Feasibility of UASB-septic tank for high strength municipal wastewater treatment in Mexico City

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Abstract
The objective of this work was to assess the feasibility of a UASB-septic tank for municipal wastewater treatment in Mexico City, as well as its performance during the start-up phase. A lab scale UASB-septic tank (45 L volume, acrylic), consisting of three chambers treated high strength municipal wastewater at ambient temperature (16 °C - 24 °C), under 72 h HRT during three months. Total and soluble COD, total BOD_5, TS and TSS removals were 75.2±6.5%, 54.8±6.7%, 64.2±4.8%, 25.9±5% and 82.9±5%, respectively. These results are comparable with the removals reported in other works with similar arrangements; and even are comparable with average removals of COD, BOD and TSS in UASB reactors installed in Latin America. The good performance obtained showed that it is possible to achieve a short start-up period with UASB-septic tank if it is inoculated with anaerobic sludge. These findings evidenced the feasibility and reliability of the UASB-septic tank system for decentralized wastewater management in Mexico.

Keywords
Anaerobic Digestion; Decentralized Wastewater Management; Low Cost Treatment; Modified Septic Tank.

INTRODUCTION

According to CONAGUA (2012), in Mexico sewage systems collect 90.5% of municipal wastewater generated, although only 47.5% of those wastewaters receive some treatment, despite government investments in centralized wastewater treatment facilities. This fact evidences that decentralized wastewater management could be a viable option for wastewater treatment in Mexico.

The septic tank, developed in 1895, is the most common, small scale and decentralized treatment plant used worldwide; though its effluent quality is low, ranging 25% - 50% COD removal (Sasse, 1998). As a result, many anaerobic modified septic tank systems have been tested and used , among which stands out the UASB-septic tank (Sabry, 2010).

The UASB-septic tank has upward flow and a gas/solids/liquid separation device, resulting in both improved physical removal of solids and improved biological conversion of dissolved components; allowing sludge to accumulate and to stabilize in the reactor (Zeeman *et al.*, 2000). Studies with UASB-septic tanks treating domestic sewage have been conducted for the onsite sewage treatment in Netherlands, Indonesia and several countries in the Middle East, with promising results (Al-Shayah and Mahmoud, 2008; Sabry, 2010).

Thus, the objective of this work was to assess the feasibility of UASB-septic tank for the treatment of high strength municipal wastewater in Mexico City, as well as its performance during the start-up phase.

MATERIALS AND METHODS

A lab-scale UASB-septic tank (45 L volume, acrylic), consisting of three compartments, was employed in this experiment (Figure 1).

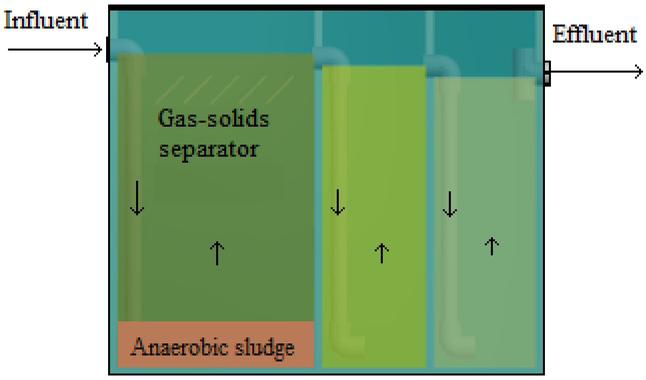

Figure 1. Schematic of UASB-septic tank

The first compartment occupied half of the total volume, had a gas-solids separator in its top and was inoculated (15% of volume) with sludge from a pilot-scale UASB reactor treating municipal wastewater. The following two compartments were made of equal size and, in total, occupied the other half of the total volume. The influent was distributed in each compartment using a PVC tube (1” diameter), following a downflow-upflow pattern.

The high strength municipal wastewater was obtained at the Metropolitan Autonomous University - Azcapotzalco Campus and pumped using a peristaltic pump (Masterflex 7553-30, Cole-Parmer, USA). The UASB-septic tank was maintained at ambient temperature (16 °C - 24 °C) and operated under 72 h HRT during three months.

Temperature, pH, dissolved oxygen (DO) and oxidation-reduction potential (ORP) were measured three times per week using an ion specific electrode (ISE) for each parameter (LabQuest, Vernier, USA). Total solids (TS), suspended solids (TSS), total and soluble chemical oxygen demand (COD), biological oxygen demand (BOD_5) and alkalinity were measured twice per week according to the Standard Methods (APHA-AWWA-WEF, 1998). The ratio between partial and total alkalinity (PA/TA ratio) was also calculated.

RESULTS AND DISCUSSION

In table 1 are shown the results obtained for the parameters measured in the influent and in the effluent of each chamber of the UASB-septic tank during the start-up phase.

Table 1 shows that pH in UASB-septic tank influent was higher than those that usually occurs in municipal wastewater. This could be associated with the fact that sewage in the university campus also collects the wastewater generated in laboratories. pH in the UASB-septic tank effluent ranged from 7.3 to 8.3, with an average of 7.7, which is suitable for the anaerobic digestion process (Chernicharo, 2007).

In Palestine, Al-Shayah and Mahmoud (2008) analyzed the start-up phase of two septic tanks UASB, obtaining an average influent pH of 7.4, while in the effluent was 7.2 and 7.3, respectively. And, as in the UASB-septic tank of this study, it could be seen that within the system occurred a slight decrease in pH that was favorable for the operation of septic tank.

Table 1. Results obtained in the influent and in the effluent of each compartment of the UASB-septic tank

Parameter	Influent	1st compartment effluent	2nd compartment effluent	3rd compartment effluent
pH	8.2±0.3	7.7±0.2	7.7±0.2	7.7±0.2
DO (mg/L)	0.1±0.1	0.1±0.1	0.1±0.1	0.1±0.1
Temperature (°C)	18.8±1.7	20.2±1.4	19.8±1.3	19.5±1.2
ORP (mv)	-153.2 ±39.5	-206.2 ±46.1	-218.7 ±49.2	-225.5 ±52.1
Alkalinity (mg/L $CaCO_3$)	194±16	211±21	215±22	220±22
Total COD (mg/L)	1048±270	320.5±55.8	293.8±54.9	250.0±51.5
Soluble COD (mg/L)	381±48	201±45	190±42	175±42
Total BOD_5 (mg/L)	381±33	178±36	158±31	138±6
TS (mg/L)	1050±121	793±45	784±44	778±46
TSS (mg/L)	233±125	76±20	69±16	63±16

Influent temperature ranged from 16.1 to 24.6 °C with an average of 18.8 °C. Lower operating temperatures were associated with the fact that the start-up phase occurred during the fall, characterized by having cold temperatures. Operation at these temperatures is feasible in this type of treatment (Elmitwalli *et al*., 2003; Kujawa-Roeleveld *et al*., 2005; Loustarinen and Rintala, 2005 and 2007). The possibility of having an efficient treatment even at low temperatures is associated with the fact that microbial activity can be sustained at temperatures as low as 10 °C (Leslie-Grady *et al*., 2011).

According to Amani *et al*. (2010), the fermentation process does not occur until the ORP is less than -300mV, although it has been reported that methanogenesis occurred when ORP ranged from -210 mV to -230 mV (Gupta *et al*., 1994); thus, ORP values found in this experiment show that the atmosphere inside the UASB-septic tank was suitable for the methane production.

Total alkalinity was produced in the first compartment and the PA / TA ratio in the effluent was 0.8 throughout the entire experiment. According to Chernicharo (2007), the ratio PA / TA is a parameter that evaluates the accumulation of volatile fatty acids in anaerobic reactors and must be kept about 1 to avoid acidification; therefore, UASB septic tank operated under stable conditions during the experiment.

Figures 2 to 6 depict the behavior of total and soluble COD, total BOD_5 and TSS in the UASB septic tank during the experiment.

Total and soluble COD and BOD_5 removal efficiencies were 75.2 ± 6.5%, 54.8 ± 6.7%, 64.2 ± 4.8%, respectively; while, total and suspended solids removals efficiencies were 25.9 ± 7% and 82.9 ± 5%, respectively. These percentages are higher than those found by Al-Shayah and Mahmoud (2008) in a UASB-septic tank with a single compartment. This difference may be associated with the fact that the UASB-septic tank of this experiment has two extra compartments that served as polishing.

Similar removals of organic contaminants were by reported Ali *et al*. (2007), during the start-up phase. These results also are comparable with removals reported in other studies with upflow septic tanks and similar arrangements (Moussavi *et al*., 2010; Anh *et al*., 2002; Kujawa-Roeleveld *et al*., 2005; Anh *et al*., 2007; Jorsaraei *et al*., 2014. Sharma *et al*., 2016). The removal efficiencies found in this experiment are even comparable with average removal of COD and BOD registered in

UASB reactors installed in Latin America, which are in the range of 56% - 79% and 45% - 81%, respectively (Giraldo *et al*., 2007).

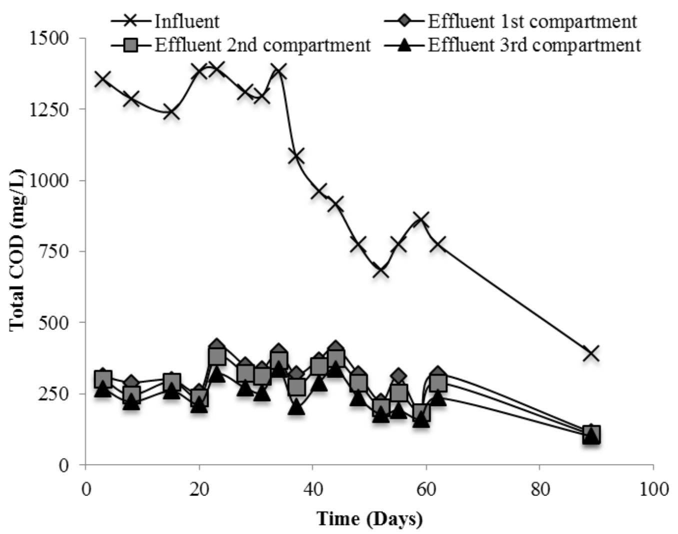

Figure 2. Total COD behavior in UASB septic tank

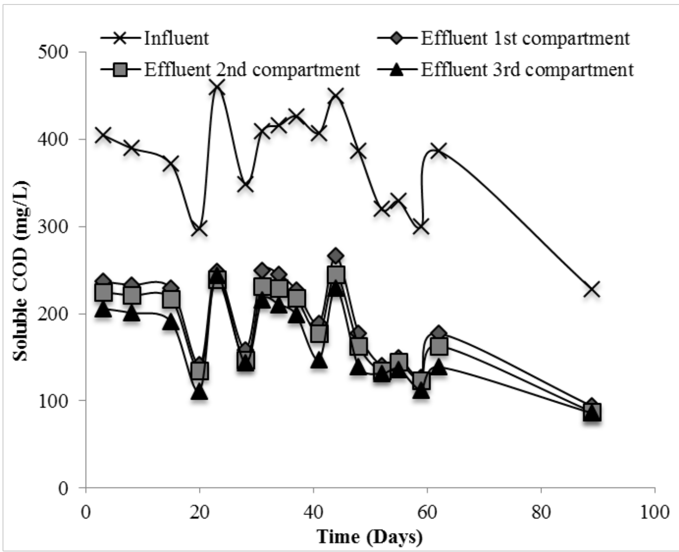

Figure 3. Soluble COD behavior in UASB septic tank

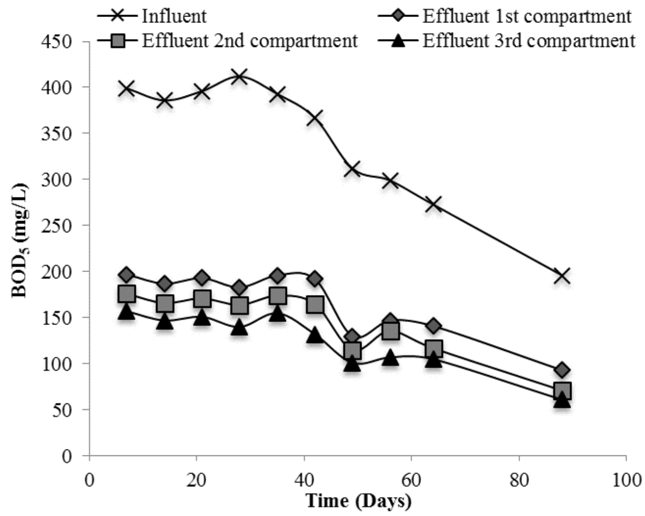

Figure 4. BOD_5 behavior in UASB septic tank

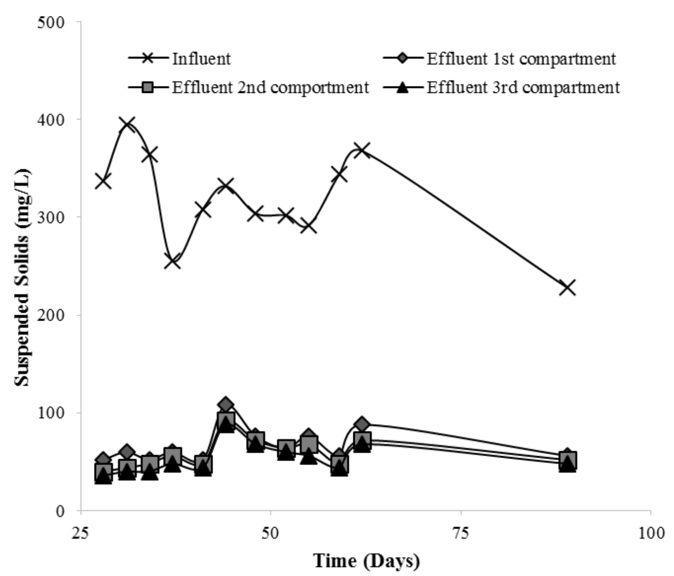

Figure 5. Suspended solids behavior in UASB septic tank

However, removal efficiencies found in the present study were slightly below those reported by Sabry (2010) and Elmitwalli *et al*. (2003). The former study was carried out at 35 °C with an upflow septic tank built into a baffled septic tank with four compartments; while the latter study was carried out using a modified septic tank with an anaerobic filter. This result stands out the importance of the system configuration and the operational temperature in pollutant removal efficiencies.

In addition, a high TSS removal was found in the UASB-septic tank, 82.9% average, probably due to the retention of suspended solids in the biological sludge, in the gas-solids separator installed on the top of first compartment as well as in the other two compartments, which acted as polishing. The proposed modifications in the UASB-septic tank improved suspended solids retention, and consequently, improved its performance, as the raw wastewater was characterized by a high COD particulate / COD total ratio, which was 60% average, reaching in some cases 75%.

Contrary to TSS removal, TS removal was low, only 25.9%. This result may be due to the presence of high concentrations of fixed dissolved solids in the raw wastewater, as well as the production of ammonium and sulfur in the UASB-septic tank.

Figures 2 to 5 show that, since the beginning of the operation and during the experiment, the UASB-septic tank was able to remove significant quantities of influent contaminants, indicating that the proposed modifications notably improved its performance, regarding conventional septic tank efficiencies reported in the scientific literature. Also, figures 2 to 5 show that effluent fluctuations were associated with those presented in the influent.

The high removal efficiency obtained along with the stability in the concentration of organic matter and suspended solids in the effluent allows to assume that it is possible to achieve a short start-up period with the UASB-septic tank if it is inoculated with anaerobic sludge. Contrary to Ali *et al.* (2007) who, despite getting 80% removal in the start-up phase, concluded that it was not practical to inoculate the UASB-septic tank with activated sludge.

According to figure 6, the first compartment removed most of the influent organics and solids with percentages ranging from 80 to 95%. This may be due to the presence of the biological sludge and the installation of the gas-solid separator on its top. The removal efficiencies of the other two compartments increased with the decrease in the influent organic load, being in some cases up to 10% for COD and 20% for BOD_5. This behavior was probably associated with the difficulty of anaerobic sludge for treating more diluted wastewater, thus, the other two compartments were a polishing treatment.

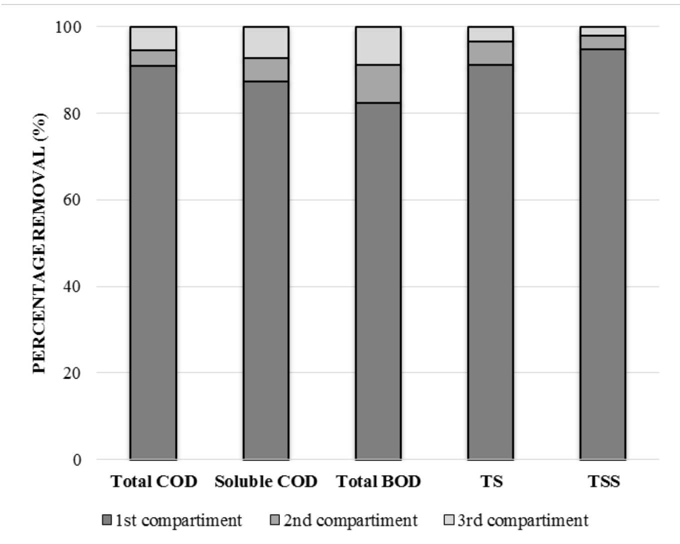

Figure 6. Total and soluble COD, total BOD_5, TS and TSS removal percentages in each compartment

In addition, it is necessary to point out that the first compartment acted as a solids accumulator, because the highest solids percentage removal was found in it. This is one of the main differences of UASB-septic tank regarding the conventional UASB reactor, as in the latter sludge accumulation is not allowed.

These results also show that the two additional compartments enhanced the UASB-septic tank performance; however, the addition of more compartments probably would not have a significant effect on the performance of the UASB-septic tank; for this reason, in a full-scale design is not recommended to install more than three compartments in total.

Regarding the maximum permissible limits of BOD_5 and TSS established by the Official Mexican Standard NOM-001-SEMARNAT-1996 (SEMARNAT, 1997), the treated effluent could be discharged to rivers used for agricultural irrigation and urban public use, natural reservoirs used for agricultural irrigation, coastal waters used for recreation and fishing exploitation, natural wetlands and estuaries; although it could not be used for direct reuse. Therefore, a post-treatment would be necessary in order to remove additional organic matter, nutrients (N and P) and pathogenic organisms (coliforms and helminths eggs).

The results obtained in this study demonstrated the feasibility of UASB-septic tank for treating high strength municipal wastewater in Mexico. In addition, since this system can be built with inexpensive and locally available materials and does not require sophisticated equipment, UASB-septic tank is also an economical alternative for decentralized management of municipal wastewater, both in urban areas without sewerage and in rural areas, given the simplicity of the technology and its easy operation.

CONCLUSIONS

In this work a modified septic tank, so-called UASB-septic tank, was designed and built. It was manufactured in acrylic, 1 cm thick, with three compartments, and was used for treating the municipal wastewater generated on the campus of the Autonomous Metropolitan University – Azcapotzalco at ambient temperature.

The proposed modifications for the design of this UASB-septic tank were the liquid downflow-upflow pattern inside each compartment, the inoculation with biological sludge along with the installation of a gas-solid separator in the first compartment and the installation of two additional compartments. These modifications significantly improved the performance of the system, regarding the conventional septic tank.

Total and soluble COD, total BOD_5, TS and TSS removals were 75.2±6.5%, 54.8±6.7%, 64.2±4.8%, 25.9±5% and 82.9±5%, respectively, which are comparable with the reports in literature. Most of the organics and solids removal occurred in the first chamber (between 80 and 95%), and the other two chambers served as polishing.

Regarding the maximum permissible limits of BOD_5 and TSS established by the Official Mexican Standard NOM-001-SEMARNAT-1996, the treated effluent could be discharged to rivers used for agricultural irrigation and urban public use, natural reservoirs used for agricultural irrigation, coastal waters used for recreation and fishing exploitation, natural wetlands and estuaries; although it could not be used for direct reuse; thus, a post-treatment would be necessary.

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