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Start-up of an UASB-septic tank for community on-site treatment of strong domestic sewage

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Abstract

Two community on-site UASB-septic tanks were operated in parallel over a six months period under two different hydraulic retention times (HRT) of 2 days for R1 and 4 days for R2 at mean sewage temperature of 24 °C. The sewage was characterised by a high COD_{tot} concentration of 1189 mg/L, with a large fraction of COD_{sus}, viz. 54%. The achieved removal efficiencies in R1 and R2 for COD_{tot}, COD_{sus}, BOD_5 and TSS were "56%, 87%, 59% and 81%" and "58%, 90%, 60% and 82%" for both systems, respectively. R2 achieved a marginal but significant ($p < 0.05$) better removal efficiencies of those parameters as compared to R1. The COD_{col} and COD_{dis} removals in R1 and R2 were respectively 31% and 20%, and 34% and 22%. The sludge accumulation was very low suggesting that the desludging frequency will be of several years. Accordingly, the reactor can be adequately designed at 2 days HRT.

Keywords: Anaerobic treatment; On-site; Domestic sewage; UASB-septic tank

1. Introduction

Developing countries suffer from the lack of proper wastewater collection and treatment facilities, especially in rural areas. The centralised collection and treatment systems are apparently too costly and complex to solve their wastewater problems. In Palestine about 73% of the West Bank households have cesspit sanitation and almost 3% are left without any sanitation systems (PCBS, 2000). The cesspits are left without lining, so sewage infiltrates into the earth layers and eventually to groundwater. Consequently, cesspits themselves pose increasing environmental pollution problems. Even for developed countries, the connection of dispersed human settlements like remote houses, summer houses, farms and recreation facilities to sewerage system is too costly. For instance, in Finland wastewater from rural areas (20% of the population) is a concern due to water sources pollution (Luostarinen and Rintala, 2005), and about 20% of the United States population, resembling more than 20 million homes, are served with onsite wastewater treatment facilities of mainly septic tanks (Scandura and Sobsey, 1997). Definitely, decentralised wastewater management is inevitable for comprehensive wastewater treatment and environmental protection world wide.

The septic tank is the most known and commonly applied system for on-site anaerobic pre-treatment of sewage. However, the performance of the septic tanks is rather poor despite the long operated HRT due to their inherent design feature, viz. the horizontal flow mode of the influent sewage (Lettinga et al., 1991; Mgana, 2003). A significant improvement of the septic tank was achieved by applying upward flow and gas/solids/liquid separation device at the top, which resulted in the so called UASB-septic tank system (Lettinga et al., 1991; Bogte et al., 1993; Zeeman et al., 2000). The reactor is operated in an upflow mode as a UASB reactor resulting in both improved physical removal of suspended solids and improved biological conversion of dissolved components, and sludge gradually accumulates and stabilises in the reactor, as in a septic tank (Zeeman et al., 2000; Luostarinen et al., 2007).

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Studies with UASB-septic tanks treating domestic sewage are scarce, and to our knowledge so far only a one research project had been conducted on the use of a UASB-septic tank system for the onsite sewage treatment at Dutch and Indonesian ambient conditions by Lettinga and his co-workers (Lettinga et al., 1991, 1993; Bogte et al., 1993). Nonetheless, the system has not been applied and demonstrated in other countries of different environments and sewage characteristics nor it has been optimised. For instance, in Palestine and Jordan in the Middle East sewage is characterised with high COD concentrations exceeding sometimes 1500 mg/L with high fraction of COD_{ss} (up to 70–80%) (Mahmoud et al., 2003; Halalsheh et al., 2005). Leitão et al. (2006) pointed out that the use of the UASB system for the treatment of sewage with relatively high COD concentration is still undergoing trials and argued that such knowledge is important to improve the reliability of anaerobic processes. This is because knowledge of the performance of anaerobic reactors treating municipal wastewater in extreme situation is limited. Moreover, as the UASB-septic tank system is an accumulation system with respect to solids, the influence of sludge bed development on solids physical removal, i.e. suspended and colloidal solids removal, and conversion, i.e. hydrolysis, acidification and methanogenesis, is still to be elucidated. The main objectives of this research were to asses the process performance of the community onsite UASB-septic tank for the treatment of domestic sewage with high total COD (COD_{tot}) concentration and with high fraction of suspended COD (COD_{ss}) and also to increase the knowledge on the system design. In view of that, two UASB-septic tank reactors treating domestic sewage in Palestine had been operated under ambient conditions for a six months period at HRTs of two and four days.

2. Methods

2.1. Experimental set-up

Two pilot scale UASB-septic tank reactors, namely R1 and R2, were installed in parallel at the main wastewater treatment plant (WWTP) of Al-Bireh city/Palestine. The reactors were made of galvanized steel with working volumes of 0.8 m^3 (height 2.50 m; diameter 0.638 m). Nine sampling ports were installed along the reactor height at 0.25 m for sludge sampling, with the first port at 0.15 m from the bottom of the reactors. The influent was distributed in the reactor through polyvinyl chloride (PVC) tube with four outlets located 5 cm from the bottom. Biogas was passed through a 16% NaOH solution for CO_2 scrubbing, and then methane quantity was continuously measured by wet gas meters.

2.2. Pilot plants start-up, operation and monitoring

The UASB-septic tank reactors were started up during spring, *ca.* April, for a period of 6 months. The reactors were fed with domestic sewage pre-treated with screens and grit removal chamber. The sewage was pumped every five minutes to a holding tank (200 L plastic container), with a resident time of about 5 min, where the reactors were fed and the influent was sampled. The reactors were inoculated with anaerobic sludge obtained from a cesspit serving a house (R1 and R2, respectively, with 10% and 20% of the reactors volume), and operated in parallel at ambient temperature. The inoculum sludge characteristics in terms of COD_{tot}, TS, VS, VS/TS, TSS, VSS and stability were 18.3 g/l, 13.78 g/l, 9.58 g/l, 0.7, 11.15 g/l, 8.59 g/l and 60%, respectively. Stability stands for the percentage of COD converted to CH_4 out of a certain incubated amount of sludge expressed as COD (see Eq. (1)). The sludge stability was measured after 100 days of batch incubation at 30 °C. Daily monitoring was started since the onset of the experiment including wastewater and ambient temperature and biogas production measurements. Grab samples of raw sewage and reactors effluents were collected and analysed two to three times a week. The atmospheric pressure was measured *in situ.*

2.3. Analytical methods

Total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), volatile solids (VS), ammonium (NH_4^+), kjeldahl-nitrogen (Kj-N), chemical oxygen demand (COD), biological oxygen demand (BOD), total PO_4-P, dissolved PO_4^{3-}-P, SO_4^{2-} and sludge volume index (SVI) were measured according to s*tandard methods* (APHA, 1995). Raw samples were used for measuring total COD (COD_t), 4.4 m folded paper-filtered (Schleicher and Schuell 5951/2, Germany) samples for paper filtered COD (CODp) and 0.45 m membrane-filtered (Schleicher and Schuell ME 25, Germany) samples for dissolved COD (COD_{dis}). The suspended COD (COD_{ss}) and colloidal COD (COD_{col}) were calculated as the difference between COD_t and COD_p and the difference between COD_p and COD_{dis}, respectively. The volatile fatty acids (VFA) analysis was carried out as described by (Buchauer, 1998). All samples were analysed in duplicate except, VFA and SVI in single.

Biodegradability of raw sewage and effluents samples were measured once in triplicate using 500 mL working volume batch reactors incubated at 30 °C for a period of 120 days as described by Mahmoud et al. (2003). Sludge stability was measured three times in duplicate as described by Mahmoud (2002).

2.4. Calculations

2.4.1. Nomenclature

COD_{tot}: amount of total COD in the tested sample (mg COD/l)

$COD_{tot,\ inf}$ and $COD_{tot,\ eff}$: amount of total COD in influent and effluent (mg COD/l)

$COD_{dis,\ inf}$ and $COD_{dis,\ eff}$: amount of dissolved COD in influent and effluent (mg COD/l)

$COD_{VFA,\ inf}$ and $COD_{VFA,\ eff}$: amount of VFA in influent and effluent (mg VFA as COD/l)

COD_{CH4}: amount of produced CH_4 $_{(liquid\ form\ +\ gas\ form)}$ (mg CH_4 as COD/l); CH_4 $_{(liquid\ form)}$ was calculated according to Henry's law assuming 70% of the biogas is CH_4

$COD_{accumulated}$: amount of accumulated COD in the reactor (mg/l)

2.4.2. Biodegradability and stability

$$\text{Biodegradability}(\%) = 100(COD_{CH4}/COD_{tot,t=0days}) \quad (1)$$

or

$$\text{Biodegradability}(\%) = 100(COD_{tot,t=0days} - COD_{tot,t=tdays})/COD_{tot,t=0days} \quad (2)$$

2.4.3. Hydrolysis, acidification and methanogenesis

Percentage of hydrolysis (*H*), acidification (*A*) and methanogenesis (*M*) were calculated according to Eqs. (3)–(5), respectively.

$$H\ (\%) = 100\left(\frac{COD_{CH4} + COD_{dis,eff} - COD_{dis,inf}}{COD_{tot,inf} - COD_{dis,inf}}\right) \quad (3)$$

$$A\ (\%) = 100\left(\frac{COD_{CH4} + COD_{VFA,eff} - COD_{VFA,inf}}{COD_{tot,inf} - COD_{VFA,inf}}\right) \quad (4)$$

$$M\ (\%) = 100\left(\frac{COD_{CH4}}{COD_{tot,inf}}\right) \quad (5)$$

2.4.4. COD – mass balance

$$COD_{tot,inf} = COD_{accumulated} + COD_{CH4} + COD_{tot,eff} \quad (6)$$

2.5. Statistical data analysis

Statistical comparisons of means was followed by "Paired samples *t*-test" for the measured parameters of the two reactors using the SPSS program for windows – Release 11.0.0, SPSS® Inc. (2001), with p value <0.05 considered significantly different.

3. Results and discussion

3.1. Sewage characteristics

The results presented in Table 1 reveal that the raw sewage used in this research is characterized with high concentration of pollutants. Mahmoud et al. (2003) postulated the high sewage strength in Palestine to low water consumption and people's habits. The sewage temperature of 24 °C with extreme values of 18.2 °C and 29 °C is similar to wastewater temperature in tropical and subtropical regions ($T > 18$ °C) (Von Sperling and de Lemos Chernicharo, 2005).

3.2. Removal efficiencies

The course and mean values of effluent COD_{tot} and fractions and the removal efficiencies of the two reactors are presented in Figs. 1 and 2 and Table 1. The results presented in Table 1 are at the '*steady state*' conditions considered after 80 days of starting up the reactors since the results in Fig. 2 clearly show that the reactors were poorly performing during the first 60–80 days. The results show that R2 achieved slightly higher removal efficiencies as compared to R1 for COD_{tot} and the separate distinguished COD fractions. However, the differences in removal efficiencies and effluent concentration between the two reactors were statistically significant only for COD_{tot} and COD_{sus} ($p < 0.05$). Removal efficiencies of COD_{sus}, as well as TSS and VSS were consistently very high, and even the highest as compared with the other COD fractions, and quite stable over the whole period of both reactors operation. Similar to COD_{tot} removal efficiencies, the results presented in Table 1 reveal that R2 achieved a slightly better BOD_5 removal efficiency as compared to R1 ($p < 0.05$). The effluent BOD_5 concentrations of both reactors were relatively stable throughout the operational period. The achieved COD_{col} removal efficiencies in both reactors were rather low with no significant difference between both of them ($p > 0.05$). Elmitwalli (2000) attributed the poor colloidal removal during anaerobic sewage treatment to poor physical removal, and showed that the colloidal particles in sewage are highly biodegradable.

The methane gas production in the UASB-septic tank reactors was strongly influenced by sludge bed development and ambient temperature. Although, both reactors were inoculated with anaerobic sludge, negative COD_{dis} removal efficiencies were observed over the period from day 1 to day 60 in both reactors as displayed in Fig. 2. This indicates poor methanogenic conditions, as 20–90% of the CODdis of both reactors was in the VFA form with an average of 55% over the whole period of operation (Table 1). This might be partly attributed to poor methanogenic capacity of the inoculum sludge which is apparent from the low sludge stability (60%) and the high COD/VS ratio of 1.91 which is similar to the ratio presented by Mahmoud et al. (2004) for primary sludge of 2.03. On the other hand, the methanogenic activity was enhanced steadily with sludge bed development, as CH_4 gas production was gradually increased particularly after almost 30 days of reactors start up (Fig. 2). No significant differences were found for COD_{dis} removal efficiencies between the two reactors ($p > 0.05$). The VFA concentrations in effluents were observed to be greatly affected by temperature, e.g. such the case during the hottest period of 69–78 days and 145–147 days, where high amounts of gas productions were detected, accompanied by reduction in VFA and COD_{dis} concentrations. Worth mentioning that when biogas production was increased, like during the period 69–78 days when the accumulated COD was converted to biogas, COD_{dis} in the effluent was sharply decreased to its lowest

Table 1
Influent and effluent characteristics and removal efficiencies (%) at 'steady state' conditions during the anaerobic sewage treatment in two UASB-septic tank reactors

Parameter	Samples #	Influent concentration	UASB-septic tank 1 (R1) (HRT = 2 days)				UASB-septic tank 2 (R2) (HRT = 4 days)			
			Effluent concentration		Removal efficiency (%)		Effluent concentration		Removal efficiency (%)	
			Range	AVR	Range	AVR	Range	AVR	Range	AVR
COD total	32	1267 (158)	366–685	555 (61)	45–73	56 (6)	266–810	530 (96)	48–77	58 (7)
Suspended	32	634 (122)	21–155	81 (36)	75–96	87 (5)	27–133	66 (29)	79–96	90 (4)
Colloidal	32	193 (48)	65–197	126 (32)	−26–67	31 (22)	72–225	122 (32)	−19–64	34 (19)
Dissolved	32	439 (68)	146–419	347 (53)	−1–50	20 (11)	108–491	342 (69)	1–63	22 (13)
VFA as COD	32	152 (21)	85–176	142 (21)	−29–42	6 (17)	72–186	139 (28)	−57–58	7 (24)
BOD_5	17	641 (76)	197–303	258 (39)	41–72	59 (8)	198–321	257 (37)	50–69	60 (6)
NKj as N	12	76 (5)	53–77	65 (7)	−1–37	15 (10)	56–74	67 (6)	−4–24	12 (9)
NH_4^+ as N	15	57.9 (3.1)	50–62	55 (3.1)	−2–17	5.5 (6)	51–65	57 (4)	−8–17	2 (7)
Total PO_4 as P	9	13.64 (0.8)	12.7–13.7	13 (0.3)	−1.8–10.9	4.42 (4.1)	12.5–14.2	13.53 (0.5)	−6.5–11	0.52 (7.1)
PO_4^{3-} as P	9	13.3 (0.97)	15.5–17.8	16.5 (0.85)	−36.1– (−10.4)	−24.9 (8.5)	16.5–18.3	17.1 (0.55)	−38.9– (−14.7)	−29.7 (8.44)
SO_4^{2-}	12	124 (16)	28–40	34 (3)	65–79	72 (4)	27–45	36 (5)	62–78	71 (5)
TSS	13	623 (111)	100–137	116 (11)	76–86	81 (3)	84–136	113 (15)	76–87	82 (3)
VSS	13	526 (95)	76–114	98 (10)	76–86	81 (3)	74–119	98 (14)	76–86	81 (3)
VSS/TSS	13	85 (3)	76–90	85 (4)	–	–	85–92	87 (2)	–	–
SVI	5	21.5 (4.7)	None	None	–	–	None	None	–	–
pH	20	7.4 (0.19)	7.12–7.49	7.27 (0.11)	–	–	7.12–7.46	7.31 (0.11)	–	–
Biodegradability	3	65 (3.43)	40–45	42 (2.7)	–	–	37–40	39 (1.4)	–	–
Fecal coliform[a]	18	2.1×10^7	–	1.55×10^6	–	16 (11)	–	1.26×10^6	–	17 (11)
Tww	104	24 (1.96)[b]	–	1.55×10^6						
Tamb.	179	24.1 (3.16)[c]								
Patm.	2	0.923 (0.008)								

[a] From Samhan (2005).
[b] Range 18.2–29 °C.
[c] Range 15.3–34 °C. Standard deviations are presented between brackets. All parameters are in mg/L except: sludge volume index (SVI) in mL/g.SS; pH no unit; VSS/TSS (%); Biodegradability (%); fecal coliform: CFU/100 mL; wastewater temperature (T_{ww}) and ambient temperature ($T_{amb.}$) (°C); pH no unit; atmospheric pressure (P_{atm}) atm; †: calculated.

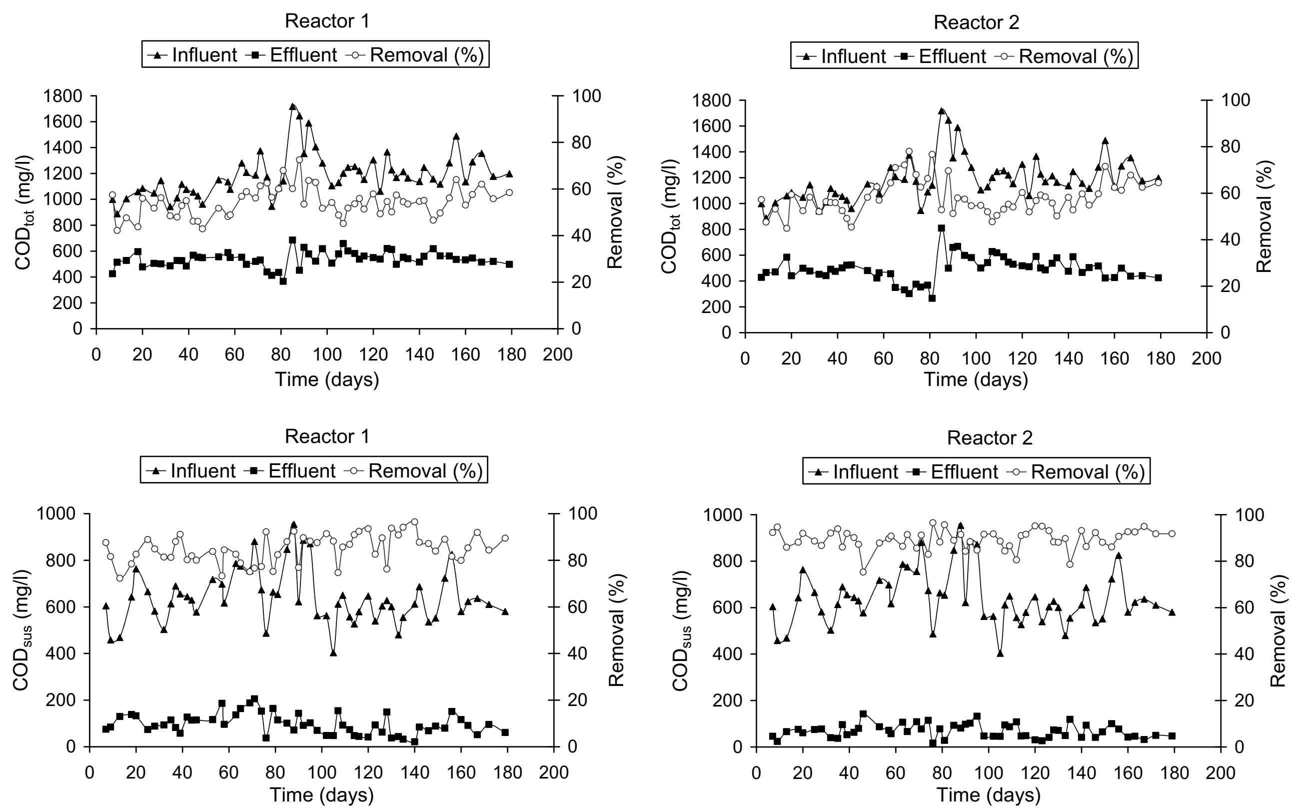

Fig. 1. COD_{tot} and COD_{sus} influent and effluent concentrations and removal efficiencies for R1 (left) and R2 (right).

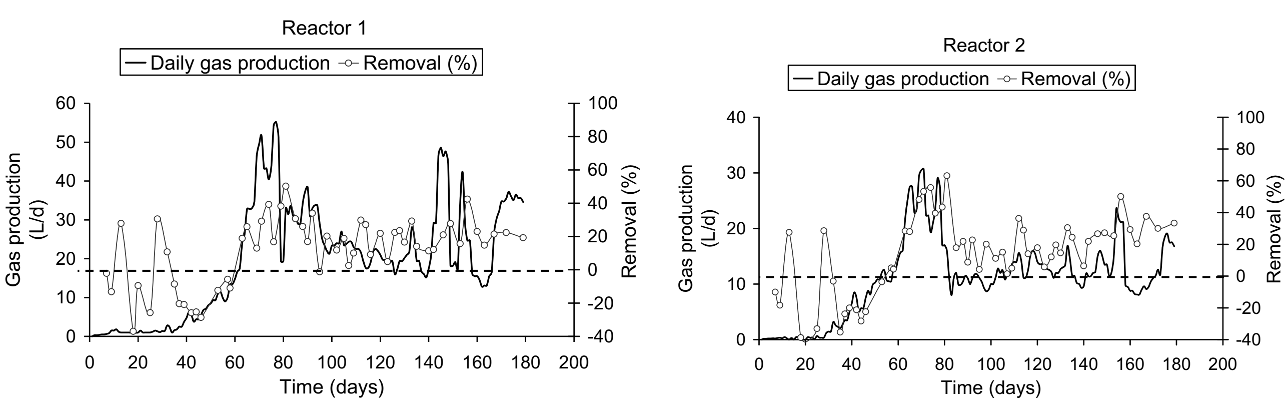

Fig. 2. COD_{dis} removal efficiencies with relation to daily CH_4 gas production (right) for R1 and R2.

limits over the whole research period, viz. 146 and 108 mg/L in R1 and R2, respectively. This is likely due to better mixing conditions in the reactor created by the intensive gas production, in addition to the enhancement of bioconversion at higher temperature.

3.3. Hydrolysis, acidification, and methanogenesis

The percentage and course of COD hydrolysis, acidification, and methanogenesis in R1 and R2 over the whole period of operation are depicted in Table 2 and Fig. 3. The considerable fluctuations in the influent sewage concentration and composition led to high standard deviation in the mean value of hydrolysis, acidification, and methanogenesis. The results reveal low hydrolysis, acidification, and methanogenesis in both reactors over the first month of operation most likely due to poor quality of the inoculum sludge, but was increased over the next months. Moreover, results clearly reveal that the methanogenesis was limiting the overall conversion of organic matter to methane in both reactors as the effluents contained a high amount of CODdis and VFA (Table 1). The occurrence of methanogenic conditions is crucial for enhancement of lipids hydrolysis and acidification which is also affected by the degree of methanogenesis (Mahmoud et al., 2004). Acidification in the UASB-septic tank reactors resulted in

Table 2
Characteristics of the retained sludge in the UASB-septic tank reactors and the percentage hydrolysis (*H*), acidification (*A*), and methanogenesis (*M*) in both reactors (R1 and R2) over the whole operation period (6 months)

Parameter	Reactor 1 (R1)	Reactor 2 (R2)
COD_{tot}	52.4 (7)	55.1(5.5)
TS	46.8 (8)	48.6 (5)
VS	34 (5)	34.6 (4)
VS/TS	73 (3)	71 (1.7)
COD/VS	1.55 (0.14)	1.6 (0.17)
Stability at day[a] = 63[b]	62 (2.4)	60.7 (2.1)
Stability at day[a] = 102[b]	56.2 (2.8)	51.8 (1.4)
H (%)	16 (9.5)	17 (8.5)
A (%)	19 (7.0)	20 (7)
M (%)	15 (6.9)	17 (7.0)

Standard deviations are presented between brackets. All parameters are in g/l except: stability (%) (g CH_4-COD/g COD); VS/TS ratio; COD/VS ratio.
[a] Stability test lasted for 100 days of batch incubation.
[b] The 63 and 102 days are the days after the start of operating the UASB-septic tank reactors.

an increase of the VFA/COD_{dis} from 41% in the influent to 52% in the effluent, with an apparent increase of VFA concentration in the effluent.

3.4. Sludge bed development and sludge characteristics

The characteristics of the retained sludge in the UASB-septic tank reactors (R1 and R2) are presented in Table 2 and Fig. 4. The sludge production was rather low as the sludge retained in both reactors was only detected at 0.15 m, viz. the first port, from the bottom of the reactors and did not reach the next port at 0.4 m all over the operational period. However, sludge hold-up and accumulation was clearly observed in both reactors as shown from the monthly mass balance (Fig. 5) and the gradual increase in the total solids (TS) content of the sludge bed (Fig. 4) as TS increased from initial sludge concentration of 13.78–46.8 gTS/L and 48.6 gTS/L respectively for R1 and R2 during the whole period. The results did not show any significant differences ($p > 0.05$) between R1 and R2 with respect to sludge characteristics, viz. VS and TS. Moreover, Fig. 4 shows a declining trend in VS/TS ratio of the retained sludge, which indicates sludge stabilisation with time. However, the average VS/TS values of 73% and 71% for R1 and R2, respectively, indicate that the sludge was not stabilized. Halalsheh et al. (2005) reported VS/TS ratio of 0.66 for a UASB reactor treating sewage in Jordan during summer time. Nonetheless, the results of sludge stability clearly reveal sludge stabilization was enhanced with time. The sludge retained in R2 was more stabilized, as measured on day 102, than that in R1 which can be explained by the lower OLR of R2 (0.3 kgCODtot/m^3 d) than R1 (0.6 kgCODtot/m^3 d).

3.5. Nutrients removal

The difference of NH_4^+-N concentrations between influent and effluent in the two reactors was very low and probably within the marginal error of the measuring instrument (Table 1). Nevertheless, after around 120 days of operation, NH_4^+-N concentration in the effluents of R1 and R2 were lower than the influent NH_4^+-N concentration by respectively 5.74(3.98) and 5.63(3.66), which might be due to complex formation, e.g. precipitation of ammonium as struvite ($MgNH_4PO_4 \cdot 6H_2O$) (Mamals et al., 1994). The Kj-N was partly removed in the reactors due to particulate N removal with no significant difference between both reactors ($p > 0.05$). The removed organic N might had been accumulated in the sludge bed and was not completely converted, viz. hydrolysed and acidified. This is speculated since NH_4^+-N in the effluent did not increase as compared to the influent which would have been expected to occur due to hydrolysis and acidification of the removed organic nitrogen. Mahmoud et al. (2004) showed during anaerobic digestion of primary sludge in a CSTR digester operated at 30 days and 35 °C, limited hydrolysis of proteins to a

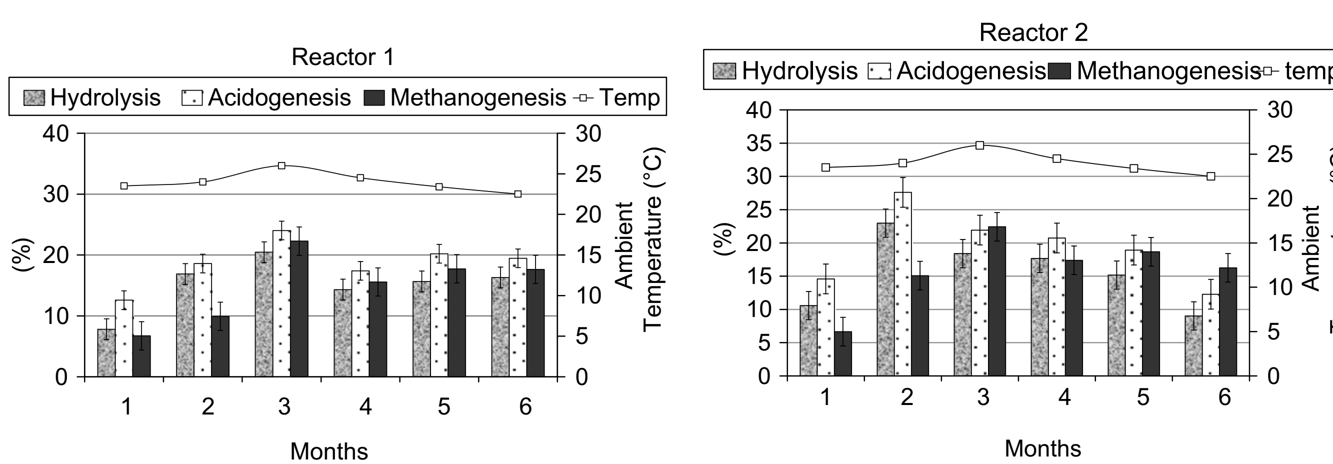

Fig. 3. Percentages of hydrolysis, acidification, and methanogenesis of domestic sewage in R1 (left) and R2 (right).

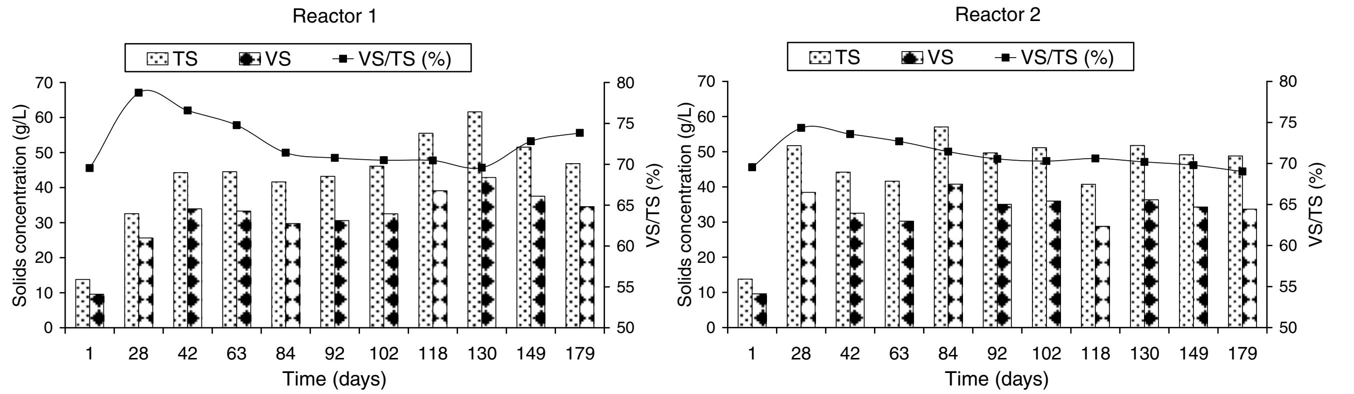

Fig. 4. Course of sludge bed development concentration in R1 (left) and R2 (right) as TS, VS and VS/TS ratio at 0.15 m height stands from the bottom of the reactors.

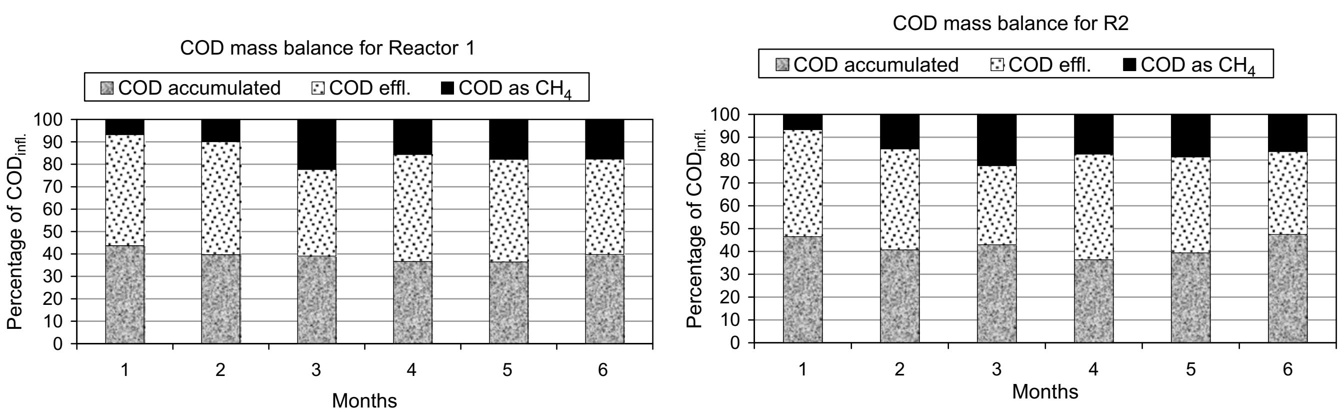

Fig. 5. Monthly COD mass balances for R1 (left) and R2 (right) as a percentage of the average influent COD_{tot} and divided over COD accumulated, COD_{effl} and COD as CH_4.

maximum value of 39%, which was postulated to proteins availability in the form of biomass.

The phosphorous was apparently not removed in both reactors; however, the effluents ortho-phosphate (PO_4^{3-}) concentrations were always higher than the influent in both reactors. The effluent PO_4^{3-} concentration of R1 and R2 were stable throughout the operation period and were not affected by the fluctuation in influent concentration. No significant differences were found for PO_4^{3-} removal efficiencies between the two reactors ($p > 0.05$).

4. General discussion

The findings of this research clearly reveal the high potential of the UASB-septic tank system for the community onsite strong sewage pre-treatment as the system satisfactorily couples wastewater treatment and sludge accumulation and stabilisation. Thus the operational results of the reactors proved the reliability of the system for the treatment of high sewage strength that was questioned by Leitão et al. (2006).

The removal efficiencies attained in R1 and R2 for COD_{tot} during the start up six months period were in the range of results obtained with well functioning conventional UASB reactors treating raw domestic sewage in sub-tropical regions. Halalsheh (2002) reported COD_{tot} removal efficiencies of 58% and (50–62%), respectively, for pilot and full scale UASB reactors treating raw domestic sewage at 24 °C in Jordan which is, from a wastewater composition and environmental conditions as well as socio-cultural perspectives, very close to the wastewater characteristics dealt with in this research. Nonetheless, the lowest achieved values of COD_{dis} and VFA are still high when compared with those obtained in a conventional UASB reactor (60 m^3) operated in Jordan at loading rates in the range of 1.5–1.8 kg COD/m^3 d, viz. VFA and COD_{dis} effluent were respectively 10 and 210 mg COD/L, during summer (Halalsheh et al., 2005). It is not clear if the high effluent COD_{dis} and VFA is due to low sludge activity and/or due to poor contact between influent wastewater and sludge owing to low mixing as a consequence of low upflow velocity and low biogas production since the reactors were operated at low organic and hydraulic loading rates. Mahmoud et al. (2003) reported that upflow velocity should be high enough to provide good contact between substrate and biomass, and to impede channel formation. Some researchers like Zaiat et al. (1996) reported that the external mass transfer resistance of substrate through a biofilm can be decreased by increasing the flow velocity. Lettinga et al. (1993) argued that all UASB systems provide sufficiently good contact between the sludge and the wastewater, unless they are not equipped with a proper feed inlet distribution system and the applied organic loading rate is below 1–2 kg COD/m^3 d. Bogte et al. (1993) also reported complete conversion of VFA into CH_4 during 3–4 months of the second year of UASB-septic tank operation (UASB-septic tanks were operated at OLR of 0.34–0.53 kgCOD/m^3 d). Based on that, it can be postulated that sludge bed development with time accompanied with further enhancement of sludge bed methanogenic activity might further improve the reactors performance. The effluent anaerobic biodegradability of R1 and R2 of respectively 42% and 39% resembling 225 mgCOD/L and 192 mgCOD/L indicate that the reactors can achieve further treatment probably after longer period of reactors operation to allow for better sludge development, and/or by technical modification of the reactors.

The reactors were not filled with sludge during the period of experiment and desludging of the reactors was deemed to be after long time of operation. This interesting observation is consistent with that reported in literature about the UASB-septic tank reactor, that the sludge hold-up time of the system is so long and the withdrawal of the sludge could be done once every 1–4 years (Zeeman et al., 2000). This implies that the costs for sludge handling associated with sewage treatment, would be reduced dramatically by using UASB-septic tank reactors.

A post-treatment step is recommended in most cases after UASB-septic tank systems, not only to remove remaining COD, but also to remove nitrogen and phosphorus (when reuse is not possible). The fecal coliforms should also be removed when the treated wastewater is going to be reused for unrestricted irrigation as the FC in the both reactors effluent as presented in Table 1 exceeded by far the 1000#/100 mL recommended by the WHO.

4. Conclusions

The here presented UASB-septic tank system represents an efficient technology for anaerobic sewage (pre) treatment at sewage temperature conditions of Palestine during summer time, i.e. it provides during start-up period average removal efficiencies for COD_{tot}, COD_{sus}, BOD_5 and TSS of 56%, 87%, 59% and 81%, respectively at 2 days HRT, and likewise, 58%, 90%, 60% and 82% at 4 days HRT.

The design of the UASB-septic tank at the longer research HRT of 4 days seems to have negligible contribution to better reactor performance as compared to the reactor operated at 2 days HRT. This suggests that the design of the UASB-septic tank at HRT of 2 days is adequate and more economical.

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