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Use of Biofilter Units to Enhance the Effluent Quality of Anaerobically Pretreated Domestic Wastewater

(Research Note)

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ABSTRACT

This study evaluates the use of a pilot plant biofilter system which is comprised of an Anaerobic Filter (AF) followed by a passive aerated Rapid Filter (RF), as a post-treatment option for Birzeit domestic wastewater. It reports on the biofilters efficacy for the removal of organic matter and nutrient removal during three different run phases. The biofilters were fed continuously with a variable daily flow rate (0.26-0.6 m^3) to study the impact of different Organic Loading Rates (OLRs) and Hydraulic Retention Times (HRTs). During the run phases 1, 2 and 3, the average removal efficiency of the biofilters (AF+RF) for COD was 28, 65 and 30%, respectively. The complete treatment chain achieved a removal efficiency of 54, 51 and 43% for suspended solids at variable OLR and HRT. At higher HRTs, the RF average removal efficiency for NH_4 reached only 8%. This research suggested an organic loading rate of 10 g COD/ (m^2.d) for the AF to achieve an effluent quality by the RF suitable for restricted agricultural irrigation. Further large-scale studies should be locally carried out to improve and validate the onsite treatment system used in this research paper.

KEYWORDS: Anaerobic treatment, biofilter, Birzeit, domestic wastewater, nutrient removal, post-treatment, treatment efficacy, Upflow Anaerobic Sludge Blanket (UASB).

1. INTRODUCTION

Current Palestinian municipal sewage works receive domestic septage of unknown quantity, quality and lack knowledge on their potential impacts. A recent study on domestic septage characteristics made by Al-Sa'ed and Hithnawi (2006) revealed that the characteristics of domestic septage from households in Ramallah-Albireh district resembled municipal wastewater quality. This could be due to different reasons such as septic tank design, the pump out interval, life style and hygiene approaches.

Wastewater management plans utilizing decentralized treatment systems including anaerobic treatment technologies can lead to the protection of sustainable water resources. The decentralized concept will not only enhance the development of master plan, where alternative wastewater management can be integrated. It creates also possibilities to reuse treated wastewater in irrigation and fertilization. This alternative wastewater management approach provides an alternative energy source (biogas utilization) while the protection of groundwater from pollution is achieved (Lettinga et al., 2001; Nhapi and Gijzen, 2005).

The most popular form of the anaerobic treatment is the Up-flow Anaerobic Sludge Blanket (UASB) technology. The sludge retention of the UASB reactor is based on the formation of the easily settling sludge flocs or granules, and in the application of internal gas/liquid/solid separation system (Elmitwalli *et al.*, 2002; Coelho *et al.*, 2004).

Chernicharo and Machado (1998) investigated the combination of UASB and AF as a promising treatment alternative for domestic sewage. The UASB removed 80% of the COD, whereas the overall COD removal for the combination of UASB and AF ranged between 85 to 90%. Investigations made by Brinke-Seiferth et al. (1999) using

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single stage biofilters revealed that nitrification and carbon removal were found in the upper part of the biofilter, whereas denitrification was found in the lower anoxic part.

Applying suspended solids or attached growth technologies in any post-treatment, nitrification and denitrification processes under aerobic and anoxic conditions are responsible for the nitrogen removal from municipal wastewater. Denitrification in activated sludge systems (suspended growth) and in biofilters (attached biofilm) is attractive as to economic and environmental aspects (Tawfik *et al.*, 2002; Tandukar *et al.*, 2005). Worldwide, several researchers investigated the financial and economic aspects of different management approaches for domestic wastewater and septage pertaining to collection, treatment, reuse and disposal methods (Ingallinella *et al.*, 2002; Koné and Strauss, 2004; Williams *et al.*, 2005). However, lack of accurate and reliable data on capital costs and annual running expenditures for the current onsite sanitation facilities in Palestine, the authors refrained presenting financial issues on the applied treatment system in this study, which is also beyond the scope of this research. However, Abu-Madi et al. (2005) published detailed information on these issues for urban sanitation systems in the Middle East and North Africa countries.

Published results by Al-Juaidy et al. (2003) and Ali *et al.* (2005) indicated that pre-treating of domestic and black wastewater in a modified UASB-septic tank technology removed only COD and suspended solid. Despite the advantages of anaerobic pre-treatment options (low cost, operational simplicity and low biosolids production), the UASB technology produces effluents of low quality. Therefore, it is of great importance to consider a post-treatment stage to enhance the final effluent quality (Lettinga *et al.*, 1997; Jimmenez *et al.*, 2000; Tandukar *et al.*, 2006). This research study aimed at the technical evaluation of anaerobic and rapid biofilter units, filled with local fixed film media, to complement the organic matter and nutrients removal, which is hardly removed by the anaerobic treatment processes.

2. MATERIALS AND ANALYTICAL METHODS

System Description and Sampling

The experimental work was conducted from 29th April to 6th August 2002 at Birzeit University campus wastewater treatment plant. The experimental work was divided into three experimental run phases as shown in Table (1). Domestic septage, delivered by tankers from septic tanks of residential houses in Birzeit town, was used to start up the UASB reactor. Raw wastewater, stored in a holding tank and refilled every three days, was fed continuously to the UASB unit as an influent at a daily flow rate of 0.26-0.6 m^3.

Table (1): Operational Design Parameters of Biofilter Units during the Three Run Phases.

UNIT	Run Phase	Run Period	Flow Rate (m^3/d)	Active Volume (m^3)	HRT (h)	Surface Area (m^2)
AF	1	29/04–9/05	0.26	0.02	2.21	21.75
	2	02/06–13/07	0.43	0.02	1.32	21.75
	3	17/07–06/08	0.60	0.02	0.95	21.75
RF	1	29/04–09/05	0.26	0.01	1.00	28.87
	2	02/06–3/07	0.43	0.01	0.69	24.97
	3	17/07–06/08	0.60	0.01	0.38	23.99
Calculated Operational Design Parameters after Data Analysis			**Volumetric and Surface COD Loading Rates**			
			Anaerobic filter (AF)		**Passive aerobic rapid filter (RF)**	
			kg COD/(m^3.d)	**kg COD/(m^2.d)**	**kg COD/(m^3.d)**	**kg COD/(m^2.d)**
Run Phase & Period	1	29/04–09/05	1.9	1.8	3.6	1.5
	2	02/06–13/07	10.7	10.3	11.0	4.9
	3	17/07–06/08	5.9	5.7	12.6	5.9

The Anaerobic Filter (AF) and Rapid Filter (RF) were operated in series (Figure 1). The biofilters were preceded by a UASB reactor. Table (2) provides data on the physical characteristic of the Packing Media (PM) used in the AF and RF. The dimensions of the Anaerobic Filter (AF) were 98 cm (height) and 20 cm (diameter) with a settling base height of around 20 cm.

The filling PM was a local crushed PVC material with a height of 65 cm, the spacing between the sampling taps (T1-T5) was about 15 cm. The Rapid Filter (RF) was with a total height of around 70 cm and internal diameter of 20 cm, filled with anthracite PM with height around 50 cm, and 15 cm between the sampling taps (T1-T3), the RF was connected to the AF through a plastic tube. Fig 1. shows the schematic diagram of the biofilter units.

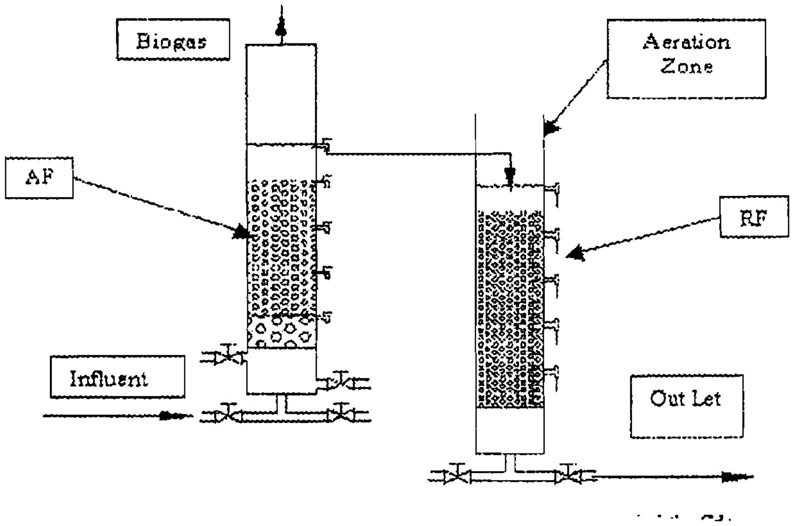

Fig 1. Schematic Diagram of the Anaerobic Filter (AF) and Rapid Filter (RF).

The Anaerobic Filter (AF) was seeded with 4 liters of anaerobic sludge obtained form a domestic septic tank bottom to insure complete anaerobic start up condition. The treatment efficacy of the different unit operations (UASB+AF), AF+RF and overall treatment system were investigated during the three run phases under variable hydraulic and organic loading rates (Table 1). The system was operated at a temperature range of 12-14°C reflecting the winter average ambient temperature of most developing countries in the region.

Table (2): The Physical Characteristics of the Packing Media (PM) Used.

Fixed Film Material	Density kg/ml	Effective Size (mm)	Mean Diameter (mm)	Porosity	Specific Surface Area (m^2/m^3)
Anthracite	1424	2	1.29	0.49	1313
Crushed Plastic	775	4.75	2.33	0.60	1030

Table (3): Performance of the Biofilter Units during All Run Phases.

Test	Run Phase	Effluent Concentration (mg/L)			Removal Efficacy (%)			
		UASB	AF Effluent	RF Effluent	UASB	AF	RF	AF+RF
COD_{total}	1	174.50	164.00	125.00	18.46	6.02	23.78	28.37
	2	589.29	284.04	209.29	52.56	51.80	26.32	64.48
	3	233.71	236.38	162.52	28.52	-1.14	31.25	30.46
TSS	1	341.25	400.25	156.25	34.56	-17.29	60.96	54.21
	2	496.00	333.26	241.51	27.41	32.81	27.53	51.31
	3	569.64	346.67	322.67	20.79	39.14	6.92	43.36
VSS	1	186.00	280.50	70.75	43.03	-50.81	74.78	61.96
	2	368.67	169.83	146.25	-6.65	53.93	13.88	60.33
	3	370.98	261.87	147.00	24.14	29.41	43.87	60.38

TKN	1	82.27	85.38	78.38	16.44	-3.78	8.20	4.73
	2	94.48	88.58	79.73	9.92	6.24	9.99	15.61
	3	78.03	80.52	68.50	7.03	-3.19	14.93	12.21
NH4-N	1	43.42	43.59	39.99	-15.06	-0.39	8.26	7.90
	2	57.76	55.61	57.90	-9.16	3.72	-4.12	-0.24
	3	53.73	55.62	51.44	-2.22	-3.52	7.52	4.26
NO3-N	1	1.23	1.07	1.46	12.83	13.01	-36.45	-18.70
	2	4.39	3.05	3.56	30.53	30.52	-16.72	18.91
	3	5.60	5.56	5.08	0.71	0.71	8.63	9.29

Physical and Chemical Analysis of Wastewater

Composite samples were taken from inlets of each unit and from all bio-filters sampling taps along the reactor's height. Twice weekly samples were collected at midday and preserved in icebox during transportation to the laboratory. Physical and chemical analyses were performed in accordance with the *Standard Methods* (APHA, 1995), as follows: Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS), sections, 2540 E., and 2540 D., respectively; Total Kjeldahl Nitrogen (TKN), section 4500-N_{org} C, and ammonium, section 4500-NH_4-N E; Chemical Oxygen Demand (COD), section 5220 C. The temperature of raw sewage and UASB reactor was measured using alcohol thermometer while the EC pH meter (HACH) was used for pH determination. Finally, temperature and pH were measured onsite while the rest of analysis was conducted later at the Water Engineering Lab of Birzeit University.

3. RESULTS AND DISCUSSION

Impact of pH Value on System Performance

The pH is one of the main factors which affect the rate and degree of hydrolysis in an anaerobic process. Average pH values along the sampling depth during the three run phases are plotted in Figure 2 for the complete treatment chain. The Figure shows a clear drop in pH values during the anaerobic stages (UASB+AF), specifically during the second run phase where the organic load compared with other run phases was high, and the increase in pH values in the third run phase was due to higher hydraulic loads. The production of volatile fatty acids (acidogenesis phase) in the anaerobic treatment units (UASB+AF) might have the direct drop in the pH values, which might cause negative impacts on COD removal and reduce the nitrification process in the post-treatment stages (Brinke-Seiferth *et al.*, 1999; Elmitwalli *et al.*, 2000).

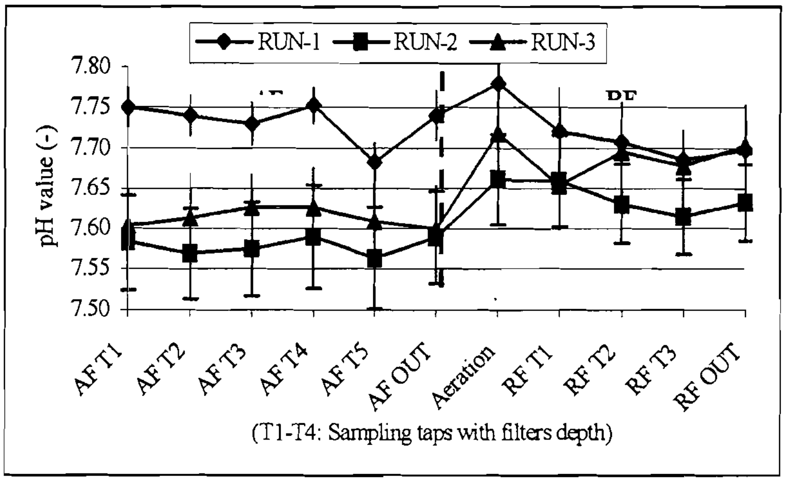

Fig. 2. Variations in pH Value within the Biofilters Depth.

An increase in the pH value of the passive aeration zone was noticed. The lowest pH value was recorded in the second run phase (high organic loading rate). The average values increased in the initial aeration zone; which might indicate a partial CO_2 striping. The drop in the pH value at the first sampling tap might be due to organic matter sedimentation on the filter media surface, where anaerobic processes dominate at low DO content.

During the three run phases, the pH range was found to be within the range of 7.5 -7.8. The average pH values obtained during all run phases for the UASB indicate that no steady state conditions were achieved. Hence, the hydrolysis stage was not reached fully, as the pH ranged between 7.5 and 8. From previous studies, it was found that the optimum pH for protein hydrolysis is in the neutral range (pH > 6.3). On the other hand, the optimum pH for the hydrolysis of carbohydrates was found by Lew *et al.* (2003) to be in the range of 5.6-6.5.

COD and Suspended Solids Removal under Variable Loading Rates

The average COD removal efficiency obtained during all run phases for the biofilter units are summarized in Table (3).

The combination of the AF and RF showed higher removal efficiencies than UASB alone (18.5, 52.6%), where the removal efficiency had increased in the first and second run phases, to (28.4 and 64.5%), respectively. However, during the third run phase, the overall removal efficiency for the treatment chain (AF+RF) had decreased to 30.5%, which might be due to the low HRT in the AF. Based on the data in Table (3), the specific surface COD loading rates applied were between 1.8-10.7 and 1.5-5.9 g COD/m^2.d for the AF and the aerobically passive RF, respectively.

The results obtained by other researchers (Nicolella *et al.*, 2001; Nadais *et al.*, 2005) revealed a similar tendency in low COD removal due to the accumulation of the organic matter inside the submerged biofilters and the loss of active biomass by sludge wash-out. Figure 3 shows clearly that the treatment system achieved better removal efficiency during run phase 2, when the UASB was operated with an HRT of 19 h and an organic loading rate of 1.5 kg COD/m^3.d. During this phase, compared to phases 1 and 3, the AF and RF were operated probably at adequate COD loading rates; 10 and 5 g COD/ m^2.d, respectively.

Figure 3 illustrates the effect of HRT, where the total COD concentration had increased in the AF depth as the HRT decreased during the third run phase. The COD removal rates were determined in the 2nd and 3rd run phases as indicated in Table (3). The removal efficiency of the AF was variable (-1.1 and 6.1%) compared to that for the RF (26.3 and 31.3 %). The results show a clear negative impact of low HRT on the anaerobic units (AF-RF); similarly a high OLR implied a negative impact on the RF efficiency. However, installing the UASB as a pre-treatment unit has improved the overall COD removal efficiency only during the second run phase (52.3%), indicating a stable anaerobic process taking place.

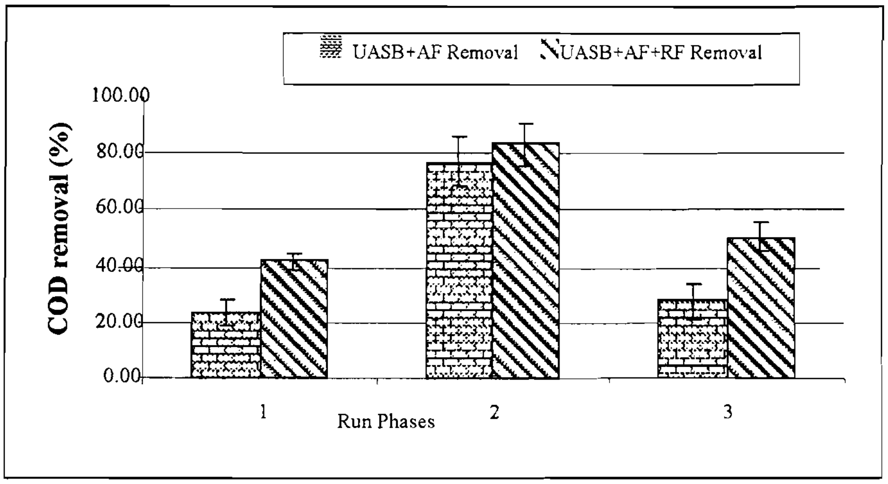

Fig. 3. COD Removal under Anaerobic and Overall System COD Removal.

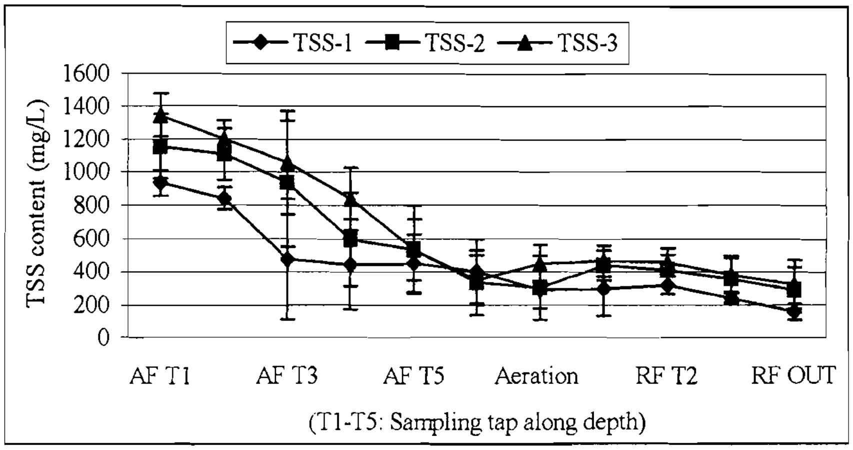

Fig. 4. TSS Removal by the AF and RF during Run Phases.

The overall TSS removal efficiency for the treatment train (AF+RF) had decreased to (54.2, 51.3, and 31.3%). From the obtained results we can realize that the removal efficiency of the RF in the first run was the highest (61.9%) due to lower organic load, where the TSS effluent from the AF is lower if compared with other runs as seen in Figure 4.

The VSS removal efficiency for the AF unit was variable (-50.8, 54, 29%), while the average overall treatment chain (AF+RF) showed a similar tendency during the three run phases (62, 60, 60). The negative removal of the AF for the VSS can be attributed to washout of the biomass and overloading organic loading rate. Hence, the RF enhanced the overall treatment efficiency of the installed system in this study.

Nutrients Removal Efficiency

Ammonium concentration has increased during run phases (Table 3) due to nitrate dissimilatory pathway under anaerobic conditions. Table (3) shows that the average content of NH_4-N in the AF during the three run phases was about (62%) of TKN, which can be attributed to proteins hydrolysis into amino acids and further to ammonia and hydrogen sulfide.

During run phases 1 and 2, the Anaerobic Filter (AF) dynamic was reflected by a slow biochemical reaction with regard to hydrolysis of TKN. Only slight removal efficiency was observed during phase 2, where about 6.2% of TKN was removed. This small removal efficiency might be explained by nitrogen uptake for microbial growth. It had been proven that the potential loss of nitrogen in the influent nitrogen due to the assimilation by biomass in the anaerobic filter (Elmitwalli *et al.*, 2000). The increase in the AF effluent TKN during run phase 3 might be due to the biomass wash out and induced by the high hydraulic loading rate in the anaerobic biofilter. But in the first run phase, where steady state conditions were not reached, the increased effluent TKN content was due to sludge seed wash out from the AF.

Minimal increase in NH_4- concentration was detected during phases 1 and 3 which might be attributed to protein hydrolysis. This assumption was conformed by an increase in TKN and SS, it has been frequently reported that AF can perform a good hydrolysis of organic nitrogen (Zeeman and Lettinga, 1999; Elmitwalli *et al.*, 2002).

From the results depicted in Figure 5 and listed in Table (3), a slight TKN and ammonia removal in the RF (passive aerated filter) was noticed. The TKN has decreased by (8.2, 10 and 15%), respectively for the three run phases due to the nitrification process which took place within the first aerobic layer of the RF. However, due to the high organic loads and lack of DO concentration, this activity was very weak. Similar data were reported by Jonsson *et al.* (1997) and *Chui et al.* (2001) on nitrogen removal in deep bed sand filters from the secondary effluent, where removal rates of around 4% TKN were reported.

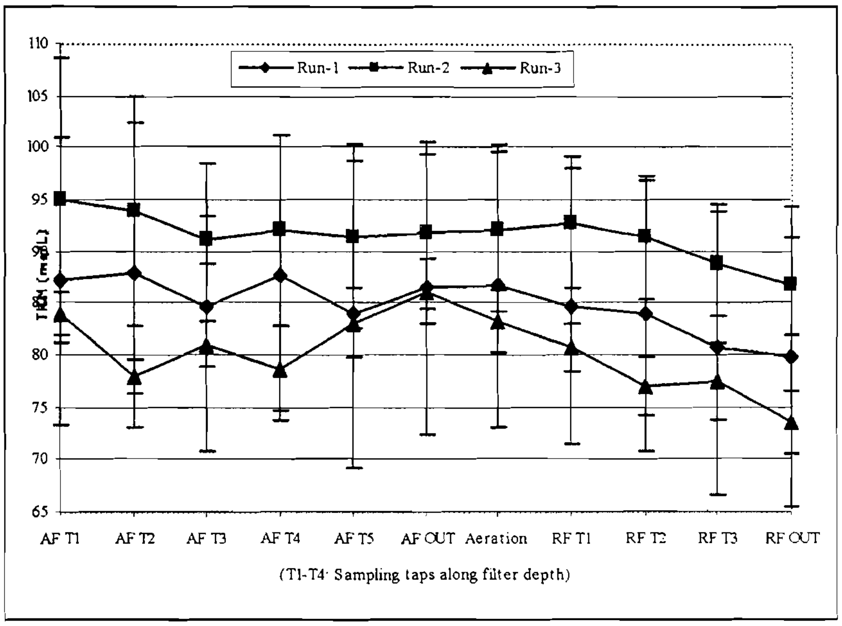

Fig 5. TKN Concentrations within the AF and RF Depths.

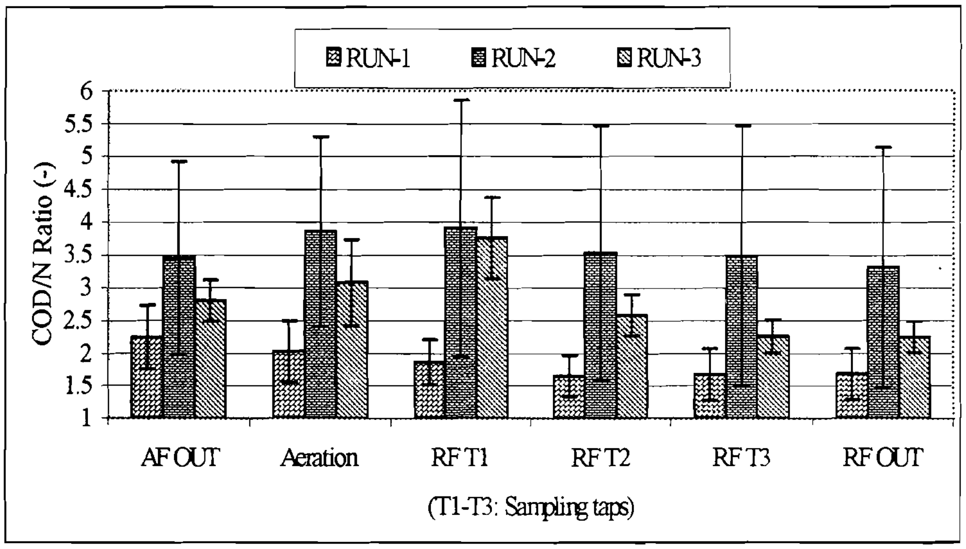

Fig 6. Depth Impact on COD/N Ratios within the RF during the Three Run Phases.

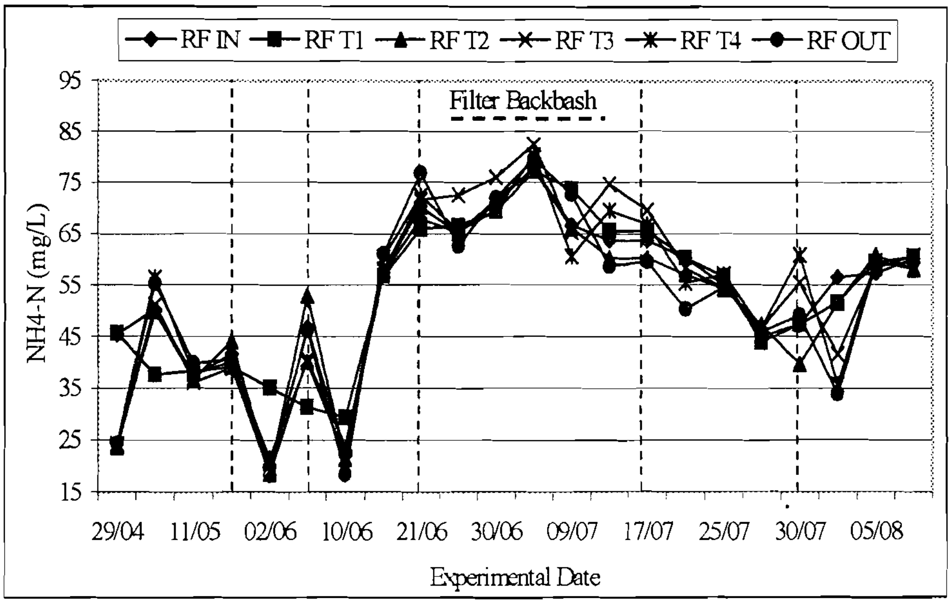

Fig.7. Backwash Impact on NH_4-N Content within the RF Depths.

Several research studies (Akunna et al., 1994; Ince *et al.*, 2000; Leito *et al.*, 2005) reported that effluent recycling was an important operational parameter having a positive impact on the nitrogen removal in aerobic filters. It was not the scope of this research study to explore the effects of effluent recycling on the RF efficacy for nutrient removal. However, intermittent filter back washing made during run phases 2 and 3 improved ammonia removal. The filter washing might have reduced filter clogging by removing accumulated biomass in the pore opening of fixed film media, which might lead to increment of DO concentration along the filter depth. Thus, the result of filter back washing increased pore volume, due to the expansion of the filter media bed.

It had been proved by Akunna *et al.* (1994) and Jimmenez *et al.* (2000) that up to 30% of the ammonium reduction in the bio-filter was used for both autotrophic and heterotrophic cell synthesis during aerobic carbon removal and nitrification of anaerobically pre-treated effluent.

At higher COD/N ratios, nitrogen removal efficiency will be limited by incomplete ammonia oxidation as nitrification was affected by the organic load and the complete oxidation which require lower COD/N ratios, while at COD/N> 4 the denitrification activity will increase. Due to that, heterotrophic biomass activity resulted in the inhabitation of ammonia oxidizer. This finding was previously reported by other researchers (Chui *et al.*, 2001; Kim *et al.*, 2004) where they investigated domestic and industrial wastewater using different biofilter systems consisting of anaerobic, anoxic and aerobic zones at varying loading rates.

Figure 6 illustrates the COD/N variations during the three run phases in RF. In the first run phase, the AF effluent value (1.9) decreased to (1.5) at sampling tap RF T2. After that, the ratio was almost constant, in the second run phase, the ratio increased in the aeration zone to 3.5 due to the higher organic load and the deposition suspended in the surface of the PM. A decrease to 2.7 at the sampling tap RF T3 was noticed and finally in the third run phase the value had decreased from 3 in the aeration zone to 2 at the sampling depth RF T2. The COD/TKN ratio is an important design parameter for a successful denitrification process, and according to some authors it should be in the range of 4–6 (Lew *et al.*, 2003). The average ratio in the RF effluent was 2.3, indicating that it would be possible to obtain nitrification, such a ratio should not be a problem for nitrification in aerobic post-treatment reactors, since the COD content decreases progressively along the reaction cycle.

Figure 7 shows the backwash impact on NH_4-N content within the RF depths.

The optimum biomass growth is plotted (Figure 7), where the active biomass was noticed at an average depth of 30 cm. The average surface area for this depth was around 17.5 m^2. Similar results were reported by Guilloteau *et al.* (1994) on active biomass in the infiltration-percolation process by determining the depth of the media colonized by the biomass.

4. CONCLUSIONS

Results presented in this paper documented the feasibility of using a two-stage biofilter system to reduce the organic and nutrient contents from the UASB effluent. The total COD removal efficiency in the anaerobic stages (UASB+AF+RF) had increased with increasing the HRT and decreasing the organic loading rates. The entrapment mechanisms of the biofilters packing materials during higher organic loading rates might have induced low removal COD and TSS efficiencies. The ammonia production increased in the anaerobic stages due to protein hydrolysis and the reduction in TKN might be due to biomass built up. The TKN removal efficiency decreased with increasing the RF organic loading rate as of dissolved oxygen depletion necessary for the nitrifiers in the RF. Effluent recirculation and maintaining an average organic loading rate (10 g COD/m^2.d) in the AF, a good AF effluent can be achieved at an adequate surface COD load rate (5 g COD/m^2.d) for the RF.

Further optimization of the design and operation of the biofilter system applied in this research is expected to offer improved and stable treatment processes. The use of alternative fixed film media, introduction of aeration devices instead of passive aeration mode and recycling of treated effluent back to anaerobic stage may offer advantages in obtaining more removal efficiencies of organics and nutrients. However, further large-scale research studies should be conducted locally to document the impacts of these recommendations on the enhancement of the effluent quality.

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استخدام نظام فلترة حيوية على مرحلتين لتحسين جودة مياه ريفية عادمة مسبقة المعالجة لاهوائياً

(ملحوظة علمية)

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ملخــص

تقيم هذه الدراسة استخدام نظام مشاهدة لوحدتي فلترة حيوية؛ فلتر لاهوائي AF (Anaerobic Filter) متبوع بفلتر سريع ذاتي التهوية RF (Rapid Filter)، كنظام معالجة لاحقة لمياه منزلية عادمة من بلدة بيرزيت. كما تتناول تقييم فعالية هذا النظام في إزالة المواد العضوية وعناصر التغذية من المياه العادمة خلال ثلاث تجريبيات مختلفة. استعملت مواد محلية قليلة التكلفة من مخلفات البلاستيك المهروس ورمل الأنثراسايت لتعبئة الفلاتر الحيوية (RF-AF) على التوالي. شحن نظام المعالجة (RF-AF) بشكل متواصل بكمية من المياه العادمة (0.26-0.6 m^3/d) للحصول على أحمال عضوية وهيدروليكية مختلفة. خلال التجريبيات الثلاث، بلغت الكفاءة الكلية لإزالة الأكسجين المستهلك كيميائياً (COD) لسلسلة وحدات المعالجة (RF-AF) 28%، 65%، 30% على التوالي. أما إزالة المواد الصلبة العالقة تحت أحمال هيدروليكية وعضوية مختلفة فقد بلغت 43%، 51%، 54% مقارنة بمعدل إزالة الأمونيا في RF (8%) تحت حمل هيدروليكي عال. توصي نتائج البحث بأن لا يزيد الحمل العضوي لوحدة الفلتر اللهوائي (AF) عن 10 g $COD/(m^2.d)$ ليتمكن الفلتر السريع (RF) من تحقيق جودة سيبب معالج ملائمة لأغراض الري الزراعي. هذا، وينصح بعمل مشاهدات محلية إضافية على نطاق أوسع لتحسين نتائج نظام المعالجة المستخدم في هذه الدراسة وتأكيدها.

الكلمـــات الدالـــة: معالجة لاهوائية، فلتر حيوي، إزالة عناصر مغذية، فعالية المعالجة، معالجة لاحقة، بيرزيت.

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