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High strength sewage treatment in a UASB reactor and an integrated UASB-digester system

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Abstract

The treatment of high strength sewage was investigated in a one-stage upflow anaerobic sludge blanket (UASB) reactor and a UASB-digester system. The one-stage UASB reactor was operated in Palestine at a hydraulic retention time (HRT) of 10 h and at ambient air temperature for a period of more than a year in order to asses the system response to the Mediterranean climatic seasonal temperature fluctuation. Afterwards, the one-stage UASB reactor was modified to a UASB-digester system by incorporating a digester operated at 35 °C. The achieved removal efficiencies in the one-stage UASB reactor for total, suspended, colloidal, dissolved and VFA COD were 54, 71, 34, 23%, and −7%, respectively during the first warm six months of the year, and achieved only 32% removal efficiency for COD total over the following cold six months of the year. The modification of the one-stage UASB reactor to a UASB-digester system had remarkably improved the UASB reactor performance as the UASB-digester achieved removal efficiencies for total, suspended, colloidal, dissolved and VFA COD of 72, 74, 74, 62 and 70%. Therefore, the anaerobic treatment of high strength sewage during the hot period in Palestine in a UASB-digester system is very promising.
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Keywords: Anaerobic treatment; Sewage; Suspended solids; UASB-digester; UASB

1. Introduction

The upflow anaerobic sludge blanket (UASB) reactor is widely used for sewage treatment in tropical countries, such as India and Brazil. In those countries, the ambient temperature ranges between 20 and 30 °C throughout the year (Von Sperling and Chernicharo, 2005; Aiyuk et al., 2006) and sewage is of low to medium strength. The current challenge in anaerobic technology development is to amend the system to treat municipal sewage in extreme situation. For instance, in Palestine and Jordan sewage is characterised with high COD concentrations of more than 1000 mg/L with high fraction of suspended COD (COD_{ss}) (up to 70%) and fluctuating temperature between winter and summer in the range 15–25 °C (Mahmoud et al., 2003a; Halalsheh et al., 2005). Previous research had demonstrated that the performance of one-stage UASB reactors at low temperatures (5–20 °C) is severely limited by the slow hydrolysis of entrapped solids that accumulate in the sludge bed when high loading rates are applied (Zeeman and Lettinga, 1999). The solids accumulation will impose a more frequent sludge discharge. Consequently, the excess sludge will increase leading to a low solids retention time (SRT) and a concomitantly less stabilised sludge bed with a low specific methanogenic activity (SMA). The latter will result in a poor soluble COD removal and an overall deterioration of the digestion process. The performance of the one-stage UASB reactor in Palestine when operated at short HRT similar to those in tropical countries will most likely be limited by the high imposed organic and solids loading rates. Leitão et al. (2006) pointed out that the use of UASB reactors for 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.

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The anaerobic sewage treatment is certainly not limited to tropical countries neither to sewage of rather low strength (Mahmoud, 2002). The results of anaerobic sewage treatment in a 64 m^3 one-stage UASB reactor operated in Jordan revealed that it is quite possible to operate the reactor under the conditions of Jordan and Palestine. In this case the reactor should be operated at a prolonged hydraulic retention time of more than 22 h (Mahmoud et al., 2004b; Halalsheh et al., 2005). The reactor in Jordan was monitored after one and a half year of operation and no data had been published on the start up phase and the reactor performance during the first year of operation. As an alternative approach to the one-stage UASB reactor, Mahmoud et al. (2004b) investigated a novel pilot-scale system consisting of an integrated high loaded UASB reactor and digester, namely UASB-digester system. In the proposed system a parallel digester unit is incorporated for enhanced sludge stabilisation and generation of active methanogenic sludge to be recirculated to the UASB reactor. The obtained results were promising as compared with the one-stage UASB reactor. Nonetheless, the system was only investigated in the Netherlands but had never been investigated in the Middle-East region, where climate and sewage characteristics are quite different.

In the present work, the anaerobic sewage treatment using a one-stage UASB reactor and a UASB-digester system in Palestine was investigated. A pilot-scale high loaded one-stage UASB reactor was started up without inoculation and operated for a period of more than a year at an HRT of 10 h. The one-stage UASB reactor was operated in order to elucidate the influence of seasonal temperature fluctuations on the system performance over the first year of operation. This is of particular importance to have base line records to be used as reference values to asses the achievements obtained from incorporating a digester. Afterwards, the one-stage UASB reactor was modified to a UASB-digester system by incorporating a digester operated at 35 °C in order to asses the system performance.

2. Methods

2.1. Experimental set-up

The experimental work was carried out over two successive periods at Al-Bireh wastewater treatment plant in Palestine. Firstly, a pilot one-stage flocculent sludge UASB reactor (volume, height, diameter: 140 l, 325 cm, 23.5 cm) was operated at ambient air temperature. Afterwards, the one-stage UASB reactor was modified to the UASB-digester system by incorporating a CSTR digester (working volume 106 l). A schematic diagram of the experimental set-up is illustrated in Fig. 1. The UASB reactor and the digester were constructed from Plexiglas and PVC tubes, respectively. The temperature of the digester content was controlled by recirculating thermostated water of 35 °C through a tube placed around the reactor. Taps were installed over the whole UASB reactor height at about 25 cm apart for sludge discharge, re-circulation and analysis. The digester content was continuously mixed at around 60 rpm.

2.2. Operation and start up of pilot reactors

2.2.1. One-stage UASB reactor

The one-stage UASB reactor was started up during spring specifically in April, coinciding the beginning of the hot period in Palestine. It was operated for a period of more than a year at ambient temperature and 10 h HRT. The reactor was fed with domestic sewage pre-treated with screens and grit removal chamber. The sewage was pumped every 5 minutes to a holding tank (200 l plastic container), with a resident time of about 5 minutes, where the reactor was fed and the influent was sampled (Fig. 1). Daily monitoring was started since the onset of the experiment including ambient air temperature and biogas production, as well as grab influent and effluent wastewater samples analysis for total COD. The influent and effluent were analysed for COD_{tot} and the distinguished COD fractions over the hot and cold periods of the year. After 144 days of operating the one-stage UASB reactor, five influent and effluent samples were collected and analysed during a period of 35 days for BOD, TSS, NH_4^+ and PO_4^{3-}. The atmospheric pressure was measured in situ. The one-stage UASB reactor was operated for 389 days of which the first 42 days were considered as a "start-up" period.

2.3. UASB-digester system

The digester was inoculated with activated sludge collected from the thickener of the extended aeration wastewater treatment plant of Al-Bireh City, Palestine. During the operation of the one-stage UASB reactor, the digester was continuously fed with activated sludge after being diluted to around 20 gTS/L with VS/TS ratio of 0.74 so as to achieve a SRT of 20 days. The digester was operated in this mode for a period of four months to accelerate the digester start up. Afterwards the digester was incorporated to the one-stage UASB reactor. The sludge bed of the UASB reactor of the UASB-digester system was kept below 40 cm from the bottom of the reactor, by discharging the sludge accumulated above 2–3 times a week. The discharged sludge was collected in a bucket, from where the sludge was immediately fed to the digester by a peristaltic pump. At the same time, the digester effluent was pumped out to another bucket, while a third pump was recirculating it to the lower part of the UASB reactor at 10 cm from the bottom. Sludge was never wasted during the system operation. The UASB-digester system was operated for 107 days of which the first 57 days were considered as a "start-up" period. The influent and effluent of the UASB-digester system was monitored for biogas production, temperature and COD measurements. A set of six samples was analysed during the steady state period for COD_{tot} and COD fractions, TSS, NH_4^+ and PO_4^{3-}.

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