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Non-Conventional Municipal Wastewater Treatment System Suitable for Egyptian Villages and Small Communities.

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ABSTRACT

The aim of this study is the development of a decentralized low-cost system for municipal wastewater treatment and reuse. The integrated system comprises two successive stages namely Horizontal Flow Biofilm Reactor (HFBR) followed by as low sand filter. The HFBR was constructed and verified for the removal of organic carbon and nutrients, whereas sand filter was operated mainly to get rid of *Faecal coliform* which was the main contaminant in the HFBR effluent. To determine the optimum load for HFBR, the system was continuously operated under three hydraulic loads equal 2.7, 3 and 4.5 m^3/m^2/day, with Organic loading rate 0.9; 1 and 1.4 kg COD/m^2/day. The results proved that, the optimum HRL was 3m^3/m^2/day, which gives high removal efficiency of COD and TSS of 82% and 86%, respectively. Also, this load was economically feasible to apply as the treatment cost of 1m^3 equal 4.96 L.E. The HFBR unit gave a high physico-chemical quality of effluent, but *Faecal coliform* was decreased by only 2-3 logs with a residual value of 2.7×10^5.Thus treated effluent needs further treatment to comply with the Egyptian legislation for reuse. The effluent of this load was chosen to feed continuously to the sand filter. Slow sand filter (SF) was constructed and operated as a post-treatment under two surface loading rate equal 0.159 and 0.37 m^3/m^2/day. The integrated system proved high removal efficiency of COD and BOD reached 91% and 92%, respectively whereas, the total nitrogen removal reached 69%. Bacteriological analysis proved that the system is successfully removed 4 to 5 logs of *Faecal coliform*. Characterization of the treated effluent is complying with Egyptian legislation for irrigation. The integrated system has many advantages; a small footprint; cost effective and also, its excellent quality of the treated effluent; thus, the system proved to be a promising treatment technology for municipal wastewater suitable for rural and urban areas.

Keywords: Wastewater treatment, pathogens, sand filter, reuse, agricultural irrigation.

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INTRODUCTION

In Egypt only about one-third of the population is connected to sanitary sewers. Egyptian villages are experiencing a major threat represented in groundwater contamination, caused by untreated sewage. There are about 4200 villages along with 2700 satellites, of the total population of about 40 million capita; less than 5% of these rural areas are served by proper sanitation and hygienically acceptable systems, and the remaining is served with the earth pit privy [1]. This, in turn, is creating great pressure on the Egyptian government to urgently find appropriate low-cost solutions for sewage treatment. The government faced a lot of impediments in the installation of traditional wastewater systems in rural areas due to the associated high operation, installation and maintenance costs [2]. Also, the Egyptian villages, where land is scarce and very expensive, it is wise to search for another non-conventional system which can save the land. HFBR can address many of the problems encountered by small-scale municipal wastewater treatment system for the following advantages; (i) simple and low cost technology (ii) small footprint (iii)to meet higher standards of nutrient removal, (iv) to retrofit poorly performing septic tank systems with the HFBR technology and, (v) as a low energy and low maintenance wastewater technology[3 &4]. The pilot scale study of HFBR proved that the system gives high effluent quality with an average carbon and nitrogen removal reached 95% and the *Faecal coliform* removal was ranging between 2 and 3 logs [5]. El-Kamah [6], stated that HFBR effluent characterization complies with the Egyptian legislation for reuse except for the *Faecal coliform* count thus the effluent needs further treatment to remove *Faecal coliform* to comply with the reuse legislation. The sand filter is the most appropriate post-treatment technology for HFBR effluent, as it considered simple, low-cost technology and it offers opportunities to reuse treated effluent for irrigation. Also, the estimated power consumption of the integrated system of biofilm system and sand filter is 0.6 kWh/$m^3$of treated wastewater which is equivalent to 0.6 kWh/kg COD removed[7],which considered very low cost compared with other conventional treatment system.

Sand filters are able to remove residual suspended solids, turbidity, organic matter and achieve simultaneous nitrification–denitrification and can produce effluent, total TKN and TN concentrations as low as 0.6 and 1.5 mg/l, respectively[8]. The single-passedpacked-bed sand filter was used to eliminate nitrogen from septic tank effluent which contains ammonia as the main nitrogen form[9]. and the mature packed-bed filter was effective in complete oxidation of ammonia (33.9 mgN/l, on average) into nitrate (38.1 mgN/l). Removal of nutrients as well as bacteria and parasites from wastewater was investigated using lab scale of combined multi-soil-layering system and sand filters [10]. At low HLR (100 l/m^2.d), the removal percentage of SS, BOD5, COD, TN, and TP were 99.73, 97.78, 98.40, 92.93 and 96.21%,respectively while log removal of *Faecal coliform* was 4.47 and total elimination of helminth eggs. Biofilm or biomass development reduce the free porosity allowing better filtration and increase water retention (HRT) with significant improvement of the treatment performance [11]. Torrens [12], proved that sand filter performance depends on the effective depth as filter with 65 cm effective depth provides significantly higher bacterial and viral removal efficiency, than the filter with 25 cm effective depth. Torrens [13], stated that the removal of *Faecal coliform* and Escherichia coli were similarly between 0.5 and 2 log units with an average removal of the indicators less than 2 logs. On the other hand, over-one-year monitoring period, the data of three different pilot-scale sand filters highlights the importance of filtration media and climatic conditions[14], while the results of microbiology showed that the sand filters can remove up to 5logs (4.6-5.4) of indicator bacteria.

The aim of this study to examine the performance of the continuously fed up-flow sand filter (USF) when used to polish and remove pathogen from HFBR effluent. The study specific objective is to improve the quality of HFBR treated effluent to comply with the Egyptian legislation for reuse.

MATERIALS AND METHODS

The pilot plant treatment system consists of HFBR as a pre- treatment unit for treatment organic matter and nitrogen from domestic wastewater. The treated effluent was subjected to post- treatment unit using sand filtration. A schematic diagram of the integrated system is shown in Figure (1).

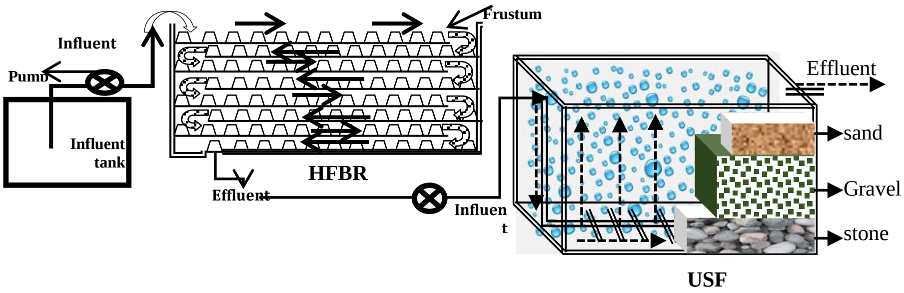


Figure (1) Schematic of the integrated treatment system

HFBR Design:

The outer frame of the reactor is constructed from polyvinyl chloride (PVC) sheets. The reactor is consisted of five stages each consists of eleven sheets Figure (1), this make it consists of 55 sheets as total. These sheets were placed and alternately offset to allow the wastewater to flow horizontally along each sheet and vertically from sheet to sheet down through the reactor[5]. The total plan surface area TSA of the sheets was equal 18.17m^2. The screened sewage was pumped continuously from a feed tank using a peristaltic pump into the top sheet of the reactor and flowed over and back along alternate sheets and down from sheet to sheet- sequentially through the unit and so, on down through the reactor. The reactor was installed and operated at Zenin wastewater treatment plant under natural conditions.

Up-FlowSand Filter (USF) Unit, Design and Operation

The sand filter unit consists of, PVC box, has adepth 0.6m, length1.0m, and width 0.7m. The unit was filled with locally available natural sand. The sand was sieved mechanically on a set of sieves. Before filling it into the unit, the sand thoroughly washed with water to remove clay and other mineral contaminants. To produce better quality effluent the up- flow sand filter was filled with 10cm layer of gravel(20-25mm) in the bottom, and then followed with three layers of coarse sand with 10 cm thickness; the size of the sand was ranging from 12mm to 0.5 mm. A specific sand material has an effective size 0.5 mm and uniformity coefficient equal 1mm Table(1).The selected sand is generally described by their effective size (*e.s*) and uniformity coefficient (*u*),the *e.s* is the 10 percentiles size, i.e only 10% of the filter sand by weight. The (*u*) is ratio of 60% size to 10 % size[15]. The effluent of the HFBR was fed continuously to the up-flow sand filter, it was operated at two surface hydraulic loading rate namely, 0.2 m^3/m^2/d and 0.45m^3/m^2/d. this HLR were chosen because the suspended solids in HFBR effluent was less than 20mg/l. According to [15]the typical hydraulic loading rates on single stage filter ranged from 0.37 to 0.56m^3/m^2.d. If the suspended solids in the influent to filter will routinely exceed 50 mg/l, the hydraulic loading rate should be reduced to 0.19 to 0.37 m^3/m^2.d.

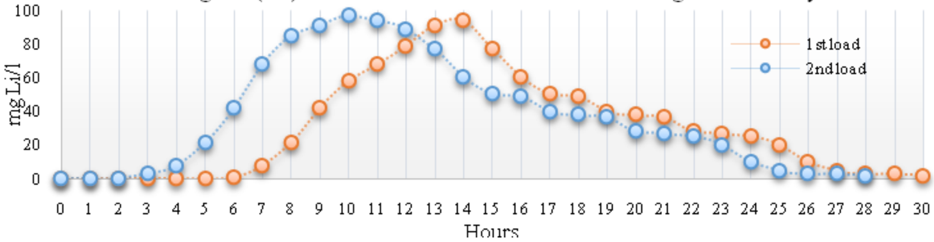
Table 1: Operating conditions and dimensions of the up-flow sand filter (USF)

parameters	Units	USF
Depth	m	0.6
Area	m^2	0.56
Sand effective size (e.s)	m.m	0.5
Sand uniformity coefficient (u)	m.m	1
Gravel effective size	m.m	1.5
Gravel uniformity coefficient	m.m	2.5
Organic loading rate		
• First load	m^3/m^2.day	0.2
• Second load		0.45

Tracer study

Tracer study using lithium was conducted to calculate detention time of the sand filter during operation. Measurements of concentration of lithium ions in the filter effluent showed that a first break through of tracer occurred after 4hrs.and 2hrs. during first and second load, respectively. The highest lithium concentration was measured after 14hrs. at the first load and after 10hrs. at second load(Figure 2) this figure represent the detention time of the sand filter during this study.

Figure (2) Detention time determination using tracer study



Performance and Characterization of Raw and Treated Wastewater

The performance of the treatment schemes was evaluated by monitoring the quality of the raw wastewater and treated effluent of each unit. The physico-chemical characteristics covers the following parameters: pH-value, total suspended solids (TSS), total phosphate (TP), chemical oxygen demand (COD), biological oxygen demand (BOD), oil & grease and total Khjeldahl nitrogen (TKN), which includes organic nitrogen and ammonia. Analyses, were carried out according to [16].

Bacteriological Examinations:

Bacteriological examinations include *Faecal coliform* identification and count. The examination was carried out as recommended by [16].

RESULTS AND DISCUSSION

Characterization of Raw Waste water

Characterization results of raw wastewater and HFBR treated effluent recorded in Table (2). The strength of the feed municipal wastewater was at a medium strength[17].Average concentration of COD,BOD,TSS and oil& grease were 308,171,164and 43mg/l, respectively. The Bacteriological examination showed that raw wastewater has an average count of *Faecal coliform* equal $4.5\times10^7\pm5.8\times10^7$ MPN/100ml, which is comparable to the data in the literature review of the urban municipal wastewater in Cairo.

From the available data, it is clear that raw domestic wastewater has count of *Faecal coliform* above the medium strength. These results are comparable to the published data of raw sewage in Egypt. Hala [17],reported that *Faecal coliform* count of 6.4×10^6MPN/100ml in raw sewage while, El-Shafai [18 & 19], reported that, average count of 2.8×10^8 and 2.1×10^8cfu/100 ml for *Faecal coliform* in raw and settled sewage during the summer period.

Performance of HFBR

As the wastewater pass through HFBR, COD concentration reduced in each stage. Figure 3, illustrate the profile concentration of COD and TSS after each stack of sheets (11 sheets). It is clear that the highest removal for COD and TSS after the first 11 sheets, with a removal percentage reached 46% and 50%, with a residual concentration of 160.6 and 75.8 mg/l for COD &TSS, respectively, these results is also proved by Rodgers [3]. The removal percentage decreased by 10% after second and third stack of sheets. After the fourth stack, it decreased by only 5% and reached 15% and 16% for COD and TSS, respectively. Thus, there was no significant reduction in concentration between third and fourth stack. After, the final stack, the removal percentage increased, and reached 32% for TSS and 28% for COD. Table 2&Figure3 showed that, the COD concentration reduced to 54mg/l in the final effluent with an average value of 82% removal, this means the average of organic areal removal is about 13.9 g COD/m^2.dand for soluble COD is 7.6 g COD_{sol}/m^2.d,this value based on total sheet surface area. This value is much higher than achieved by Rodgers [3], who reported that HFBR remove 1.8gCOD_f/m^2.d. Organic removal of 3.1 g COD/m^2.d was reported by Verho even and Meuleman [20], for constructed wet land. Also, TSS concentration reduced to 23mg/l, with an average 86% removal percentage. Final removal percentage of BOD and Oil & Grease were 86 and 83% (Table 2),with average residual concentration values of25and 8.6 mg/l, respectively.

Table 2: Characters of raw wastewater and treated effluents

parameters	Wastewater	HFBR		Sand filter			
				Load 1	St.Dev.	Load 2	St.Dev
pH-value	7.5	7.7	± 0.3	7.9	± 0.2	7.2	± 0.1
COD_{tot}	308	54	± 20	17.9	± 6	16	± 9
COD_{sol}	160	22	± 10	8.9	± 4	7.6	± 6
BOD	171	25	± 11	9.8	± 2.4	10	± 2.7
TSS	164.6	23	± 9	9.7	± 1.9	7.9	± 2.4
T. P	2.1	1.1	± 0.3	1.2	± 0.7	0.7	± 0.1
T.K.N	49.5	15	± 8.7	9.1	± 2.6	11.7	± 3.4
Ammonia	23.7	6.8	± 5.6	4.7	± 2.3	6.9	±1.3
Nitrite	0.1	0.7	±0.5	0.9	± 0.6	0.3	± 0.1
Nitrate	0.3	8.6	±4.6	1.7	± 0.7	1.3	±0.4
Oil & Grease	43.6	8 .6	± 4.8	0	0	1.5	±1.3
Faecal coliform	4.5E+07	1.5E+05	± 1.3E+05	1.1E+04	1.9E+04	2.9E+03	±3.0E+03

There is low decrease in Ammonia concentration values, the first 44 sheets gave removal percentage values ranged between 11 to 15%, but from sheet 44 onwards it increased to 45%, thus the final removal percentage was 72%, with average residual concentration value of 7mg/l. Maximum removal value of total nitrogen was from sheet 44 onwards the nitrogen reduction was 37%, thus final removal of the system was 68%, with a residual concentration value of 16mg/l (Table 2 &Figure 4&5).The nitrogen removal may be due to cell synthesis and denitrification in anoxic zone of the biofilm system [3].

The HFBR provided treated effluent with *Faecal coliform* count ranging from 6.0×10^{4}and 2.8×10^{5}cfu/100ml (Table 2), which is more or less similar to the microbial quality of the activated sludge effluents and biofilm reactors treating municipal wastewater. *Faecal coliform* density has decreased by an average of 2 logs and has an average residual count of 5logs.

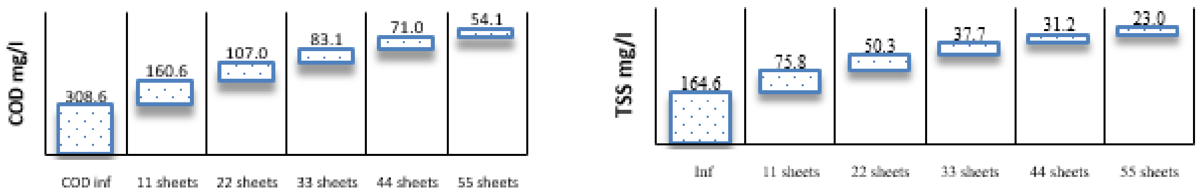


Figure (3) Profile of COD & TSS Down through the sheets of HFBR

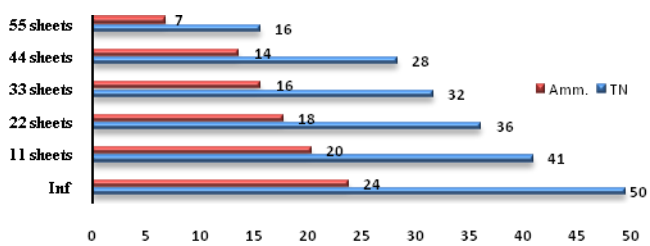


Figure (4)Profile of TN and Amm. concentration down through HFBR sheets

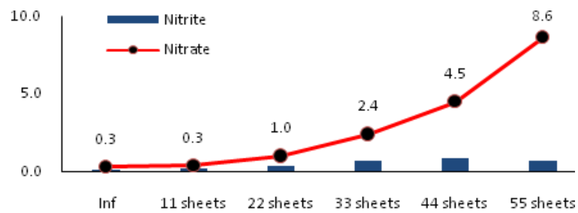


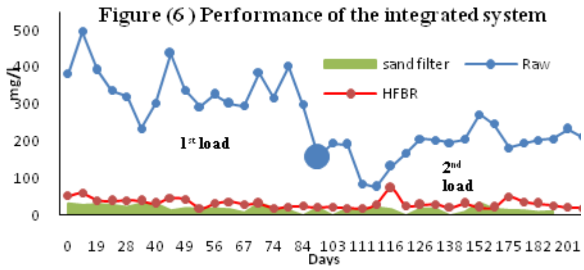
Figure (5) Profile of Nitrate and Nitrite Down through HFBR sheets

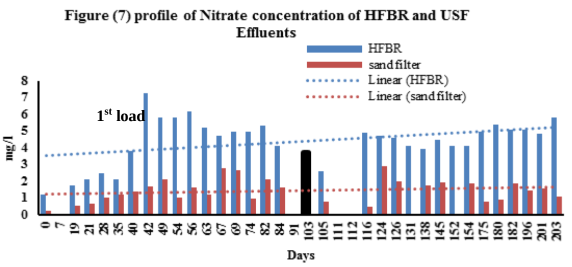
It is clearly showed that HFBR have high removal efficiency of carbon, nitrogen and suspended solids but the main problem for safe reuse of the treated effluent is the pathogen concentration which is not compatible with national legislation for safe reuse, thus, there is an essential requirement for post treatment as sand filter which was applied in this study.

Up-Flow Sand Filter Performance

The effluent of the HFBR was contiuously fed to the up-flow sand filter (USF). The sand filter was operated at two surface hydraulic loading rates namely0.2 $m^3/m^2/d$ and 0.45 $m^3/m^2/d$. The system was working for 200 days. During the study period, there was no clogging during the two operating loads, this may be dependent on the up-flow distribution of the influent to use the hall infiltrative area and also help the biological degradation process to tack place. Stevik[3], stated that, the distribution of a dose over the filter surface can avoid fast localized preferential flow paths and utilize more of the filter surface and depth volume. The performance of the (USF) during the first and the second load represented in Table (2). The available data indicated that the variation of the load have no significant effect on the removal efficiency(Figure 6). During the first loading rate, average residual concentration values of COD, BOD and TSS were 18, 10 and 10 mg/l, respectively with average percentage removal values of 42, 39 and 41%,respectively. During the second load, average residual concentration values of the COD, BOD and TSS were 16, 10 and 8 mg/l with average removal efficiency were 50, 31 and 46%, respectively.

Nitrate, is the form of nitrogen that is the primary focus of nitrogen removal technology because of its mobility in groundwater. Nitrate concentration in HFBR effluent was high it reached 16.6 mg /l, with an average 8.6mg/l, after sand filter nitrate average removal percentage was 63% in first load and 75% in the second load, with average residual concentration values of 1.7mg/land 1.3mg/l, respectively (Figure 7) this could be attributed to denitrification process due to the absence of oxygen in the USF.





The data of the bacteriological quality showed that, the sand filter was able to reduce the *Faecal coliform* count by 1 and 2 log during the two hydraulic loads, respectively (Table 2). In spite of the higher count in the effluent of the sand filter during the first load (low HRL), the sand filter was less efficient and provides less removal (low log removal value) comparing to the second run with the higher loading rate. This might be attributed to the impacts of longer operation period which enhance more biofilm growth around the sand and so more efficient removal during the second run in spite the high loading rate, as the main removal mechanism are physical straining and adsorption [15].

Performance of the Integrated Treatment System

The integrated system used in this study (HFBR+USF) gave high quality effluent; results recorded in Table (3) prove that the final effluent characterization is complying with Ministerial Decree for reuse and it confirms with class B, which allows the irrigation of fruit trees with peeling, roses, ornamental plants***, fiber crops (e.g Flax),*** berry used for silk production ***and*** crops for animal fodder. The system gave high removal efficiency of carbon as well as nitrogen. The results recorded in Table 3 showed that the final COD & TSS removal percentage were almost the same 92%. Average removal of ammonia was reach 75%, where total nitrogen was 71%. The System succeeded in removing 4.2 log of *Faecal coliform* from raw wastewater.

Table (3) Performance of the integrated system

Parameters	Raw	Final Effluent HFBR+USF	Final Removal	Egyptian Legislation
pH	7.5	7.2		6-9
COD mg/l	308	16	92%	80
BOD mg/l	171	10	92%	60
TSS mg/l	164.6	7.9	91%	50
TN mg/l	49.5	11.7	71%	
Ammonia mg/l	23.7	6.9	75%	
Faecal coliform	4.5E+07	1.9E+03	4.2 log	5000

CONCLUSIONS

In this study, it can be concluded that, Horizontal Flow Biofilm Reactor followed by Up-Flow Sand filter could be considered as promising biological treatment system for treating municipal wastewater from small communities, where treated effluent can be reused for recreational purposes or safely discharge in drains. There is no clogging occurred in HFBR or UFS during the study. The system succeeded to remove 4.2 log of *Faecal coliform*, raising the effluent quality to the permissible limit for reuse.

ACKNOWLEDGMENT

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