increase resistance to variations in feed load, temperature and pH, (Barber and Stuckey, 1999).

The HABR configuration satisfies the main characteristics required for biological treatment systems to be simple and efficient: a) high biomass concentration inside the reactor, propitiating high cellular retention times; b) development of structured multi-cellular aggregates in the form of granules or dense sludge, composed by different species and micro organism groups responsible for the conversion of organic matter into methane and carbon dioxide; c) low requirement of nutrients and low excess sludge production; d) high stability in response to normal fluctuations of influent composition and concentration; e) capacity of accommodating high organic loading rates (OLR), (Foresti, 2001).

Construction costs, installations and operation of the HABR are lower than those of conventional aerobic units because the reactor does not require equipment for process maintenance and control. In fact, the environmental conditions inside the reactor are adequate because anaerobic processes are mainly self controlled. Additionally, the production of excess sludge is minimal and energy balances are quite favorable due to the production of methane. The most significant advantage of the HABR is its ability to separate acidogenesis and methanogenesis longitudinally down the reactor, allowing the reactor to behave as a two-phase system without associated control problems and high costs (Weiland and Rozzi, 1991). Two-phase operation increases acidogenic and methanogenic activity by a factor of up to four as acidogenic bacteria accumulate within the first stage (Cohen et al., 1980, 1982), and different bacterial groups can develop under more favorable conditions. The advantages of two-phase operation have been extensively documented by Pohland and Ghosh, 1971, Ghosh et al., 1975 and Cohen et al., 1980, 1982.

Hence, the aim of this research was to evaluate the performance of the full scale HABR plant for treating domestic wastewater by determining the achieved removal efficiencies for the wastewater pollutants. Also, comparing the full scale with Nawag pilot scale performance.

MATERIALS & METHODS

A) Demo full scale plant

Demo, housing and educational complex consists of one hundred house buildings, seventy four were constructed and the remaining twenty six are under construction, in addition to four schools (the secondary school, commercial secondary school, technical secondary school and the handicapped school), also there is a scientific inventions center and a health unit. The area of Demo complex is a rectangular area reaches 70 feddan, the permanent populat-ion is 10000 capita and the total average wastewater discharge is 1678 m^3/d. The HABRs receive settled wastewater from septic tanks via a small bore sewer network consists of (u.P.V.C) pipes ranging in diameters from 4 to 8 inches. The treated effluent from the HABRs is collected again via a network of pipes extended to a 3 m in diameter pump station. At the pump station, the effluent is aerated and disinfected in order to be discharged by two submersible pumps (1+1) via a 8 inch force main to the drain 4500 m away from Demo. This system has the advantage that, there is no definite site combining the treatment plant components, but these components are distributed within the whole area of the complex as shown in figure (1).

The HABRs were designed to achieve 2.5 days hydraulic retention time (HRT). Four large reactors were constructed, and seven existing septic tanks were reformed to be house HABRs. The four large HABRs (1 reactor 750 m^3 and 3 reactors 550 m^3) are distributed within the housing area as shown in figure (1). The media used in all tanks is plastic with a specific surface area of 80 m^2/m^3 and an average depth of 1.0 m as shown in figure (2). All reactors are constructed from reinforced concrete as shown in figure (3). Table (1) shows the summary of the HABRs dimensions.

Table (1) Demo HABRs Dimensions

Model	Vol. (m^3)	N	Dimensions (m)	No. of compartm
1	750	1	22*11.5*3	4
2	550	3	22*8.4*3	4
3	75	7	8.5*3.5*2.	3

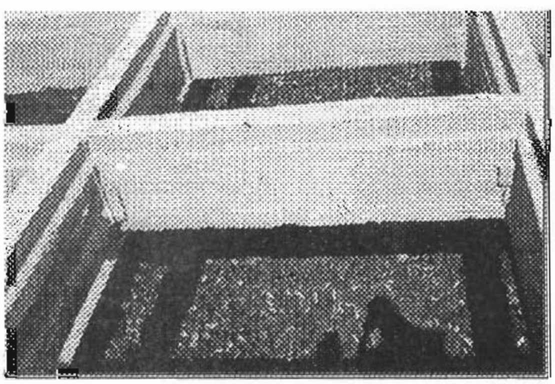


Fig. (2) Demo HABRs biological media

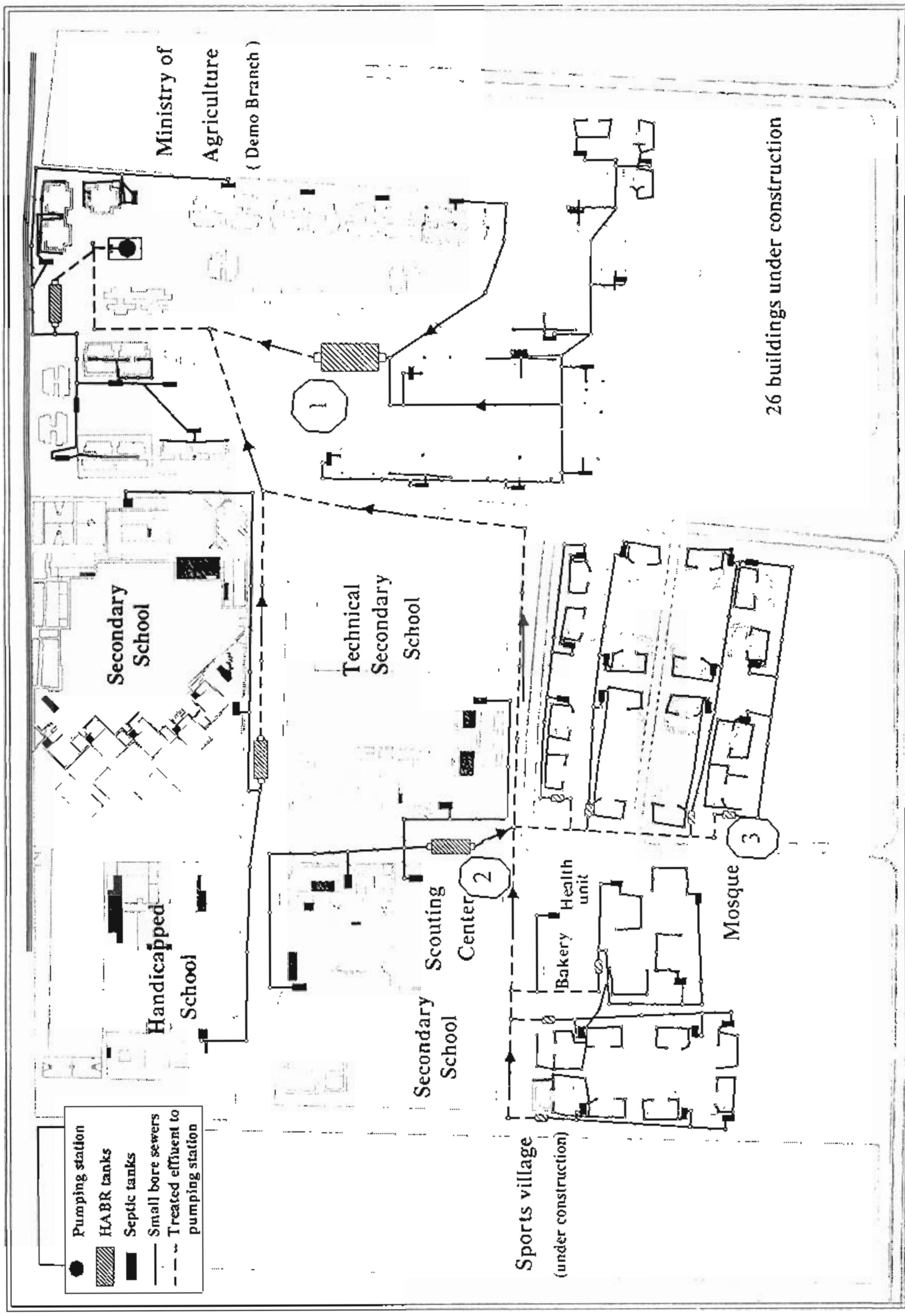


Fig. (1) Layout of the large Scale project at Demo

Three HABRs were selected to be studied, in addition the pump station. The sampling points were from the inlet and the outlet of the units except the pump station at which samples were taken from the well. The selected Units are shown in figure (1) and they are as follows:

- HABR1 with volume 750 m^3, which serves part of the 46 house buildings.
- HABR2 with volume 550 m^3, which serves the secondary and commercial secondary schools in addition to the scientific inventions center.
- HABR3 with volume 75 m^3, which serves part of the 8 house buildings.
- The pump station.

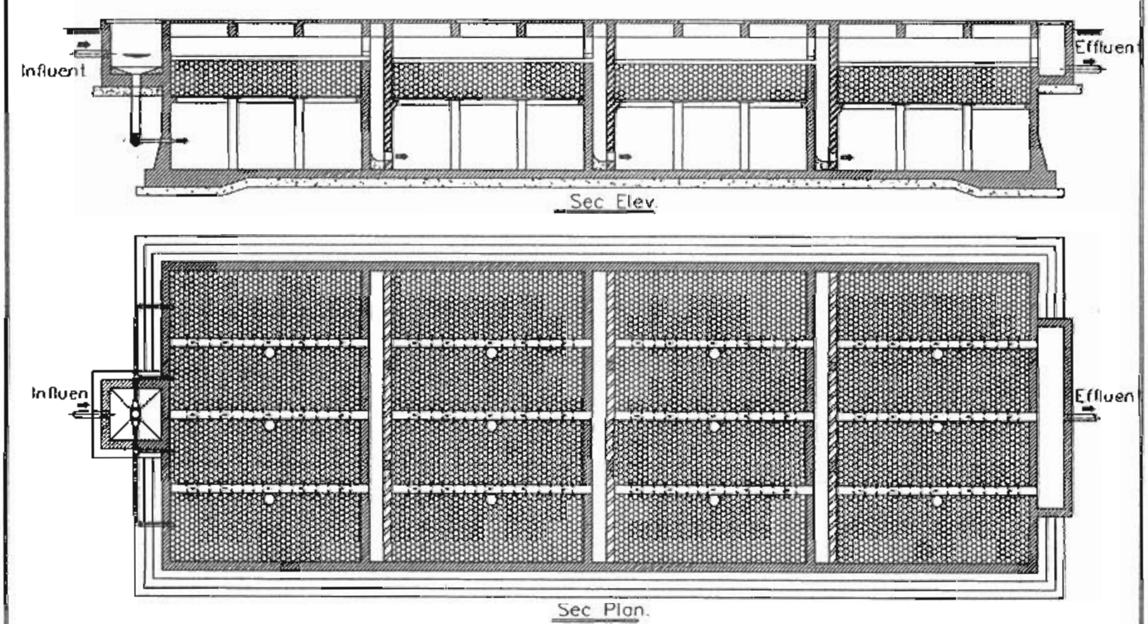


Fig.(3) sections in the HABR at Demo

B) Nawag pilot plant

Four reactor trains were constructed each with a total volume of 800 liters (0.8 m^3). Figure (4) shows section elevation of the pilot plant and its components. To achieve the baffling configuration (compartmentalization), 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, (Khalil, 2002). Table (2) gives a brief summary for the reactors configuration. The average influent COD was 300 mg/l and the average SS was 175 mg/l, Various HRT were applied (3.5, 2.5, 1.5, 1, 0.5) days.

From the analysis of Nawag pilot plant results, Khalil 2002 mentioned that the HRT of 2.5 days was the most suitable and satisfying retention time to be applied, in order to obtain high removal ratios for COD and SS, also HABR with plastic media achieved the best performance. Finally there was no need for pH or temperature control. Thus, the HABRs of Demo were designed to achieve a HRT of 2.5 days using plastic media according to the recommendations obtained from the pilot study.

Table (2) Details of the pilot plant HABRs of Nawag

Item \ Reactor	1	2	3	4
Volume (m^3)	0.8	0.8	0.8	0.8
Compartment numbers	4	4	4	4
Type of media	Plastic	none	gravel	gravel
Depth of media (m)	0.6	--	0.3	0.6
Specific surface area (m^2/m^3)	100	--	60-65	
Void ratio (%)	97	--	40 – 50	
Mass/unit volume (kg/m^3)	20 – 25	--	1200 - 1400	

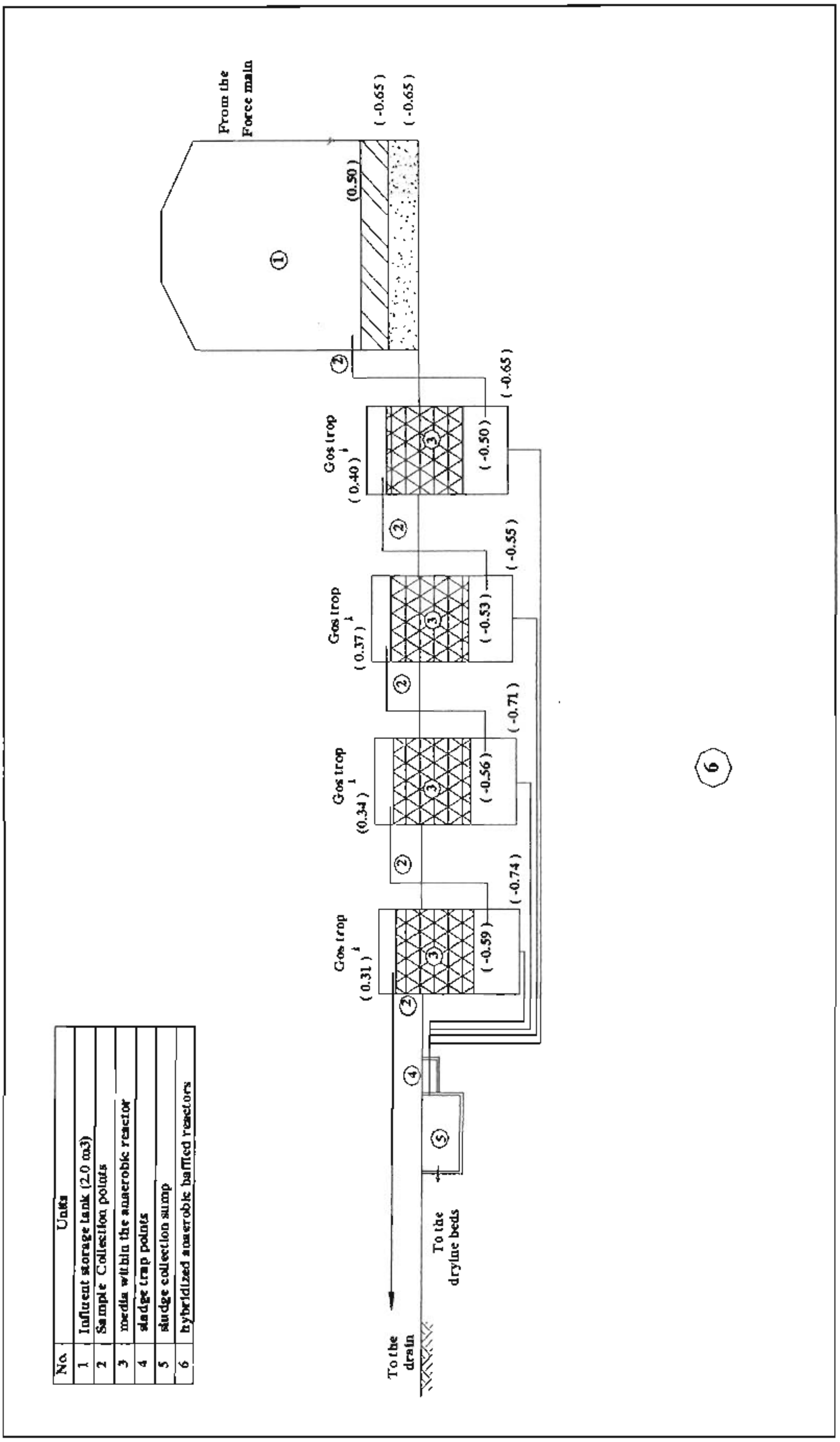
Samples were collected from the inlet and outlet of the previous mentioned studied HABRs at Demo and from the inside of the pump station. Samples were analyzed according to the Standard Methods, 1992 in order to measure the chemical oxygen demand (COD), suspended solids (SS), pH.

RESULTS & DISCUSSION

This section deals with the discussion of the results obtained from the analysis of Demo samples as well as, comparing its results with Nawag pilot plant results (only with the 2.5 HRT and plastic media HABRs).

A) COD Removal Ratios

Table (3) summarizes the achieved COD removal ratios for the different HABRs at Demo. It can be noticed that the average removal values are nearly the same except for HABR2. These values are (53.08 ± 4.53), (30.10 ± 10.65), (53.82 ± 5.20) for HABR1, HABR2, HABR3 respectively, while the average COD removal ratio for Nawag plant was (83.12 ± 1.24). The difference between the results of pilot and large scale plants refers mainly to the inconvenient



Fig(4) shows the section elevation of the pilot plant

HRT (2.5 days) which is too high for the low strength wastewater at Demo plant. This is also implemented by the argument that low hydraulic retention times (6 - 2) hours are feasible during low strength treatment (Orzco, 1988). Confirming such hypothesis, the performance of both building HABRs (1, 3) is nearly the same while, the schools HABR2 gave a very low performance. Figure (5) shows the COD removal ratios for the studied HABRs while, figures (6) illustrate that the influent wastewater strength at Nawag is high (250-350 mg/l) compared to what found at Demo (Max influent COD = 130 mg/l) due to the presence of septic tanks. HABR2 usually has very low influent and effluent COD and SS values accordingly too removal ratios, because it receives its wastewater from the septic tanks of the secondary schools, these schools work a limited time during the day, as well as some months during the year, so this tank could be omitted.

Table (3) COD Removal Ratios for HABRs

HABR \ %COD removal	Average	Standard Deviation	Max	Min
HABR1	53.08	4.53	61.86	44.83
HABR2	30.10	10.65	50.0	7.69
HABR3	53.82	5.20	61.11	33.33
NAWAG	83.12	1.24	84.76	81.33

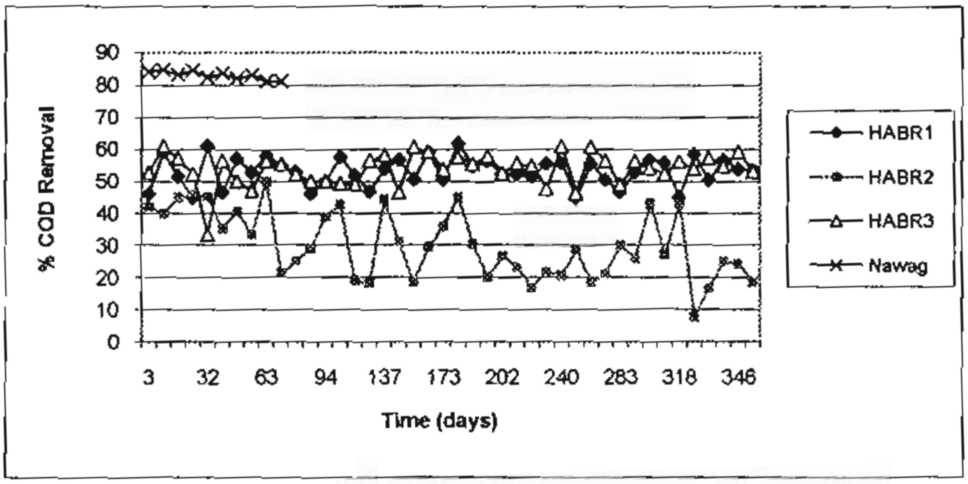


Figure (5) COD removal ratios for the HABRs

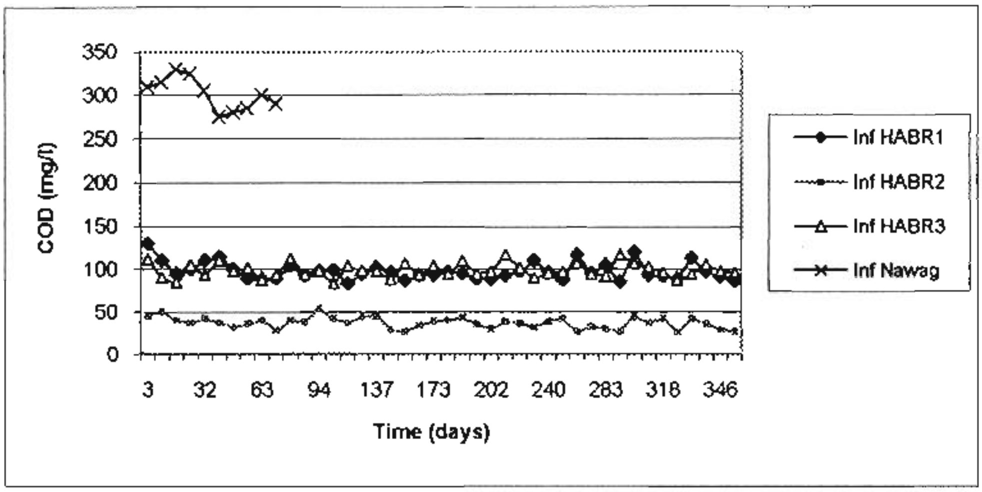


Figure (6) Influent COD values for the HABRs

B) SS Removal Ratios

Table (4) summarizes the achieved SS removal values for the different HABRs at Demo. It can be noticed that the average removal ratios are close to each other for Demo Plant except for HABR2. These values are (54.49 ± 5.65), (45.45 ± 5.56), (51.45 ± 8.27) for HABR1, HABR2, HABR3 respectively, while the average SS removal ratio for Nawag plant was (83.58 ± 2.92). It is logic to have low removal ratios for SS from Demo plant according to the fact that SS represents the major COD fraction in domestic sewage thus, low removal of SS will lead to low removal of COD and vice versa. Figure (7) shows the SS removal ratios for the studied HABRs. It can be noticed that the influent SS concentration at Nawag was high (150-200 mg/l) compared to Demo influent concentrations figures (8). The achieved SS removal of Demo plant is much lower than anticipated from the previous pilot work experience. This is certainly due to the low SS concentration in the influent.

Table (4) SS Removal Ratios for HABRs

%SS removal / HABR	Average	Standard Deviation	Max	Min
HABR1	54.49	5.65	70.59	40.68
HABR2	24.95	9.65	45.45	5.56
HABR3	51.45	8.27	70.79	31.58
NAWAG	83.58	2.92	87.65	78.92

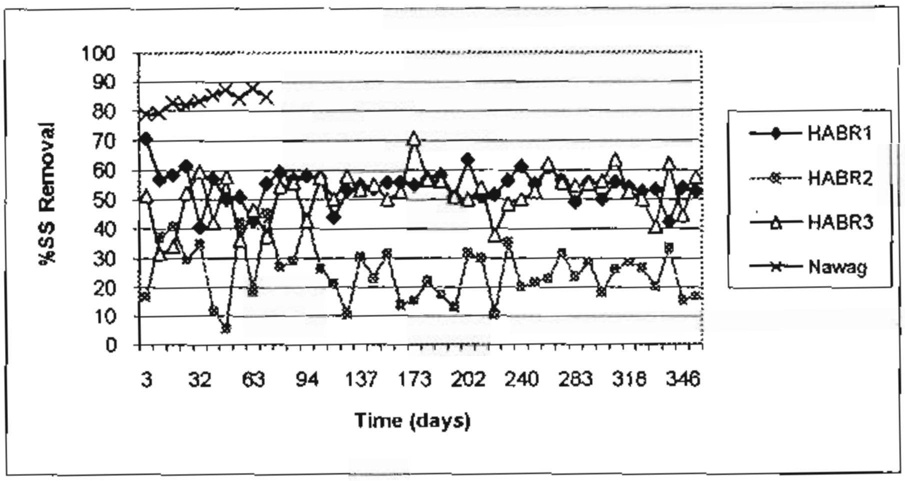


Figure (7) SS removal ratios for the HABRs

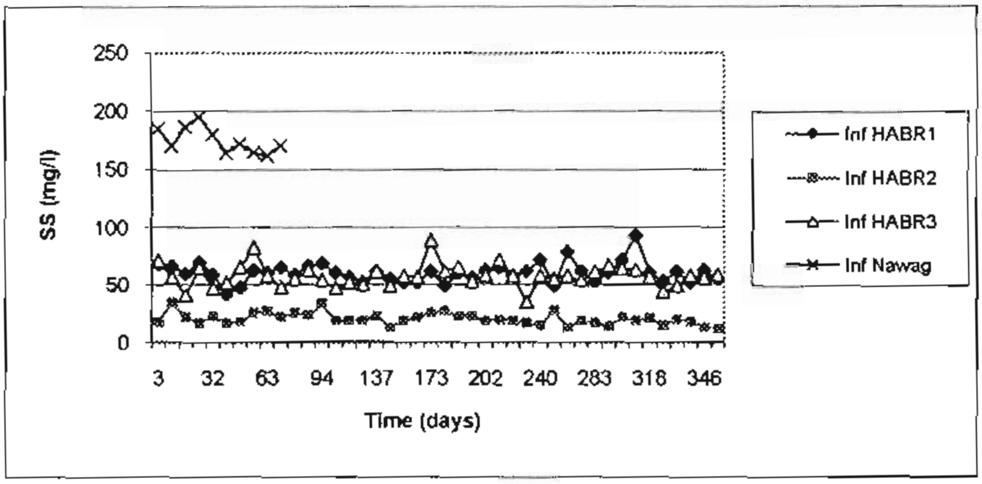


Figure (8) Influent SS values for the HABRs

C) pH Variations

Table (5) shows the variation of the influent pH for the studied HABRs. The average influent pH was (7.27 ± 0.17), (7.30 ± 0.18), (7.28 ± 0.18) for HABR1, HABR2, HABR3 respectively. Table (6) shows the effluent pH variations which were (7.25 ± 0.18), (7.29 ± 0.21), (7.31 ± 0.16) for HABR1, HABR2, HABR3 respectively. The pH variation range was not tangible and all the values were vibrating around the neutral value making a suitable environment for the methanogenic bacterial activity, figures (9,10) show the influent and effluent pH variations for the studied HABRs. With regard to Nawag plant the pH was studied for the reactor along its four compartments, the average influent pH was about 7.25, it was decreased in the first two compartments due to the acidogenic activity and reached about 7.10 and then started to increase again in the last two compartments due to the methanogenic activity till it reached its final value which equals 7.60, (Khalil, 2002).

Table (5) Influent pH variations for HABRs

Influent pH / HABR	Average	Standard Deviation	Max	Min
HABR1	7.27	0.17	7.60	6.80
HABR2	7.30	0.18	7.70	6.80
HABR3	7.28	0.18	7.60	7.0

Table (6) Effluent pH variations for HABRs

Effluent pH / HABR	Average	Standard Deviation	Max	Min
HABR1	7.25	0.18	7.70	6.70
HABR2	7.29	0.21	7.60	6.70
HABR3	7.31	0.16	7.60	7.0

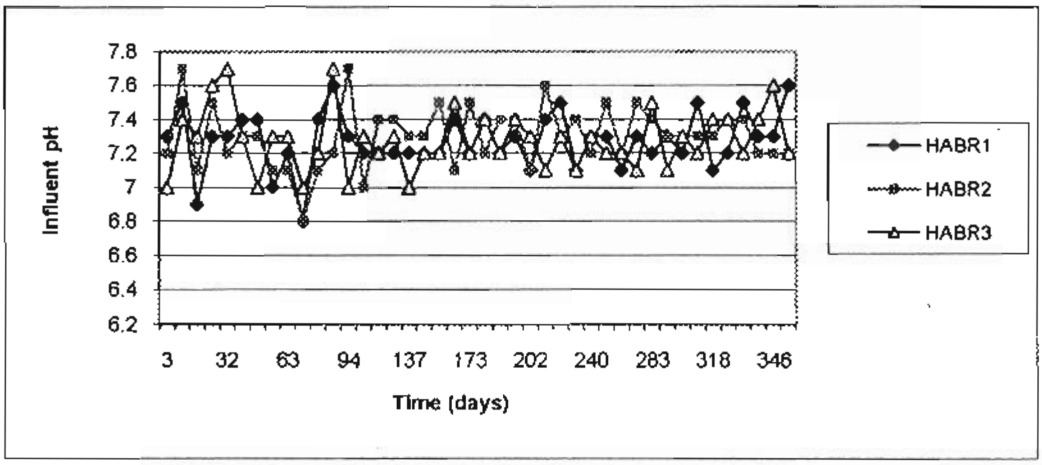


Figure (9) Influent pH variations for the studied HABRs

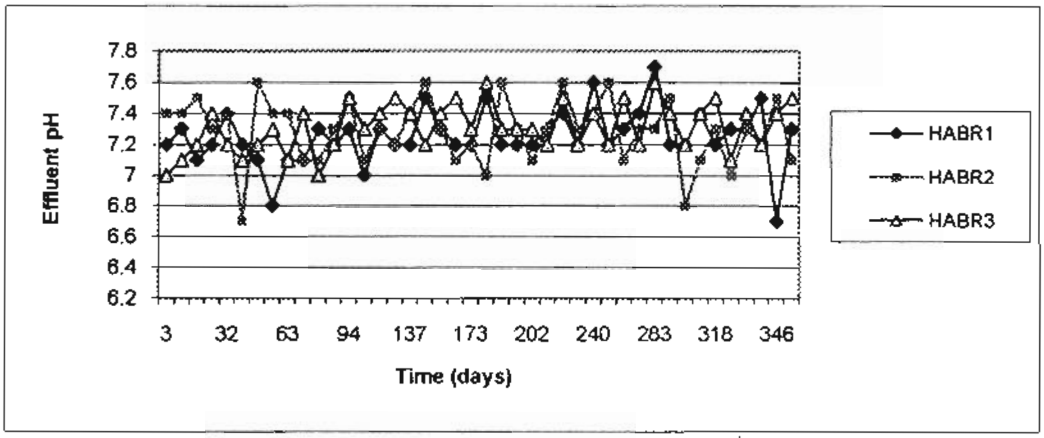


Figure (10) Effluent pH variations for the studied HABRs

Pump Station Results

- ***COD Variations***

From table (7), the average obtained COD concentration inside the pump station was 42.64 mg/l with standard deviation of 4.44. The mode was equal to 43 mg/l and the median was equal to 43 mg/l, which means that the averages have nearly the same value. The maximum COD concentration was 53 mg/l and this is also not far from the average value while, the minimum was 34 mg/l. The COD concentration inside the pump station during the study period didn't exceeded (even the maximum value) the Egyptian limitations that organizes the disposal of the treated wastewater to the drains, which must not exceed 80 mg/l. Figure (11) shows the COD variation inside the pump station during the field study period.

Table (7) COD variations inside the Pump Station

COD / Parameter	Average	Median	Mode	Standard Deviation	Maximum Value	Minimum Value
Inside P.S	42.64	43	43	4.44	53	34

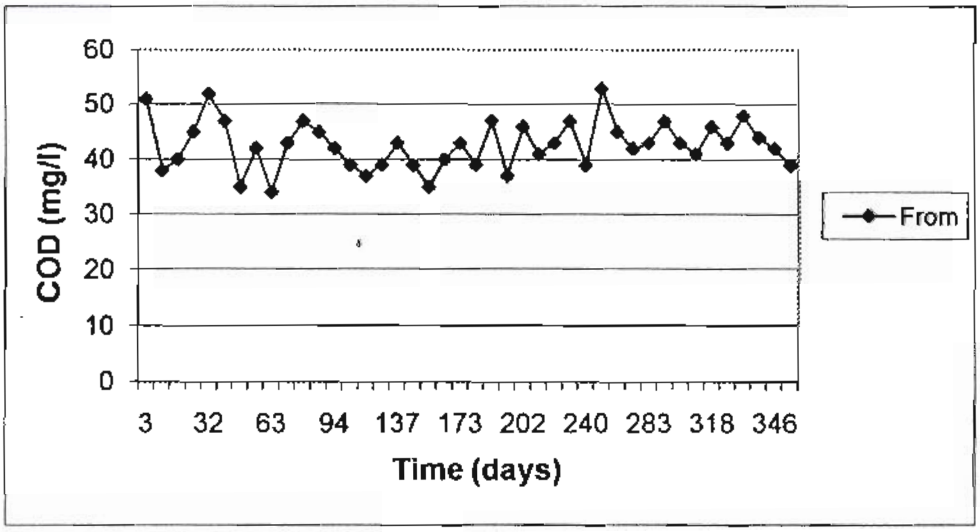


Figure (11) COD concentration inside the pump station

- ***SS Variations***

Table (8) shows that the average obtained SS effluent concentration inside the pump station was 27.69 mg/l with standard deviation of 3.85. The mode was equal to 24 mg/l and the median was equal to 27 mg/l. The maximum SS concentration was 39 mg/l while, the minimum was 22 mg/l. The SS concentration values are very low if it is compared with the

Egyptian specification which limits the maximum SS concentration in the treated wastewater not to exceed 50 mg/l. Figure (12) shows the SS concentrations inside the pump station during the study period.

Table (8) SS variations inside the Pump Station

SS / Parameter	Average	Median	Mode	Standard Deviation	Maximum Value	Minimum Value
Inside P.S	27.69	27	24	3.85	39	22

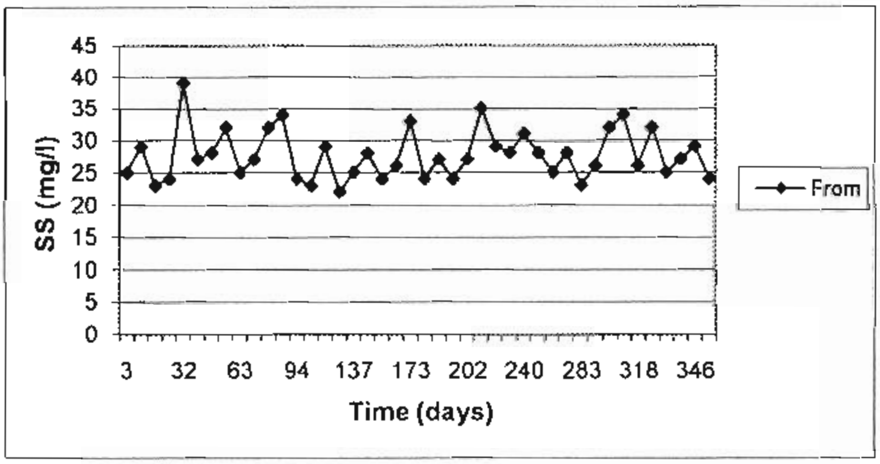


Figure (12) SS concentration inside the pump station

- ***pH Variations***

Table (9) shows that the average pH within the pump station was 7.30 with standard deviation of 0.13. The mode and the median have also the same value that equals 7.30. The maximum pH value was 7.6 while, the minimum was 7.10. According to the Egyptian specifications for the disposal of the treated wastewater to drains, the allowable pH range is between 6.0 and 9.0. The achieved pH is coinciding with the limits. Figure (13) shows the influent and effluent pH variations along the study period inside the pump station.

Table (9) pH variations inside the Pump Station

pH / Parameter	Average	Median	Mode	Standard Deviation	Maximum Value	Minimum Value
Inside P.S	7.30	7.30	7.30	0.13	7.6	7.1

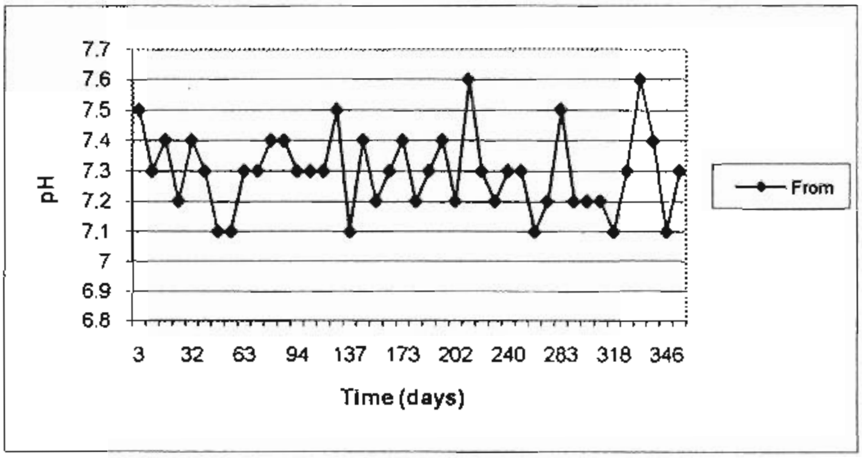


Figure (13) pH Variations inside the pump station

CONCLUSIONS

- The full scale HABR at Demo achieved an effluent wastewater quality cope with the Egyptian standards but, the performance was not as anticipated from the pilot study experience.
- The design HRT of 2.5 days was not the appropriate HRT to be applied for Demo because of the low strength wastewater and the bacterial starvation especially along the last compartments of the HABRs.
- The maximum achieved COD removal for the large scale HABRs was 61.86%, while the maximum SS removal ratio was 70.59% and in general the most frequented removal ratios for COD and SS were around 50 % differing from the pilot scale HABR which achieved average removal ratio of 83.12% and 83.58% for COD and SS respectively.
- The specific surface area of the plastic media used in HABR should be more than 100 m2/m3 according to the results obtained from the pilot plant.
- There was no need for pH control because it was always at the required pH range (6-9).

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