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Community onsite treatment of cold strong sewage in a UASB-septic tank

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ABSTRACT

Two community onsite UASB-septic tanks namely R1 and R2 were operated under two different HRT (2 days for R1 and 4 days for R2) in parallel over a year and monitored over the cold half of the year. During the monitoring period, the sewage was characterised by a high COD_{tot} of 905 mg/l with a high fraction of COD_{ss}, viz. about 43.7%, and rather low temperature of 17.3 °C. The achieved removal efficiencies in R1 and R2 for COD_{tot}, COD_{sus}, COD_{col}, COD_{dis}, BOD_5 and TSS were "51%, 83%, 20%, 24%, 45% and 74%" and "54%, 87%, 10%, 28%, 49% and 78%", respectively. The difference in the removal efficiencies of those parameters in R1 and R2 is marginal and was only significant ($p < 0.05$) for COD_{sus}. The sludge filling period of the reactors is expected to be 4–7 years. In view of that, the UASB-septic tank system is a robust and compact system as it can be adequately designed in Palestine at 2 days HRT.

1. Introduction

Decentralised wastewater management is inevitable for comprehensive sustainable wastewater treatment and environmental protection world wide. For instance, in Palestine only 6% of the total West Bank population is served with functioning treatment facilities consisting of a one centralised extended aeration wastewater treatment plant. The Palestinian experience with constructing that plant is not too promising due to the technical requirements and the fractional recovery of the operational and capital costs. The inadequacy of the centralised main stream technologies is also evident in Europe and the United States. The challenge there is to provide wastewater management services for remote houses and settlements (Scandura and Sobsey, 1997; Luostarinen and Rintala, 2005).

Several treatment systems, such as trickling filter, activated sludge, septic tank, membrane bioreactor (MBR), constructed wetland (CW) and ponds have been applied for onsite wastewater treatment (Lens et al., 2001; Metcalf and Eddy Inc., 2003; Abegglen et al., 2008; Carty et al., 2008). Anaerobic technologies are the core of the sustainable decentralised wastewater treatment systems (Lettinga, 1996; Hammes et al., 2000; Mahmoud et al., 2004; Luostarinen et al., 2007). The interest in the anaerobic systems, as had been traditionally perceived, is due to process simplicity, low operational costs and the independency on electricity. The need for energy efficiency and CO_2 emission reduction potentials are prime driving forces for applying anaerobic technologies in recent environmental engineering trends (van Lier, 2008).

For more than 150 years, the septic tank had been widely applied for onsite anaerobic pre-treatment of sewage. A significant improvement of the septic tank was achieved last two decades 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 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).

The UASB-septic tank was firstly investigated 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). Recently, Al-Shayah and Mahmoud (2008) reported results about the system performance during start up period in Palestine. In Palestine sewage is characterised with high COD concentrations exceeding sometimes 1500 mg/l with high fraction of COD_{ss} (up to 70–80%) and sewage temperature goes below 15 °C during winter time (Mahmoud et al., 2003; Halalsheh et al., 2005). They operated two UASB-septic tanks for a 6 months period during the hot half of the year, but the system performance during the subsequent cold half of the year was not investigated. Previous research has demonstrated that the performance of single stage UASB systems at low temperatures (5–20 °C) is severely limited by the slow hydrolysis of entrapped solids that accumulate in the sludge bed (Zeeman and Lettinga, 1999). This phenomenon is of particular concern when the reactor is fed with highly concentrated raw sewage at low temperature as the case in Palestine and some other Middle Eastern countries with Mediterranean climate like Jordan during the cold half of the year. Leitão et al.

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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_{CH_4} 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)

(2006) reported 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.

The main objectives of this research were to asses the process performance of the community onsite UASB-septic tank for the treatment of concentrated sewage under rather low temperature conditions and to increase the knowledge on the system design. To achieve those objectives, two UASB-septic tank reactors were operated in Palestine under ambient conditions at HRTs of 2 and 4 days for a whole year. The results of the reactors performance during the start up period of 6 months coinciding the hot half of the year were previously presented by Al-Shayah and Mahmoud (2008). In this research, the results of the reactors performance over the last 6 months which are the cold period of the year are presented.

2. Methods

Experimental set-up: Two UASB-septic tank reactors, namely R1 and R2, were installed in parallel at the centralised sewage treatment plant of Al-Bireh City/Palestine. The reactors were made of galvanized steel with working volumes of 0.8 m^3 (height 2.50 m and 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.

Pilot plants start-up, operation and monitoring: The UASB-septic tank reactors were previously started up and operated at ambient environmental conditions for a 6 months period (April 2004–October 2004) covering the hot half of the year by Al-Shayah and Mahmoud (2008). Right after that, within the here presented research, the reactors were further operated and monitored for the subsequent cold 6 months of the year (October 2004 till March 2005). The reactors were fed with domestic sewage pre-treated with screens and grit removal chamber. The sewage was pumped continuously to a holding tank (200 l plastic container), with a resident time of about 5 minutes, where the reactors were fed and the influent was sampled. Grab samples of raw sewage and reactors effluents were collected and analysed 2–3 times a week. Samples were stored at 4 °C till being analysed. Daily monitoring included wastewater and ambient air temperature and biogas production measurements. The atmospheric pressure was measured *in situ.* At the end of the research period, viz. 1 year of operation, the whole sludge was emptied from the both reactors and the sludge volume and TSS and VSS were measured.

2.1. Analytical methods

Total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), volatile solids (VS), sludge volume index (SVI), ammonium (NH_4^+), Kjeldahl-nitrogen (Kj-N), chemical oxygen demand (COD), biological oxygen demand (BOD), total PO_4–P, dissolved PO_4^{3-}-P, and SO_4^{2-} were measured according to standard methods (APHA, 1995). Raw samples were used for measuring total COD (COD_{tot}), 4.4 μm folded paper-filtered (Schleicher and Schuell 5951/2, Germany) samples for paper-filtered COD (COD_p) and 0.45 μm 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_{tot} 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). pH was measured using EC pH meter (HACH). All samples were analysed in duplicate except VFA and SVI in single.

Biodegradability of the effluent COD and sludge stability of both reactors were measured twice in duplicate. These parameters were assessed using batch reactors of 500 ml working volume incubated at 30 °C for a period of 120 days as described by Mahmoud et al. (2003).

2.2. Calculations

2.2.1. Biodegradability and stability

$$\text{Biodegradability/stability}(\%) = 100(COD_{CH_4}/COD_{tot,\ t=0\ days}) \quad (1)$$

2.2.2. Hydrolysis, acidification and methanogenesis

Percentage of hydrolysis (H), acidification (A) and methanogenesis (M) were calculated according to Eqs. (2)–(4), respectively.

$$H\ (\%) = 100\left(\frac{COD_{CH_4} + COD_{dis,\ eff} - COD_{dis,\ inf}}{COD_{tot,\ inf} - COD_{dis,\ inf}}\right) \quad (2)$$

$$A\ (\%) = 100\left(\frac{COD_{CH_4} + COD_{VFA,\ eff} - COD_{VFA,\ inf}}{COD_{tot,\ inf} - COD_{VFA,\ inf}}\right) \quad (3)$$

$$M\ (\%) = 100\left(\frac{COD_{CH_4}}{COD_{tot,\ inf}}\right) \quad (4)$$

2.2.3. COD – mass balance

$$COD_{tot,\ inf} = COD_{accumulated} + COD_{CH_4} + COD_{tot,\ eff} \quad (5)$$

2.3. 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. Influent specifications

The results presented in Table 1 reveal that the sewage used in this research is rather concentrated. However, the COD_{tot} is less