Municipal Wastewater Treatment Using Low Cost Treatment Technology in Small Communities

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Abstract

The aim of this study is to evaluate the performance of the horizontal flow bio-film reactor in the treatment of municipal wastewater in small communities. Horizontal flow bio-film reactor was designed, constructed and tested for the removal of organic carbon and nitrogen from domestic wastewater. It consists of a stack of 40 horizontal polyvinyl chloride (PVC) sheets embedded with 15 mm deep frustums. The wastewater continuously dosed onto the reactor and flowed horizontally along each sheet and vertically shifted down through the reactor. The system operated for almost 466 days, under four hydraulic loading rates, namely 225.6, 347.7, 451.1 and 582.71 l m^{-2} d^{-1}. The calculations of the hydraulic rates are based on the Top Plan Surface Area (TPSA) of the reactor. The performance of the treatment system was monitored via complete physico–chemical and bacteriological analysis of both raw and treated wastewater. The overall efficiency of the treatment system resulted in considerable removals of COD (91%), BOD (93%), TSS (92%) and ammonia-Nitrogen (74%). Horizontal Flow Bio-Film Reactor technology could provide a suitable alternative, which can be applied in rural areas and small communities. The system has proved that it has many benefits such as, low cost in manufacturing and maintenance, simplicity of operation, as well as the production of high quality effluent which can be reused in multiple aspects.

Keywords

Biological treatment; HFBR; municipal wastewater; rural areas; small communities.

Introduction

In the developing countries like Egypt, villages are experiencing a major threat represented in groundwater contamination and the quality of fresh water sources is deteriorating caused by the discharge of untreated or poorly treated domestic wastewater. Egypt suffers from lack of adequate domestic wastewater collection and treatment system especially in rural areas. Most of the urban and rural areas lack proper sanitation systems; only one third of the population is connected to sanitary sewers (Abd-El Wahaab and Omar,2012, Shaden Abdel-Gawad, 2007). The difficulties in the installation of traditional centralized wastewater systems in rural areas were due to the associated (i) high installation, operation, and maintenance costs (El-Gohary,2003; El-Gohary*et al*.1998). (ii) high energy requirements (iii) production of large volumes of sludge (iv) they are geared towards environmental protection rather than human health protection – for example, most conventional wastewater treatment works do not significantly reduce the content of pathogenic material in wastewater (Wilderer and Schreff,2000).There is an urgent need for simple low- maintenance biological technologies for treating domestic wastewater from small isolated communities.

Many drawbacks of the centralized wastewater treatment system approaches can be overcome when applying decentralized sanitation concepts. These concepts like the treatment in or near the community, application of low cost and sustainable treatment systems, recovery and reuse of useful by-products (for example, water & nutrients for agriculture purposes) (Lettinga G. 1996).The decentralized approach for wastewater treatment which employs a combination of onsite and/or cluster systems is gaining more attention. Such an approach allows for flexibility in management, and simple as well as complex technologies are available. The decentralized system is not only a long-term solution for small communities but is more reliable and cost effective (Van Riper &Geselbarch, 1998, Rodgers, M and Clifford, E. 2009, and Hala *et al*., 2015).

Biofilm wastewater treatment reactors are now commonly used to treat wastewaters from small communities because of the availability of high specific surface- area plastic media and the robustness of the biofilm process. In biofilm system, the microorganisms are attached in a biofilm to the surface of an inert packing material or substratum (Characklis W.G. *et al*, 1990).

The main objective of this study is the development of low cost eco-biotechnological system for the treatment of domestic wastewater that can serve small to medium size communitiesin rural areas. These systems essentially consist of biological treatment using horizontal flow bio-film reactor (HFBR), for the recovery of the purified sewage.Domestic wastewater is pumped continuously onto the top of the stack. Wastewater flows along each sheet from one end to the other and back again on the next underneath sheet, down through the stack. As the wastewater flows through the sheets of the stack of biofilm forms; the organic carbon, total suspended solids, nutrients and bacteria are removed.

The treated wastewater will instantly be used for irrigation and /or fertilization. The (HFBR) is a novel simple technology with a flexible design that provides a new effective technology for carbon and nitrogen removal from domestic wastewater (Hala*et al*.,2016; Rodgers and Clifford, 2009). The unit achieved excellent solids and carbon removal with high levels of nitrification with an annual running costs of around 1.71€/ person (Regan C. *et al* 2003). Clifford E. *et al*.,(2010); stated that BOD_5 and filtered COD removal averaged 97% and 85% respectively also the NH_4-N removals averaged 95% with an average total N removal of 62%; thus the system performed well in comparison to other technologies in removing organic carbon and nitrogen.The system has been previously applied successfully to both wastewater and waste gas treatment (Kennelly et. al, 2012; Clifford et al., 2010).

Materials and methods

Location of the **study**

The treatment unit is located in a nearby wastewater treatment plant, Giza, Cairo. The system is fed continuously with a prescreened real domestic wastewater using pump.

Design of the horizontal flow biofilm reactor (HFBR)

The treatment system consists of: a wastewater feed tank, a peristaltic feed pump and a horizontal flow biofilm reactor(HFBR). The reactor consists of 40 horizontal polyvinyl chloride sheets (PVC) positioned one above the other (Figure 2.1), which are supported by the frame. Each sheet measured 380mm×280mm×5mm and contained vertical frustums formed during manufacture with 15mm deep and 15mm diameter (Figure 2.2). Three sides of each sheet were turned up to a height of 15mm to direct the flow along the sheet to its exit end. The sheets were placed horizontally and alternately offset, to allow the wastewater to flow horizontally along each sheet and vertically from sheet to sheet down through the reactor. The plan surface area of each sheet is 0.1064 m^2. The total plan surface area TSA of the sheets was equal 4.256m^2 .The top plan surface area (TPSA) averaged (TSA/40). The frustums increased the available biofilm plan surface area and provided for solids accumulation. Domestic wastewater pumped from a feed tank using a peristaltic pump onto 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.

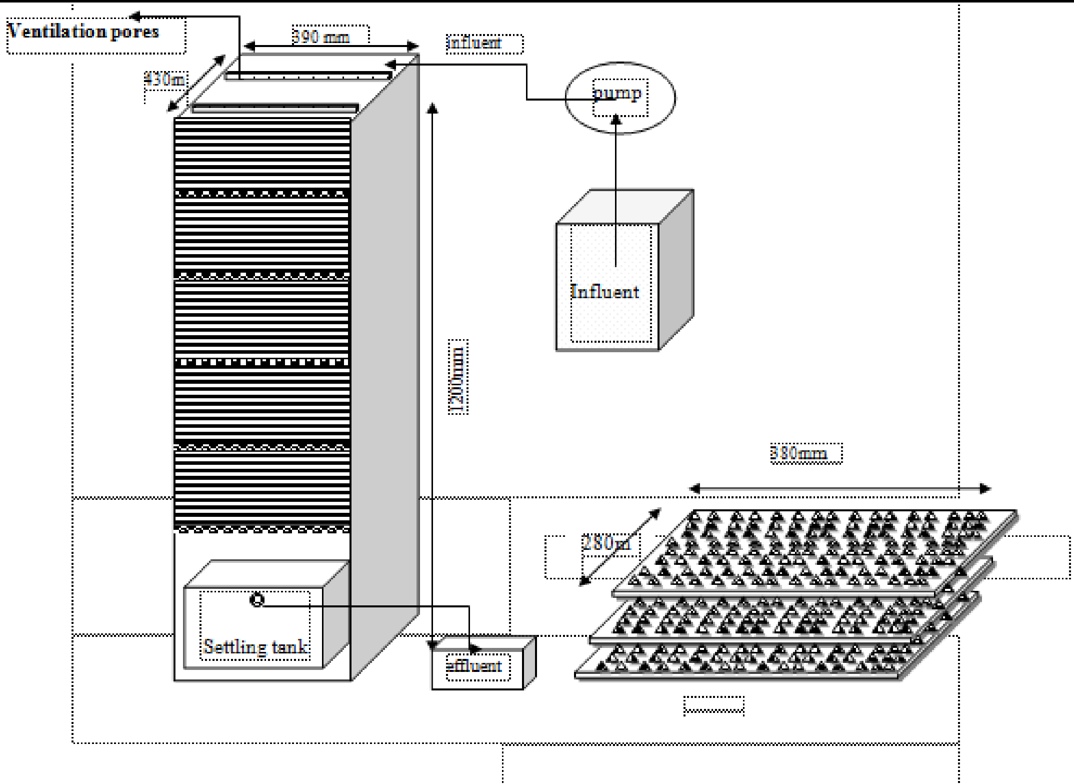

Figure (2.1) Vertical section of the Horizontal Flow Biofilm Reactor (HFBR)

Figure (2.2) IndividualPVCsheet details

Sampling and analysis of municipal Wastewater

Raw wastewater samples were taken from the influent feed tank and the final effluent collected as the treated wastewater dropped from the last sheet which collected in the settling tank. Samples also collected from the various sheets down through the reactor, the pH-value of the samples were daily measured. The samples were collected twice a week and immediately analyzed. The physico-chemical analysis included, chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), total phosphate, oil and grease, organic nitrogen , ammonia, nitrite and nitrate. Bacteriological Analysis including; Total bacterial counts; Total Coliform, Fecal Coliform and Fecal Streptococci. Analyses were carried out according to the American Standard Methods for water and wastewater analyses devised by APHA (2012).

Hydraulic loading rate

The HFBR operated for almost 466 days; under four hydraulic loading rates namely, 225.6, 347.7, 451.1 and 582.71 l/ m2/ d. With an organic loading rates equal to 98.6; 151.9; 197.1 and 254.6 g COD/m2/d, respectively. The municipal wastewater was pumped continuously onto the top of the reactor and flowed horizontally along each sheet and vertically from sheet to sheet down through the reactor. The calculations of the hydraulic loading rates (HLR) were based on the top plan surface area average (TPSA) of the reactor.

Results and Discussion

The system was operated for 466 days under the normal weather conditions. The starting up period of the HFBR system with gradually improving performance take only 20 days, after this period the system stabilized until the end of the experiment. The average influent and effluent concentrations are shown in Table (3.1). Strength of the domestic wastewater can be classified as medium strength (Metcalf and Eddy 2003). Chemical oxygen demand ranged from 180mg02/l to 1020mg02/l with an average value of 437.5mg 02/l. Corresponding BOD values ranged from 85mg02/l to561mg02/l with an average value of 219 mgO2/l. BOD5/COD ratio were found vary in the range of 0.2-0.9 for raw wastewater with an average value of 0.53.Thus, the biodegradability of the wastewater is around 50%. This ratio was given as 0.6 for raw domestic wastewater by (Íleri 2000). Evaluate of NH4–N fraction to organic nitrogen for total, wastewaters is 1: 0.6. In this study, TKN/COD ratio according to the average values was ranging between 0.08 to 0.17, with an average value of 0.14, this is also relevant with the data were given by (Rössle and Pretorius, 2001). The results showed that the reactor performance was steady during the different loads. The efficiency of the treatment system resulted in considerable removals of 91% COD, 93% BOD5, 92% TSS, 74% NH4-N and 38% Organic nitrogen (Table 3.1&Figure 3.1). The stability of the system during the different loads was confirmed by consistent of the results over time (Figure 3.2).

Microbiological examination revealed a reduction in total and fecal coliform counts. Total coliform and Fecal coliform density has decreased by 3 logs and 4 logs, respectively (Table 3.2). No sloughing of solids or clogging of media occurred during the study.

Table 3.1: Overall performance of the HFBR during the four loading rate

	pH	COD	BOD	TSS	O.N	NH4-N	NO3-N	Oil & grease	PO4
Influent									
Average	7.6	480	215	164	21	39	0.12	29.6	2.5
Std.dev	0.3	185	80	64	6	13	0.16	9.8	1.1
Effluent 1st HRL									
Average	7.9	42	12	13	10.8	11	2.6	1.3	0.9
Std.dev	0.4	17	5	6	3	4	1.6	0.8	0.7
Average % removal		91%	93%	92%	43%	30%		95%	57%
Effluent 2nd HRL									
Average	7.7	28	10	9	11	9	6.8	1.7	1.5
Std.dev	0.3	8	2	4	5	2	8	0.4	0.6
Average % removal		89%	92%	90%	45%	44%		93%	61%

Effluent 3rd HRL									
Average	7.7	31	14	9	11.5	9	11.5	2	0.7
Std.dev	0.3	11	6	9	4.9	3	11.2	0.5	0.6
Average %removal		90%	93%	92%	43%	53%		93%	60%
Effluent 4th HRL									
Average	7.8	48	20	11	18	12	8.8	1.9	0.6
Std.dev.	0.3	10	8	7	6	6	10	0.6	0.5
Average % removal		88%	91%	93%	31%	46%		94%	67%

(Average values during 466 operation days)

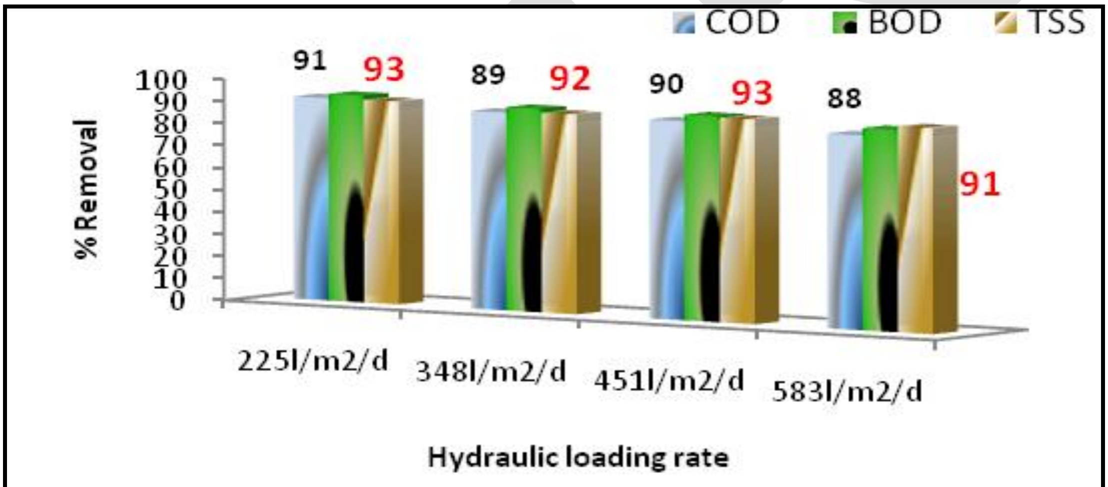

Figure (3.1)Total COD removal percentage during the diffrent hydraulic loads

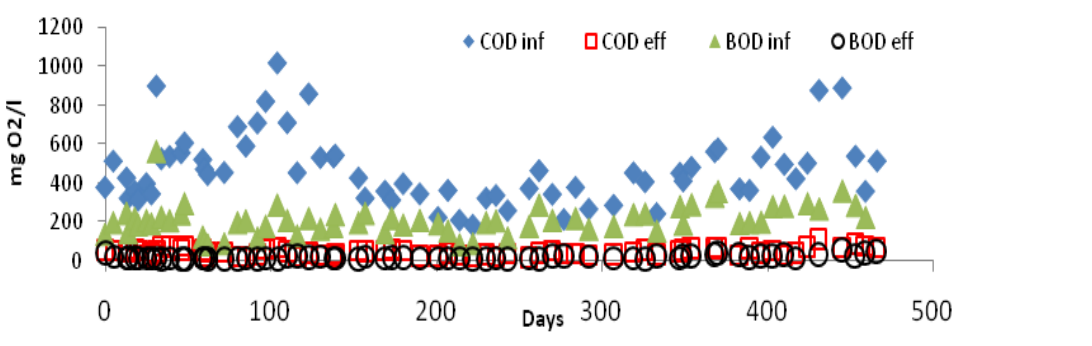

Figure (3.2) Influent and effluent COD &BOD concdentrations during the operation days of the system

Table 3.2: Bacteriological analysis of the influent wastewater and treated effluent

Parameters	Units	Average	
		effluent	influent
MPN/100ml	Total coliform	3.0×103	2.6×106
MPN/100ml	Faecal coliform	4.1×102	1.2×106
MPN/100ml	E.coli	1.3×102	9.6×105

Overall Efficiency of the HFBR

Carbon and Total Suspended Solids Removal

From the results obtained, high removal percentage of carbon and suspended solid, from Sheets 1-8 and from sheets 32-40 were detected this results was also observed by, Clifford et al 2010. Most COD, BOD and TSS removal took place in the top of 8 sheets with removal average values not more than 57%, with average residual values of 170mg/l, 85 mg/l and 70mg/l, respectively (Figure 3.3&3.4). Most biodegradable organic matter removal took place in the top of 8 sheets of the unit. This is in agreement with Rodgers et al (2008), in which they stated that, most of organic matter (COD & BOD) and nutrient removals took place in the top 7 sheets of the unit. The removal efficiency from sheets 16 to 32 didn't exceed 33% for COD, BOD and TSS. The unit quickly from sheets 33 to 40 reduced the TSS, BOD and COD removal values of 48%, 42% and 38%, respectively.

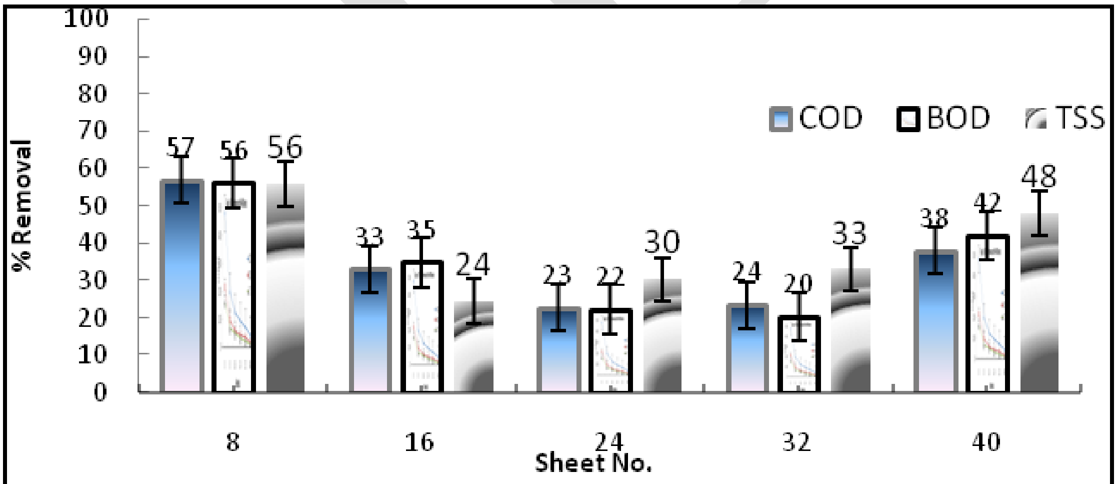

Figure (3.3) The removal effeciency of the diffrent sheets

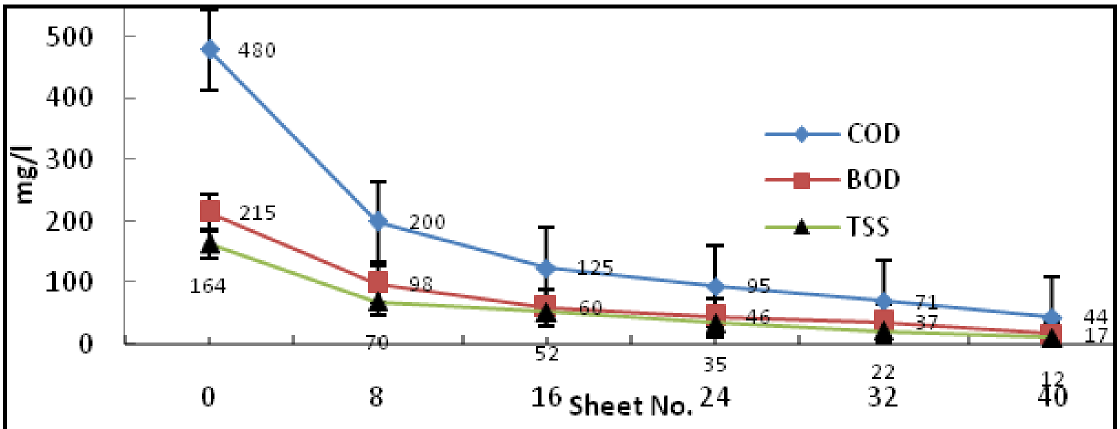

Figure (3.4) The residual concentration of COD, BOD and TSS at the diffrent sheets

Nutrient removal

Average concentration total ammonia of 39mg/l in the influent was reduced by 74% to the average of 11 mg/l in the effluent (Figure 3.5). Rodgers et al. 2005; achieved almost the same removal rate of ammonia using stratified sand filter. At sheet 32-40, most of the carbon had been removed and the majority of nitrification occurred where ammonia decrease and Nitrate level increased(Figure 3.6), Rodegers et al. 2008. Overall, the organic nitrogen in the unfiltered samples was reduced by 38 % from 21 mg/l in the influent to14 mg/l in the effluent; the maximum removal at sheet 40 was observed (Figure 3.7).

Total phosphorous was reduced by 62% from 2.5 mg/l in the influent to 0.9 mg/l in the final effluent.

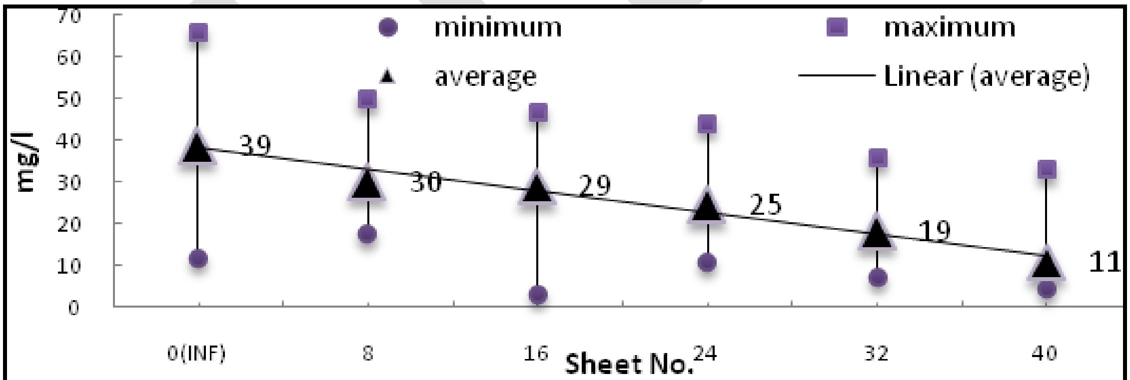

Figure (3.5) Ammonia concentrations during the various stages

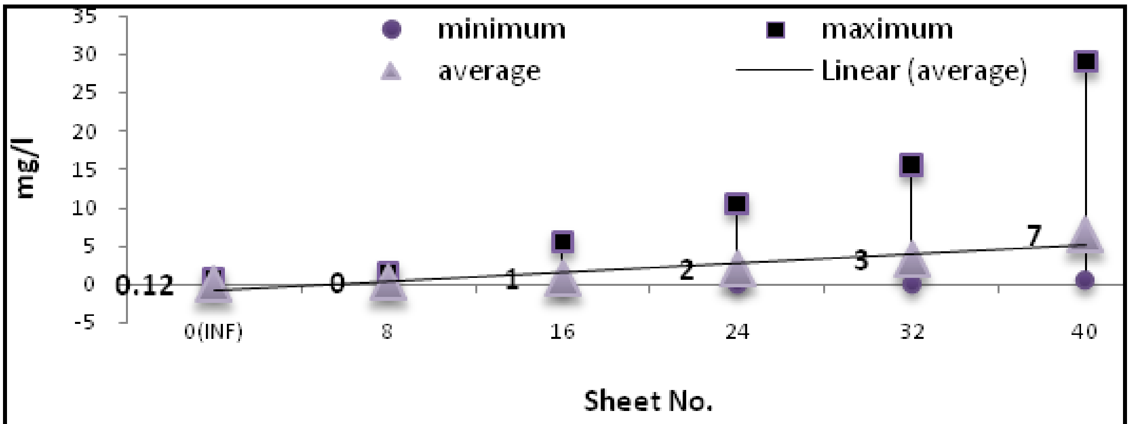

Figure (3.6) Nitrate concentrations during the various stages

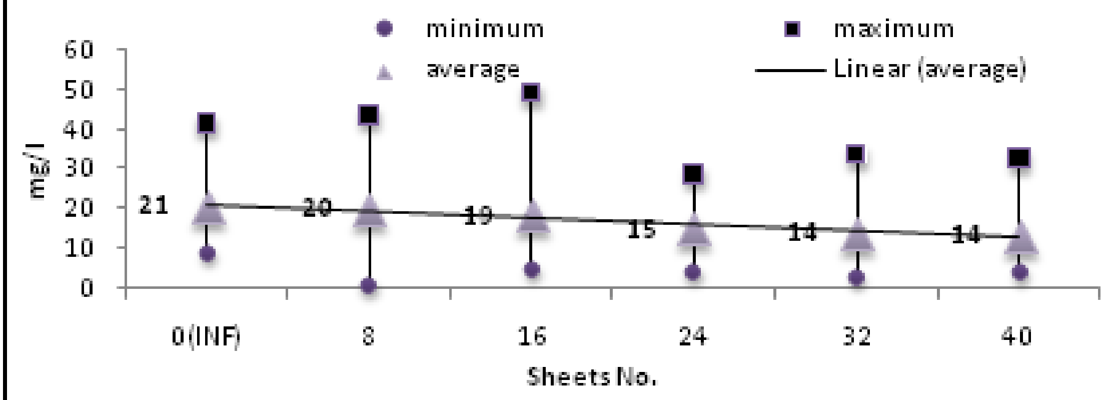

Figure (3.7)Organic nitrogen concentrations during the various stages

Conclusion

The study proves that, Horizontal Flow Bio-Film Reactor (HFBR) technology could provide a suitable alternative, which can be applied in rural areas and small communities. The system has proved that it has many benefits such as, low cost in manufacturing and maintenance, simplicity of operation as well as small footprint. The unit produced a high-quality effluent complying with the National Regulatory Standards for wastewater reuse in restricted agriculture.

The system performed excellently in removing COD, BOD and TSS with average removals of 93 %BOD, 91% COD, and 92% respectively during the four applied loads.

High removal percentage of carbon and suspended solid, from Sheets 1-8. The COD, BOD and TSS removal percentage were not more than 57%. Most biodegradable organic matter removal took place in the top of 8 sheets of the unit.

At sheet 32-40, most of the carbon had been removed and the majority of nitrification occurred where ammonia decrease and Nitrate level increased.Average removal of the total Ammonia and organic nitrogen reached 74% and 38% respectively.

Microbiological examination revealed a reduction in total and fecal coliform counts Total coliform and Fecal coliform density has been decline by 3-4 logs.

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