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Reclamation of Municipal Wastewater Using Cost Effective Biological Treatment System in Egypt.

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ABSTRACT

Horizontal Flow Biofilm Reactor (HFBR)system with total plan surface area (TPA) of the media 18.17m^{2}was installed in sewage treatment plant and studiedfor two years. The removal efficiency of carbon and nitrogen reached 85% and 56%, respectively. Removal of fecal coliform reached only 2 logs. Algal pond enhanced bylamella settler (APLS)was operated as a post treatment for HFBR system to fulfill the requirements for reuse and reclaimed the treated effluent. The results obtained showed that the use of APLS produced effluent compatible with Egyptian legislations for reuse. APLS improved the removal of nutrients and organic carbon as well as pathogen.Also, lamella settler which installed in the pond enhance the removal of suspended solids which was a huge problem in the traditional algal pond. The APLS removal of total nitrogen was 51% and Fecal coliform removed by 1.6 log with the final count ranged from 10^2 to 10^3 MPN/100ml.The integrated system (HFBR + APLS) has high efficiency for the removal of organic contaminant as well as pathogen, thus it could be suitable for municipal wastewater treatment in small communities because of its relatively low capital & operating cost andsmall foot print.The aim of this study is to develop an innovative pilot plant compact system for decentralized treatment and reuse of domestic wastewater.

Keywords: HFBR, algal pond, lamella settler, municipal wastewater, microalgae, Fecalcoliform, biological treatment.

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INTRODUCTION

Horizontal flow biofilm reactor, proved to be the most appropriate biological treatment system of municipal wastewater treatment in urban and rural areasin developing countries because of its simplicity, low construction& operational costs, small land requirement, low excess sludge production and a high quality of effluent produced from it[1]. Unfortunately, HFBR effluent characteristics don't compatible with the standard regulations for reuse in most of the developing countries because, it still contains a significant number of pathogens. The waterborne disease has raised the public concerns regarding the safety of the water supply and in specific water reuse [2]. The treated wastewater has been used as viable solution of water shortage [3&4]. Thus, there is a persistent need of a post-treatment system to further treat the HFBR effluent. Stabilization pond technology considered the most cost effective wastewater treatment technology for the removal of pathogenic organism, it is mostly suitable for developing countries this is because, it is cheap, easy to construct and they do not require high skilled labor and it is suitable for tropical and subtropical region [5]. The treatment process is achieved by natural disinfection mechanism, depending mainly on the intensity of sunlight and temperature. Since microalgae supply oxygen to non-photosynthetic microorganisms which degrade complex organic material and produce the CO_2 needed for microalgae growth [6].Microalgae produce in the stabilization pond deactivate pathogen by raising pH and DO concentration in the pond effluent[7&8]. Also, it plays a major role in nutrient removal as it consumes high amounts of nitrogen and phosphorous for protein synthesis, and during the raise of pH value which is related with photosynthesis there is also increase in NH_3 striping and P precipitation[9&10]. The most important feature of the oxidation pond is the production of algal biomass which gave the capability to extract a wide range of economic valuable substances for use such as food, cosmetic and pharmaceutical industries as well as biodiesel [11]. Algal biomass, especially of Chlorella vulgaris, is used in aquaculture for feeding purposes [12] and as an additive for animal feed that is rich in vitamins [13].

The hardest challenge facing oxidation pond technology is the algal biomass harvesting or separation process from the treated effluent, this is because:1) the small cell size of algae, it is in the range less than 30 µm, makes separation with filter systems extremely difficult [14 and 15]; 2) the similarity of the density of the algae cells to that of water,[16];3) the algae have negative charge on its surface that results an algal suspensions, especially during the growth phase [17; 18 and 19]. It has been estimated that 20 -50% of micro-algae biomass production cost is deducted to harvesting [20; 15; 21]. Amer et al.,[22], have been estimated that 90 % of the algal biomass production equipment cost in open systems may come from harvesting and dewatering.

El-Kamah et al., [23]; studied oxidation pond as a post treatment for HFBR effluent, they detected that, its high removal efficiency of Fecal coliform, but the algal growth increase suspended solids in the treated effluent thus, they installed duckweed pond after it to remove suspended solids and it succeeded by more than 70% removal.

Mohn[24]; and Sim et al.,[25];,concluded that centrifugation, flocculation and flotation are the most common harvesting techniques but they are expensive and only economic in special cases. Milledge and Heaven[26]; and Shen et al.[27]; showed that sedimentation is the lower cost harvesting technology and it could possibly use as a first stage to reduce energy input and cost of following stages. For an efficient harvesting process, it should be easily maintained and minimized technical costs and expenses on personnel, lamella settler could be the solution applying these requirements. Lamellar settler could be a very reasonable alternative for separating the micro-algae also, it has a simple construction, low investment costs, nearly no operating expenses and scaling-up is possible, [28].

This type of settler can operate 2 to 4 times normal rate settler, this could be explained because of the layers of inclined lamellas which decrease the settling distance for particles or algae. The inclination angle of the lamellas means that the friction of rest of the sludge is overcome by gravity and the biomass is taken out of the separator [29].The inclination angle should guarantee the continuous sliding of the sludge. The useable separation area directly depends on the number of lamellas, the inclination angle and the geometrical dimensions of the lamellas.

The aim of this study is to investigate the suitability of impeding the lamella settler in the oxidation pond and evaluating the characteristics of the treated effluent and its compatibility to the Egyptian legislation for reuse.

MATERIAL AND METHODS

The integrated treatment system is consisting of HFBR system followed by algal pond with lamella settler (Figure 1).

Design and Construction

Photo (1) Vertical section of lamella

A pilot scale HFBR system has been designed and trailed on site for the treatment of municipal wastewater on continuous basis for more than one year at Zenin wastewater treatment plant. HFBR equipped with 55 PVC shelves with total plan surface area (TPA) of the media 18.17m^2, the detailed designed measurements were considered by [30]. The operational parameters of the system are recorded in Table (1). Hydraulic loading rate (3m^3/m^2.d) was applied during this study period, which is approximately equal to the load of one house by 7 residents.

Algal- pond with a 40-cm effective water depth, total surface area of 0.63 m^2 and 0.25m^3 volume has been constructed. The pond was provided by a lamella settler of 0.028 m^3 volume for algal separation Figure (1). The lamella made of light PVC which could be easily installed and support in the effluent through above the sludge hopper and fixed with an angel ranging between 45-50° Photo 1.The water flow upward in the tubes, the algae settle on the inclined parallel lamella and slide into the sludge hopper. The operational parameters were recorded in Table 1. The pond was inoculated with phytoplankton collected from the River Nile water after being concentrated via phytoplankton net at the start up and continuously fed with HFBR effluent.

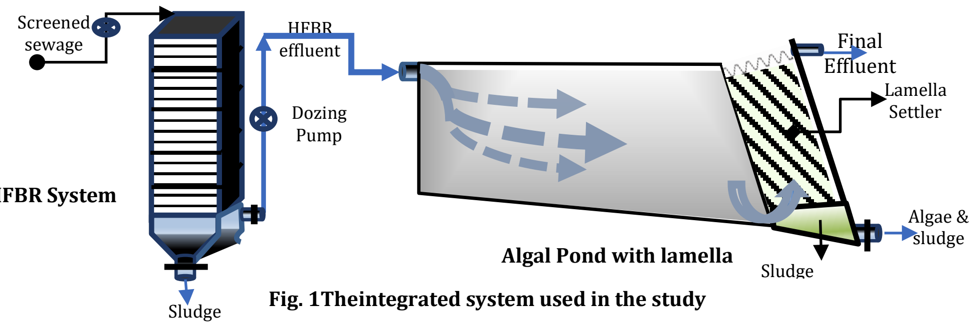

Fig. 1Theintegrated system used in the study

Table 1: The operational parameters of the integrated treatment system

Unit	*HRT*	*HLR* $m^3/m^2/d$	*Organic Loading Rate* Kg $COD/m^2/day$
HFBR	1.5 h	3.0	1.2
AP	4 days	0.09	0.005

Sampling and Analysis

Sampling of the integrated system for water quality analysis included collection of raw municipal wastewater as influent, effluent of HFBR and algal pond effluent. The collected samples were tested for its quality according to the [31]. The analysis cover 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.

Analysis of algal pond

The biomass of algae was monitored twice a week to determine chlorophyll"a" content using spectro-photometric method according to[31]. Investigation of the changes in the community structure according to the key of the fresh water algae [32] was carried out. Total protein content was measured according to [33]. Total carbohydrate content was estimated as glucose using the spectro-photometric method described by [34].

Bacteriological examinations:

Separate samples for the microbiology were collected in 1-L sterile glass bottles. Samples were subjected for the cultivation and enumeration of *Faecal coliform*. FC was detected and enumerated using poured-plate technique and mFc media as indicated in the standard methods [31]. The water samples were subjected for serial dilution according to the quality of the sample. Raw wastewater was serially diluted till 1 to 10^4 and 1 to 10^5. Samples from the bio-filter were serially diluted to 1/10, $1/10^2$ and $1/10^3$, while samples from the algae pond were diluted to 1/10 and $1/10^2$. 1 ml from the selected dilution was taken and poured in the pre-sterilized Petri dish and pre-melted mFc media with agar (with temperature 47-50 C^o) is added and mixed thoroughly with the sample and kept on the bench to cool and then covered and moved to the incubator that is previously adjusted to the recommended temperatures. The colonies with yellow (ifBromocresol purple is used) or blue color (if aniline blue is used) were enumerated and count in the original sample is calculated.

RESULTS AND DISCUSSION

Performance of the HFBR System

The average influent and effluent concentrations of HFBR are recorded in Table 2. Results showed that, strength raw municipal wastewater was in medium strength, this is in agreement with the urban municipal wastewater in Cairo [35and36]. The COD concentration ranging between 158 &498 mg/l whereas BOD values ranging between 63 to 222mg/l. This clearly illustrate that sewage strength is fluctuated intensively during different seasons (Fig.2). Bacteriological examination showed that domestic wastewater has an average count reached*FC*5.4×10^7MPN/100ml.

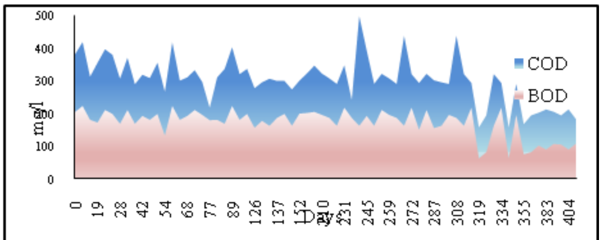

Fig. 2 COD & BOD Concentrations of Domestic Wastewater

The results clarify that HFBR remove 83% of COD, 85% of BOD and 86% of TSS. HFBR could remove 69% of total nitrogen and achieved almost full nitrification (Table 2). Rodgerset.al.,[37]; concluded that HFBR remove 56% of total nitrogen, it may be due to cell synthesis and denitrification in anoxic zone of the biofilm system.

The Fecal coliform removal in the HFBR unit was only 2.3 logs and has an average residual count of 4.1×10^5 MPN/100ml. No leaching of solids and no clogging occurred during the study. HFBR have high removal efficiency of organic carbon, nitrogen and TSS, but the main problem for safe reuse of the treated effluent is the pathogen concentration which is not compatible with Egyptian legislation for safe reuse.

Table 2: Analytical Results of Influent and Effluent of the Integrated System

	COD_{tot} mg/l	COD_{sol} mg/l	BOD mg/l	TSS mg/l	TN mg/l	NH_4-N mg/l	NO_3-N mg/l	FC MPN/100ml
Influent								
Average	309	159	171	165	50	24	0.3	5.4×10^7
Std. dev.	70	38	40	41	10	5	0.5	7.4×10^7
Effluent of HFBR								
Average	54	22	25.6	23	16	7	9	4.1×10^5
Std. dev.	20	11	10.8	9.1	8.7	5	4.6	9.6×10^5
Removal	83%	86%	85%	86%	69%	72%		2.3 logs
Std. dev.	6.3	6	5	4.9	15	17		0.5 logs
Effluent of APLS								
Average	78.7	38	34	33	8.6	4.1		4.2×10^3
Std.dev.	28	18	13	13.8	6.5	2.6		1.1×10^3
Removal	-62%		-48%	-67%	51%	47%		1.5 logs

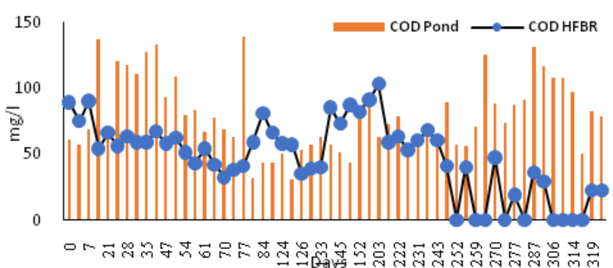

Fig. 3 COD concentration of the HFBR and APLS Effluents

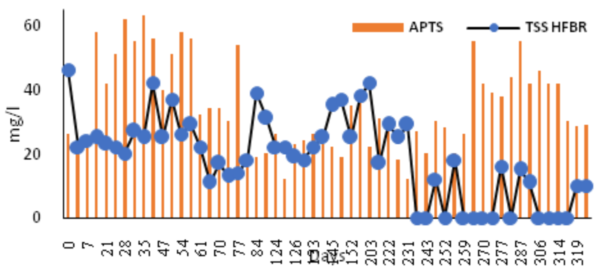

Fig. 4 TSS concentation of the HFBR and APLS Effluents

Performance of Algal Pond Enhanced by Lamella Settler

Algal pond was fed with HFBR effluent to mainly remove pathogen and nutrients and it was tested for more than one year under Egyptian weather conditions. The results of the pond effluent recorded in Table 2. The results showed that, pH value increased to 8.9,this could be enlightened by the limitation of CO_2 during daytime algal photosynthesis [38]. Also, it is cleared that the effluent COD, BOD and TSS concentrations increased by significant quantity as a result of algal growth in the pond (Table 2& Fig.3).

Total Nitrogen and Ammonia concentrations decreased significantly by an average removal of about 50%. Algal pond based wastewater treatment has several advantages over conventional treatment technologies, including recovery of nutrients and reduction in CO_2 and CH_4 emissions, due to their autotrophic metabolism [39].

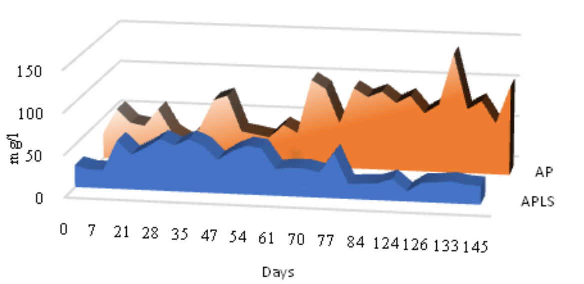

Fig. 5 TSS concentration of traditional AP and APLS

Total suspended solids concentration increased by 67% than its concentration in HFBR effluent Fig.4. From previous study [23], using traditional algal pond, the average suspended solids concentration was 68 mg/l thus, they forced to put a duckweed pond followed to algal pond to remove suspended solids to comply with the reuse legislations. Algal pond in this study is enhanced with lamella settler which increase the removal percentage about 50% than traditional algal pond, thus there is no need to put further treatment step. Fig. (5) compare the suspended solids concentration from the traditional algal pond and algal pond with lamella settler.

The APLS remove 1.5 logs of Fecal coliform with a residual 1.1×10^{3}MPN/100ml. The high removal of Fecal Coliform is due to their receiving direct sunlight and their high pH value. Prolonged exposure to ultraviolet (UV) radiation and toxic chemicals from algae is a result of being away from a suitable host for microorganisms [40].

The obtained results showed that the HFBR system could make available to form an adequate biofilm enhance the removal of biodegradable organic carbon as well as nitrogen but the removal of fecal coliform wasn't more than 2 logs. Thus, algal pond with lamella settler (APLS) plays an important role in the removal of pathogen as well as nutrients. Table (3), summarize the final treated effluent of the integrated system (HFBR +APLS), it proved, its compatibility to the Egyptian Legislation for reuse.

Table 3: Average Final Effluent Characterization of the Integrated System

Parameters	*unit*	*HFBR+APLS Effluent*	*Egyptian Legislation for reuse Grade B**
pH		8.2	6-9
COD	mg/l	78	80
BOD	mg/l	34	
TSS	mg/l	33	60
Total Nitrogen	mg/l	8.6	
Fecal Coliform	MPN/100ml	4.2×10^{3}	5×10^{3}

Modified Ministerial Decree 44 for 2000.

Algal growth and population

The results illustrated in (Fig. 6)showed that the change occurred in the Chlorophyll (a) concentrations. The concentration increased gradually from 102µg /l to 3544 µg/l, and then decreased at the end of experiment.

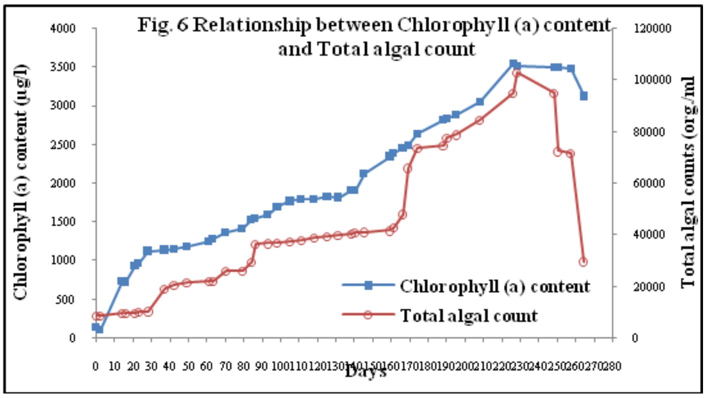

Fig. 6 Relationship between Chlorophyll (a) content and Total algal count

These can be correlated with the distribution pattern of algal population. On the other hand, positive correlation between total algal count and chlorophyll “a” content of algal biomass took place. Also, the protein and the carbohydrates contents increased gradually ranged between1.3 to 46.8 mg/gm for protein content and from 0.44 to 15.3 for carbohydrates. The maximum biomass (chl “a”3544 µg/l)was equivalent to 46.8&15.3mg/gm of protein and carbohydrate of dry weight, respectively.Fig.7, showed that, the positive correlation between protein, carbohydrate and chlorophyll “a” contents for algal biomass. These results had been reported by [41],who found that protein, carbohydrate and pigments were activated during active microalgae biomass increase in aquaculture systems. The distribution pattern of algae in the AP unit throughout the study period was illustrated in (Fig.8). It may be shown that various algal species belong to four algal groups namely, *Chlorophylla*, Flagellated algae(*Euglenophyta* and *Cryptophyta*), *Cyanophyta* and *Bacillariophyta*. The total algal count ranged between8481to102637 org/ml. The four algal groups included13.0 species, (3 species of *Chlorophyta*, 3 species of Flagellated algae 2 species of *Cyanophyta* and 5 species of *Bacillariophyta*) throughout the study period.

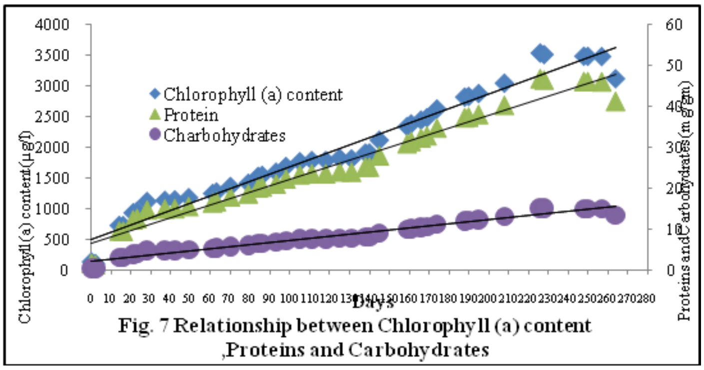

Fig. 7 Relationship between Chlorophyll (a) content ,Proteins and Carbohydrates

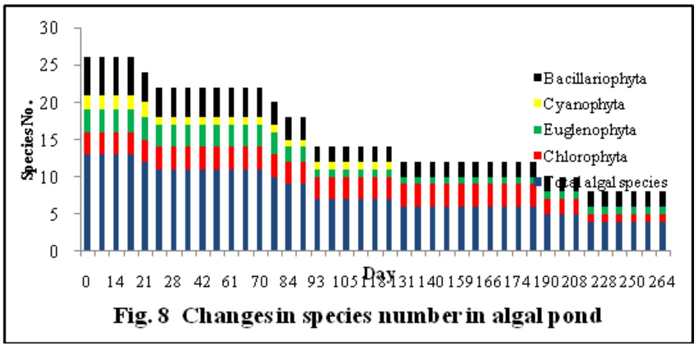

Fig. 8 Changes in species number in algal pond

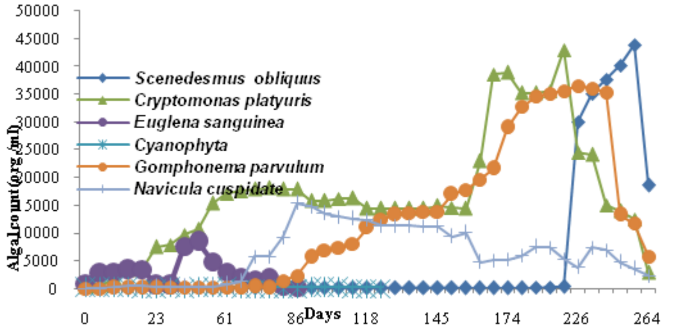

Fig. 9 The dominant algal species in algal pond during study period

Figure9 showed that *Chlorophyta*is the dominant algal group only at the last days of operation representing by *Scenedesmusobliquus*. Also, *Bacillarophyta* were detected especially at the last days of the experiment representing by *Gomphonemaparvulum* and *Navicula cuspidate*. Flagellated algae were dominant algal group throughout all the time of operation. The dominant species were *Cryptomonasplatyuris* and *Euglena sanguinea*, but *Euglena sanguinea* were disappeared gradually during the last days of operation. *Cyanophyta* appears to be evident only during the first days of operation, but gradually disappeared during the experiment. The most species diversity was detected in *Bacillarophyta*. The lowest diversity was associated with *Cyanophyta*. During the experimental run, there are decrease in diversity of flagellated algae, however *Cryptomona sparameculum* was the most dominant species at the last days of experiment.

CONCLUSIONS

The overall study parameters, proved that the HFBR system is simple to construct and operate with very low maintenance cost, achieved high removal of organic carbon and almost comprehensive nitrification occurred. The only problem facing this technology is the fecal coliform removal. Thus, it needs simple and low cost post treatment. Algal pond with lamella settler represent this kind of technology as in this study, it proves that the effluent characterization quality is better than the traditional pond effluent. The lamella remove 50% of the suspended solids than the traditional pond. In this study APLS removed 1.5 log of fecal coliform and 57% of the total nitrogen. It proved to be a satisfactory factor for the removal of organic, inorganic pollutants, and pathogens. The pond shows low algal species diversity with higher algal biomass throughout the operation period. Also, harvested algae provide valuable protein, and carbohydrates sources for animal and fish fodder. The characteristics of the treated final effluent is complying with the Egyptian Legislation for reuse. Thus, the integrated system could be considered as a good alternative biological treatment technology for the conventional treatment technology to use in small communities.

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