START-UP PHASE ASSESSMENT OF A UASB–SEPTIC TANK SYSTEM TREATING DOMESTIC SEPTAGE

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الخلاصــة:

يتم سنوياً في فلسطين جميع ما يقارب من 65% من مياه الصرف في حمآت تشكل خطراً على الصحة العامة وتلفاً مستمراً للبيئة. وسوف نقدم في هذا البحث دراسة مبدئية كمرحلة إرشادية لخزان تــَعَقُّن UASB لمعالجة مياه الصرف لبلدة بيرزيت تحت ظروف تشغيل مختلفة. وقد تم تقييم أداء النظام فأظهرت النتائج الأولية أن إزالة الملوثات العضوية يُعزى إلى العمليات البيوفيزيائية مثل الترسب والتحلل الميكروبي. وحافظ نظام التشغيل خلال المرحلة الابتدائية على كفاءة أداء لـ COD_{total} قدرها 80% تقريباً مقارنة بـ COD_{col} و COD_{dis} التي تعادل 71% و 43% على التوالي. كما أظهرت طريقة التشغيل المستمرة فعالية النظام في إزالة الملوثات العضوية. وقد تبين لنا من خلال الخبرة التشغيلية عدم جدوى تغذية الخزان (UASB) برسوبيات منشطة خلال المراحل الأولية للتشغيل. وأخيراً ظهرت إمكانية استخدام خزان الحمأة (UASB) ، وبخاصة إذا تم تشغيله ومراقبته لفترة زمنية طويلة.

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ABSTRACT

About 65% of the annual domestic wastewater in Palestine is currently collected in cesspits, where inadequate disposal might cause cumulative public health risks and annual environmental degradation. This research presents the preliminary results for the start-up period of a pilot-scale UASB-septic tank system treating domestic septage of Birzeit town. Under different operational conditions, the performance of the pretreatment system for the removal of organic matter and nutrients was evaluated. Initial results showed that organic pollutants removal was mainly due to biophysical processes including sedimentation and microbial degradation. During the start-up phase, the system attained removal efficiency for COD_{total} of about 80% compared to the removal for COD_{col}, and COD_{dis} of 71% and 43%, respectively. Similarly, the continuous operation mode demonstrated that the system was quite effective in removing organic pollutants. Operational experience from the initial results revealed that seeding the UASB reactor with activated sludge during the start up period was not practical. Finally, the advantages of the UASB–septic tank application appeared to be achievable if adequate system operation and control over a long monitoring period were maintained.

Key words: Anaerobic treatment, removal efficiency, decentralized sanitation, domestic septage, nutrient removal, start-up phase, UASB–septic tank

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1. INTRODUCTION

The realization of the necessity to reconsider seriously the management of existing water resources, either due to the scarcity of or water concern over its pollution has motivated experts in the water and sanitation sector to search for alternatives. With the very limited existing disposal systems throughout the country, Palestine is now threatened by this waste, which may infiltrate and pollute its underground water resources unless measures are taken to alleviate this dilemma. More than 65% of the wastewater generated in the West Bank is collected in cesspits. Domestic septage is frequently evacuated from households cesspits by tankers and disposed of partially either in seasonal wadis or co-treated in urban sewage works [1].

Anaerobic digestion has become the most frequently used method for the treatment of medium-and high-strength wastewaters, due to the economy of the process, and the low generation of surplus sludge. The most popular form of anaerobic treatment is the upflow anaerobic sludge blanket (UASB) technology. The sludge retention of the UASB reactor is based on the formation of easily settling sludge flocs or granules, and in the application of a internal gas/liquid/solid separation system [2–5]. In a conventional UASB systems, the sludge bed acts as a filter to the suspended solids (SS), thereby increasing their specific residence time. In this way, the UASB reactor may achieve high COD and SS removals at a very short HRT. On the other hand, the accumulation of SS and adsorbed soluble organic matter in the sludge bed may provoke the displacement of active cells, leading to the formation of sludge with a very low methanogenic activity. However, little attention has been paid to the quality and characterization of biomass developed in UASB reactors treating domestic wastewaters. The standard UASB reactor has been combined with the conventional septic tank. The UASB-septic tank system is designed for the accumulation and stabilization of the sludge, therefore, this system operates in a continuous mode with respect to the liquid, but in a fed–batch or accumulation mode with respect to the solids [6].

According to Zeeman and Lettinga [7], complex wastewaters containing high amounts of suspended solids will limit the performance of a one-stage UASB reactor. Thus, with the implementation of this pre-treatment method, it is necessary to consider the strength of the wastewater. Based on wastewater classifications presented by Metcalf and Eddy [8], the municipal wastewater in the West Bank can be classified as a strong domestic wastewater due to the high concentration of pollutants such as COD, TKN, phosphorus, sulfate, ammonia, SS and VSS [9]. Recently, Al-Sa`ed and Hithnawi [10] found that domestic septage characteristics from households in Ramallah–Albireh district resembled municipal wastewater quality. Septic tank design, pump out interval, and life style were among the reasons behind these findings.

The objective of this study was to evaluate the start-up phase of a pilot scale UASB–septic tank system as a pretreatment stage for domestic septage from Birzeit town. The performance of the treatment system was monitored during different run phases in order to determine the design and operational parameters necessary for further testing in Palestine.

2. MATERIALS AND METHODS

2.1. Experimental Set-Up of the UASB Pilot Plant

The set-up of the UASB reactor is shown in Figure 1. Preceding the UASB reactor (0.4 m^3), a holding tank with an effective liquid volume of 1.2 m^3 served as a storage tank for the septage delivered from Birzeit town. The holding tank secured a continuous feeding for the UASB reactor for three days. The holding tank was not considered as a pretreatment unit, as a mixing device was installed in the holding tank to prevent solids settling and avoid removal of pollutants.

Figure 2 shows the geometrical dimensions of the UASB reactor with a volume of 0.4 m^3 (h= 1.88m and ϕ =0.265m). The influent is led via the central inlet pipe (1) to the bottom of the reactor, from where it flows upward through the sludge bed at the bottom (2). The lower baffles are located at the middle of the reactor (3) and are basically the connection of the two PVC tanks. An upper baffle is installed (4) with holes near the centre, to allow the produced gas move into the gas collector (5). The gas collector is an essential part of the UASB system, where the produced biogas is measured by a wet gas meter (6) and then freed into the atmosphere. The reactor contains five lateral taps to collect sludge or wastewater samples.

2.2.1. Phase I (13/2-27/5/2001)

During this phase the domestic wastewater from a resident in Birzeit was analyzed. It is safe to assume that this wastewater represents septage removed from cesspits in Palestine. In addition, the selection of an appropriate inoculum for the reactor was selected. Thus this phase was subdivided into two further divisions.

Seeding the UASB reactor

Three attempts were performed, of which only two were successful.

1st Inoculation (8/4/2001):

Activated sludge (return sludge line) from the central wastewater treatment plant (contact stabilization) at Birzeit University campus was used. This attempt failed, probably due to the degradation of exopolymeric substances bridging the sludge flocs.

2nd Inoculation (7/5/2001):

Activated sludge from the same wastewater treatment plant was used. The sludge possessed the following characteristics:

COD_{tot} = 26,844 mg/l; volume of inoculum $\approx$60 liters; TSS = 41.6 g/l and VSS = 16.42 g/l. The volume of the inoculum was determined by ensuring that at least 10g of VSS per liter were initially used according to Lettinga and Hulshoff-Pol [5]. This attempt also failed.

3rd Inoculation (27/5/2001):

To hasten the biological activity within the UASB reactor, anaerobic sludge from the primary sedimentation of the ponds at BZU was added. This step was undertaken when noticing that there hardly existed any methanogenic activity (gas meter did not show any sign of movement). The previous sludge (1st and 2nd inoculum) would most likely possess facultative microorganisms. Due to the fact that anaerobic digestion is the key treatment process in the UASB reactor, it is rational to obtain anaerobic organisms. The previous inoculation would apparently require more time for the adjustment and production of these anaerobic microorganisms. This inoculum possessed the following characteristics:

COD_{tot} =27 100 mg/l

TSS = 34 780 mg/l and the VSS = 13 915 mg/l and Ash = 40% of TSS

Volume of inoculum = 190–200 liters, with this inoculum, 70 liters would suffice and give at least 10g of VSS per liter. However, as the sludge bed increases in depth, this will enhance the biological activity. To check the activity of the sludge bed the fraction of $gCOD_{inf}/gVSS_{inoculum}$ was 0.05, which lies within the range (0.1–0.08) suggested by Lettinga and Hulshoff-Pol [5].

2.2.2. Phase II (28/5-28/6/2001)

The reactor was operated as a fed-batch with a septage daily volume between 50-70 liters. Monitoring began on 28th May until 28th June.

2.2.3. Phase III (3/7-12/7/2001)

The reactor mode in this phase was a continuous flow, as it should be. As the gas meter began to show that there was a slight methane gas production ($\approx$0.01 l/d), it was decided to change the mode of operation to the continuous state. During this run phase, the daily flow rate to the system was maintained at 0.4 m^3 of domestic septage to achieve a hydraulic retention time (HRT) of 14 hours and an upflow velocity of 0.13 m/h to prevent any washout.

3. ANALYTICAL METHODS

Collected raw sewage samples were analyzed in duplicate for total suspended (TSS) and volatile suspended solids (VSS), total COD (COD_{tot}) and COD fractions. Particulate COD (COD_p) fraction was determined using 4.4 μm folded filter papers, while 0.45 μm membrane filters were used for the analysis of dissolved COD (COD_{dis}) fraction. The COD fractions, suspended COD (COD_{ss}) and colloidal COD (COD_{col}) were calculated by the difference between COD_{tot} and COD_p, COD_p and COD_{dis}, respectively. Determination of TSS, VSS, COD_p, COD_{dis}, total and orthophosphates and ammonium was carried out as recommended by the *Standard Methods* [10]. The temperature values of raw sewage and UASB-system were measured using alcohol thermometer while the EC-pH meter (HACH) was used for pH determination.

4. RESULTS AND DISCUSSION

4.2. Operation and Performance Monitoring

Although the seeding of the reactor was during the second week of April till the end of May, the actual monitoring period was during June and July were the ambient temperature range was from 22°C – 28°C. The difference of temperature along the height of the reactor was insignificant, where the effluent had an average temperature of 24°C and the sludge bed 24.54°C. The pH variation throughout the height of the reactor stayed within the range of 7.3–7.86. The influent's pH had a higher range of 7.4–8.1. According to the classification made by Metcalf and Eddy [8], Table 1 shows a typical domestic septage with moderate contents. Other local studies [10] made on domestic septage from urban dwellings revealed higher strength (328–23028 mg TS/L) and ammonium (83 mg NH_4–N/L). In this study, storage of Birzeit domestic septage in the holding tank at a hydraulic retention time of 3 days might be behind the reduction in its strength.

Table 1. Characteristics of Domestic Septage from Birzeit Town (Units in mg/l, except pH)

Parameters		Number of Samples	Domestic Septage Characteristics*		
			Range	Average	STD
TSS		11	330–1160	560	280
VSS		11	240–450	330	70
Total Solids		7	460–1620	800	260
pH		16	7.4–8.1	7.69	0.18
COD_{tot}	Total	14	267–888	566	217
COD_{ss}	Suspended	14	117–740	363	191
COD_{col}	Colloidal	14	31–212	109	48
COD_{dis}	Dissolved	14	22–260	94.12	63
BOD		7	116–333	200	85
NH_4^+-N		6	19.8–57	39	15.4
Total P		6	4.3–15.4	8.1	4.7
PO_4^{3-}–P		6	2.2–11	5.39	4.18

4.3. Organic Removal Efficiencies

The COD_{tot} removal efficiency attained an average value of 79% considering the entire period of operation. However as the unit was operated in a continuous feeding mode, the removal efficiency attained a relatively high value, where the major contributor to the COD_{tot} was the removal of suspended solids. These findings are presented in Figure 3. The average removal efficiencies for COD_{col}, and COD_{dis} were 71% and 43% respectively. The removal rates for COD observed in this study at 24 °C are in accordance to results reported by others [5–7]. However, the negative removal of the dissolved COD might be due to acidification of the accumulated solids, particularly as ambient temperature increased with time. The results obtained in this work showed a similar tendency to that reported by Nadais *et al.* [12] who justified the low COD removal efficiency by accumulation of the organic matter inside the UASB reactors and the loss of active biomass by sludge wash-out. Other studies [13] reported that a great variability in the initial anaerobic COD biodegradation might be due to different sources of seeding sludge.

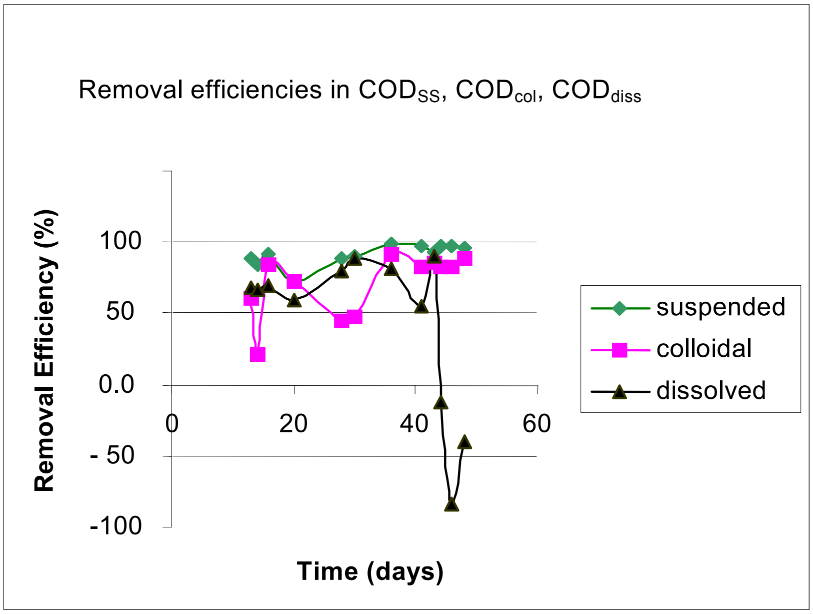

Figure 3. Removal efficiencies in COD fractions (COD_{tot}, COD_{col}, and COD_{dis})

As to the of the efficiencies removal of the TSS and VSS, it can be seen from Figures 4 and 5 that, during the entire monitoring period, the average removal efficiency was 28.2% and 24% for the TSS and VSS removal efficiency, respectively. During the last phase, higher TSS and VSS removal efficiencies were attained (28 and 30% respectively), under continuous–feeding mode. The influent possesses the lowest mean percentage value of VSS/TSS, indicating that approximately 33% of the TSS content is of non-biodegradable nature. On the other hand, the effluent shows the highest VSS/TSS content (Tap 1), which might be due to the accumulation of organic matter and presumably low methanogenic activity. This is reflected by the low biogas production rate recorded by the gas meter installed.

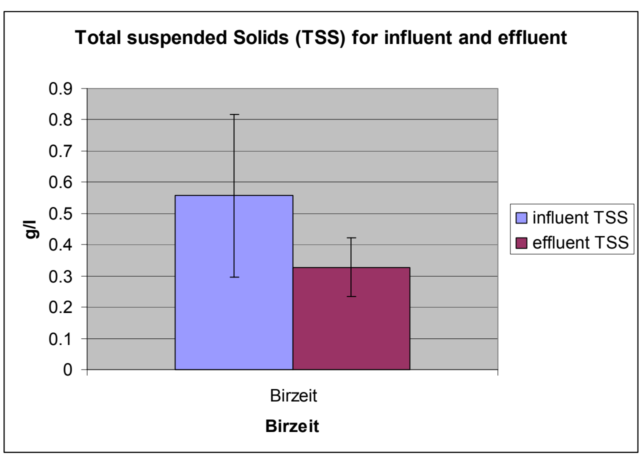

Figure 4. Influent and effluent average TSS

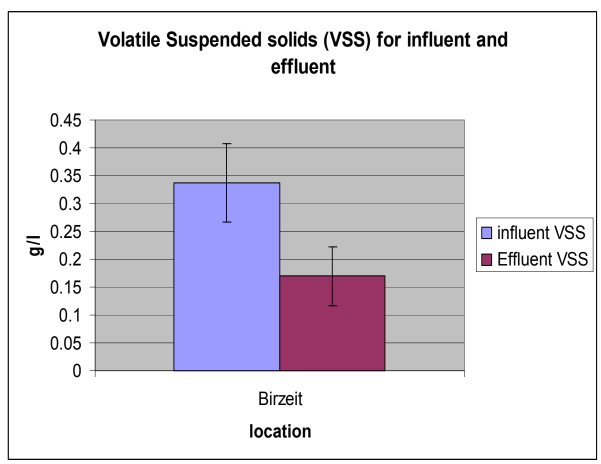

Figure 5. Influent and effluent average VSS

The performance of the UASB-system during phase 2 is illustrated in Figures 6 and 7. From these figures, a significant difference in the TS value in the taps at different heights along the reactor was noticed.

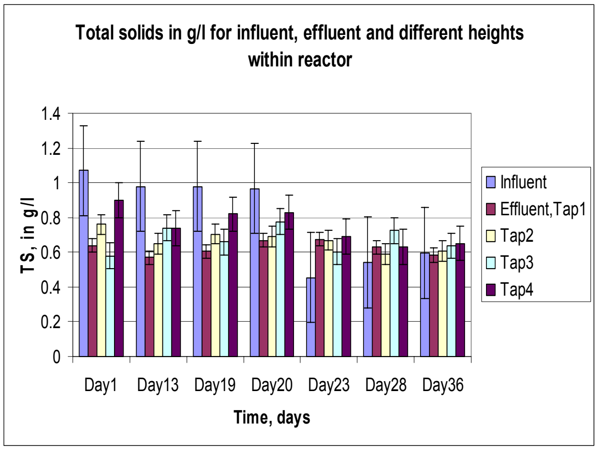

Figure 6. TS for influent and along height

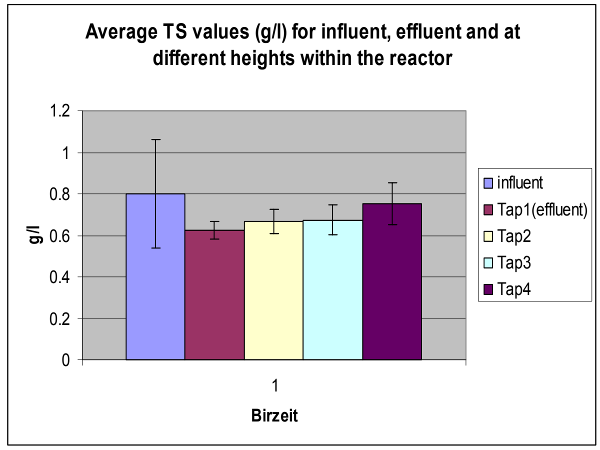

Figure 7. Average TS for influent, effluent of the UASB reactor at different heights along the UASB reactor

During the first run phase, the reactor was operated in a batch mode; minor degradation processes were noticed and thus merely behaved as a sedimentation tank. Similarly, during the final experimental run phase, a smaller difference between the TS within the different taps was also noticed (Table 2).

Table 2. Average* Content of Influent TSS, VSS, and VSS/TSS Ratio at Various UASB Heights

Parameter	Influent			Tap 1 (Effluent)			Tap 2			Tap 3			Tap 4		
	TSS	VSS	VSS/TSS	TSS	VSS	VSS/TSS	TSS	VSS	VSS/TSS	TSS	VSS	VSS/TSS	TSS	VSS	VSS/TSS
Average	0.56	0.33	0.67	0.30	0.23	0.81	0.37	0.31	0.84	0.43	0.31	0.74	0.47	0.34	0.73
STD	0.28	0.07	0.18	0.09	0.05	0.09	0.08	0.06	0.05	0.10	0.06	0.08	0.14	0.13	0.11

* Units in g/l except VSS/TSS ratio

Operational difficulties including flow measurement and control during this research was behind hydraulic shock loads, which lead to short HRT and small STR during the continuous–feeding mode of the UASB system. This has been recently confirmed by Al-Fuqaha and Al-Sa`ed [14], where they stated that at a constant HRT the efficiency of the UASB system dictates the removal efficiencies of the biofilters installed as a post-treatment stage. The upflow velocity is also an effective parameter in the TSS and VSS removal efficiency [15].

The continuous mode of operation has caused obviously a disruption in the sludge blanket at the bottom of the reactor, resulting in biomass washout. The results presented here, in relation to the effect of the HRT on the behavior of the UASB reactor used for septage pretreatment, indicate that a rise in the HRT will benefit the system in terms of COD removal efficiency and mechanization of the substrate removed.

Raising the HRT may have two opposing effects in the UASB performance, namely it may increase the contact time between the biomass and the substrate, allowing for a better degradation of the organic matter. While, on the other hand, lowering of the upflow velocity may diminish the mixing inside the reactor and for that reason impair the contact between the substrate and the biomass. Within the range of volumetric flows tested in this work, the raising of the upflow velocity will cause more biomass entrainment, heavier formation of sludge layers on the top of the reactor and consequently a higher biomass wash-out. The results presented in Figure 3 confirm that the loss of biomass was higher with the lower HRTs. A significant loss of biomass was observed during the first 40 d of continuous operation.

Miron *et al.* [15] found that there was a marked decrease in the efficiency from ca. 90% at V_{up}=0.25 m/h to ca. 75% at V_{up}=0.71 m/h, whereas the critical upflow velocity was found to be 0.6 m/h after which there was a steep decline in the removal efficiency. This sharp decrease was perhaps due to the opposite effects of the upflow velocity and the settling velocity of the particles. Since the upflow velocity used in this research was approximately 0.15 m/h, high TSS and VSS removal efficiencies (80% and 55% respectively) were achieved, especially during the third experimental phase.

The basis of the UASB is that the flocs of anaerobic bacteria will tend to settle under gravity, when applying a moderate upflow velocity. In this way no separate sedimentation tank is required. The anaerobic bacteria will be able to develop and settle in the reactor compartment, whereas the wastewater organic compounds are consumed by the bacteria under passage of the wastewater through the sludge layer.

4.4. Nutrients Removal Rates

4.4.2. Phosphorus removal

There was an increase in the accumulation of phosphorus within the reactor due to the inflow of the influent. Table 3 shows that in the sludge blanket in Tap 4 the amount of phosphorus has continuously increased. Ortho-P (P_o) formed about 60% of total-P (P_t) in the influent, whereas 90% of the P_t was P_o. From Figures 8 and 9, the value of ortho-phosphate is very close to the total phosphate, which indicates that the main contributor to the phosphate is washing detergents.

Table 3. Total Ortho-Phosphate and Ortho/Total Ratio in Influent, and Laterals of UASB Reactor

Parameter	Influent			Tap 1 (Effluent)			Tap 2			Tap 3			Tap 4		
	P_t	P_o	P_o/P_t	P_t	P_o	P_o/P_t	P_t	P_o	P_o/P_t	P_t	P_o	P_o/P_t	P_t	P_o	P_o/P_t
AVG	8.1	5.4	0.6	9.9	9.2	0.93	10.2	9.4	0.92	10.4	9.4	0.91	10.5	9.5	0.91
STD	4.7	4.1	0.1	1.2	0.5	0.06	1.2	0.4	0.07	0.94	0.4	0.05	0.96	0.47	0.05

[*] Units in mg/l except P_o/P_t (ratio)

A reasonable explanation for the gradual increment in both total and ortho-phosphate along the UASB laterals cannot be arrived at easily. Tap 4 showed around 30% more in total-P compared with the influent concentration.

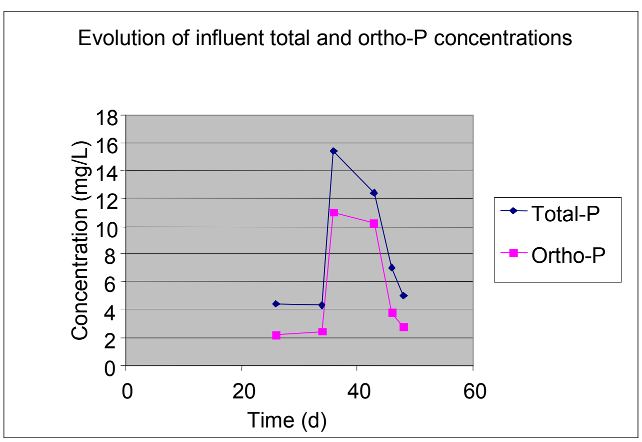

Figure 8. Influent total and ortho-phosphate

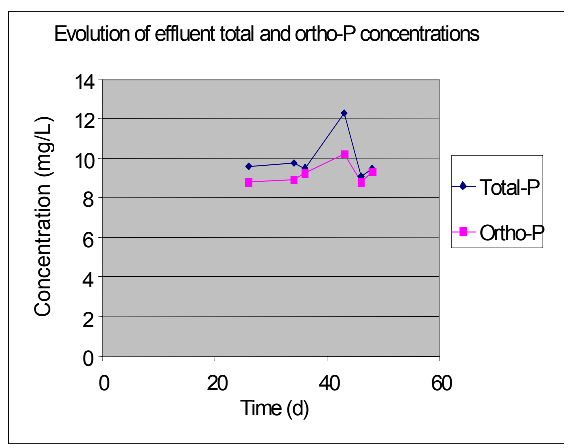

Figure 9. Effluent total and ortho-phosphate

Similarly, the ortho-P content in same lateral port was found to be about 76% more than that in the raw sewage. The bio-P release from microbial cells cannot be excluded as one further reason behind accumulation of phosphate molecules within the sludge blanket, though no alternating oxic and anoxic conditions were prevailing along the height of the UASB digester. However, cell lyses, bio-sorption, adsorption, and sedimentation of phosphate on sludge floc particles might be behind this phenomenon.

4.4.2. Ammonia removal

Figure 10 shows higher effluent ammonium content compared to influent. Similar results were reported by Sanz and Polanco [16], where they found that about 90% of the effluent TKN was NH_4–N, and about 70% of the influent Org-N was converted into to NH_4 under anaerobic conditions. Hence, the increase in ammonium content might be due to cell hydrolysis and biomass decay. During experimental run phase 2 (batch fed), ammonium has increased from 25 mg/l in the influent up to 90 mg/l in the effluent (tape 1). Whereas a slight increment between influent and effluent (45 and 55 mg/l respectively) was noticed during phase 3 (continuous flow mode) under small HRT and low SRT values compared to design parameters prevailed in the first experimental run phase.

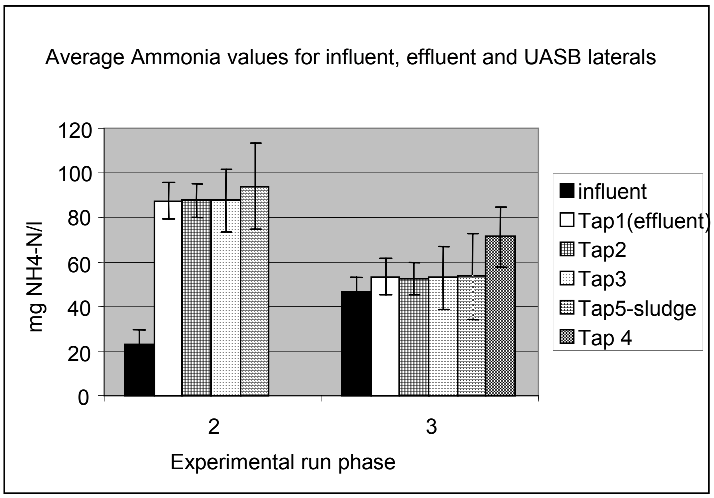

Figure 10. Average ammonium concentrations in influent, effluent, and along the height of the UASB reactor

The use of the UASB-Septic tank reactor for the removal of phosphorus and the ammonia content of the domestic wastewater was not appropriate [14,16]. On the contrary, accumulation and increment in phosphate concentrations was noticed as reported by Leitào *et al.* [17]. Under anaerobic conditions, the capability of heterotrophic microorganisms to metabolize organic matter was sharply reduced. Also, with the limitations of a terminal electron acceptor, organic matter cannot be oxidized to generate energy.

5. CONCLUSIONS

Changing the operation of the UASB reactor from batch-fed during start-up period to a continuous mode considerably improved the COD removal efficiency. Although the biogas production was yet low during start-up phase, the removal efficiencies were quite encouraging. This was caused by the high rate of sedimentation, due to the long HRT ($\approx$14 hours). In the UASB reactors, the microbial activity played an important role in the removal of COD, while conventional septic tanks only perform as settlers. It is only during the start-up phase that the gas production is low. However, to attain the full potential of the UASB reactor, adequate operation and process control over a long monitoring period are needed.

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