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INFILTRATION STUDIES ON SOAKAWAYS RECEIVING EFFLUENTS FROM SINGLE HOUSEHOLD UASB AND SEPTIC TANK REACTORS

ESTUDOS DE INFILTRAÇÃO EM SUMIDOUROS RECEBENDO EFLUENTE DOMÉSTICO DE REATORES UASB E TANQUE SÉPTICO

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ABSTRACT

Clogging tendency has been analyzed in sandy soil soakaways at pilot scale receiving either septic tank effluent (SUM1) or UASB effluent (SUM2) and also at laboratory scale (SUMB1 and SUMB2), in relation to Chemical Oxygen Demand (COD) and accumulated Suspended Solids (SS) concentrations. Clogging was also estimated, by modeling the predicted time for infiltration hydraulic failure. The laboratory results obtained with SUMB1 and SUMB2 confirmed the results obtained for SUM1 and SUM2, showing that soakaways built in sandy soils which receive effluent from septic tanks treating predominantly domestic wastewater tended to clog 58% faster than those receiving UASB effluent. The good correlation observed between the decrease in average infiltration rate and the time of operation suggests that the UASB reactor is a promising technological alternative to septic tanks as a pre-treatment prior to effluent soil disposal for on-site decentralized wastewater treatment systems.

Keywords: decentralized treatment; UASB; septic tank; infiltration; sandy soil.

RESUMO

O trabalho objetivou comparar o tempo para ocorrer a colmatação de sumidouros (SUM1 e SUM2) contendo areia média, alimentados respectivamente por efluentes de tanque séptico e de um reator UASB, em escala piloto e com replicação confirmativa em escala de bancada (SUMB1 e SUMB2), quanto ao impacto da concentração acumulada de Demanda Química de Oxigênio (DQO) e dos Sólidos Suspensos Totais (SST) na colmatação do meio, em função do tempo. Estimou-se ainda, por meio de um modelo, a predição do tempo para a falha hidráulica. A colmatação do SUMB1 à frente do SUMB2 confirmou os resultados de campo obtidos para os SUM1 e SUM2, demonstrando que sumidouros construídos e operados recebendo esgoto doméstico tratado em tanque séptico em solos arenosos tenderão a colmatar 58% mais rápido do que aqueles com tratamento prévio em reatores UASB. A boa correlação entre o decréscimo da taxa média de infiltração nos sumidouros em função de período de operação sugere o reator UASB como promissora alternativa aos tanques sépticos para disposição de efluentes no solo em sistemas descentralizados unifamiliares de tratamento de esgotos.

Palavras-chave: tratamento descentralizado; reator UASB; Tanque Séptico; infiltração; solo arenoso.

INTRODUCTION

Wastewater soil disposal is an ancient and well-established worldwide practice (LOFRANO & BROWN, 2010). However, this practice, if not suitably managed, can degrade natural resources by contaminating the soil matrix or even inducing its collapse (RODRIGUES; MOLINA JÚNIOR; LOLLO, 2010).

Anaerobic treatment technologies of domestic wastewater prior to soil disposal are widely employed, with simple septic tanks being the most common solution (CRITES & TCHOBANOGLOUS, 1998; PARTEN, 2010). However, the UASB reactor and its variants have been suggested as a feasible alternative (AL-SHAYAH & MAHMOUD, 2008; SABRY, 2010; MOUSSAVI; KAZZEMBEIGI; FARZADKIA, 2010).

Most household on-site wastewater treatment systems depend upon effluent soil infiltration for final disposal (PARTEN, 2010). However, the design parameters for this process are still not clearly defined and this complex subject still attracts considerable discussion and demands more studies under different operational conditions (SIEGRIST; MCCRAY; LOWE, 2004; BUMGARNER & MCCRAY, 2007; PEDESCOLL *et al*., 2011). Wastewater percolation, through unsaturated zone, has been reported as being controlled by a low conductivity layer in the upper layers of the soil (RICE, 1974) and is also influenced by infiltration flow speed and substrate concentration (RICE, 1974; OKUBO & MATSUMOTO, 1983; SIEGRIST; MCCRAY; LOWE, 2004).

Recent studies have confirmed the influence of the growth of the soil biomat on soil infiltration capacity when receiving effluents with accumulated total and volatile suspended solids (TSS and VSS). This developing biomat has been considered as one of the main causes of head losses, which influence significantly the hydraulic regime under unsaturated conditions (OKUBO & MATSUMOTO, 1983; VIVIANI & LOVINO, 2004; BEAL *et al*., 2006; THULLNER, 2010; KIM; CHOI; PACHEPSKY, 2010).

Mathematical modeling has been employed to estimate clogging in soils inundated with anaerobic reactor effluents. Predictive models have taken into consideration intervenient physical, chemical and biological parameters (BEAL *et al*., 2006; LEVERENZ; TCHOBANOGLOUS; DARBY, 2009; THULLNER, 2010).

This paper evaluates the infiltration of domestic wastewater effluents previously treated in a septic tank (ST) and a UASB reactor in relation to the impact of total suspended solids (TSS) and biochemical oxygen demand (BOD) on soil clogging using experimental soakaways packed with sand, both at laboratory and pilot scale. Predictive modeling for infiltration failure was compared to the experimental data using the predictive model presented by Leverenz, Tchobanoglous and Darby (2009).

MATERIAL AND METHODS

Phase I studies

During the first phase of the study, laboratory replication scale soakaways (LREs) were fed daily for 15 days, three times a day, with a volume of 9.5 L of domestic wastewater.

The LRE, as shown in Figure 1, was composed of two header tanks of 20 L for gravity feeding; two plastic cylindrical soakaways (PVC) with diameter of Φ 250 mm and useful volume of 9.5 L packed with 0.034 m^3 of medium sand with effective diameter of D_{10}=0.3 mm, uniformity index of C_u=3.33, porosity of η%=43%, maximum diameter of D_{max}=4.8 mm, bulk density of γ= 2.602 $g.cm^{-3}$ and saturated hydraulic conductivity of K_{sat}=0.1925 $cm.s^{-1}$.

Application of Predictive Modeling

Leverenz, Tchobanoglous and Darby's (2009) predictive model, presented in Equation 1, was applied to the prediction of failure time for sandy soil infiltration systems:

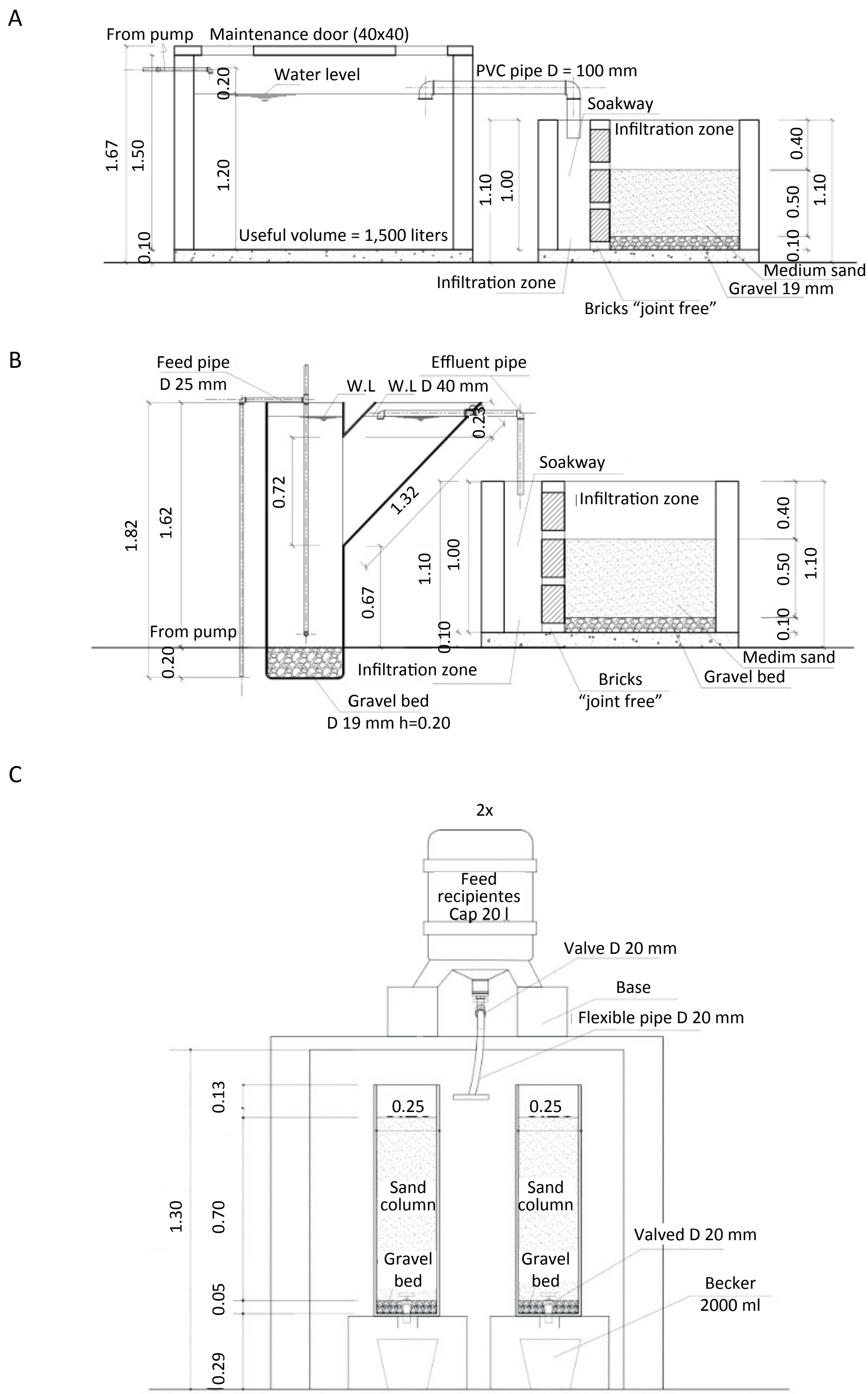

Figure 1 – Construction features of: A) ST+SUM1; B) UASB+SUM2; C) the laboratory scale system.

$$Tf = \left[\frac{[19.6 - 13.9log(TSSLR)]}{[5.257\times10^{-6}\times COD^{1.318}_{i}\times Dd^{1.120}\times HLR^{0.343}]}\right]^{1.053} \quad (1)$$

Where:

T_f: Period of operation until failure (days);

TSSLR: Total suspended solids loading rate (g $TSS.m^{-2}.day^{-1}$);

COD_i: Influent Chemical Oxygen Demand (COD) concentration ($mg.L^{-1}$);

Dd: Dosing frequency ($doses.day^{-1}$);

HLR: Hydraulic loading rate ($m.day^{-1}$)

Infiltration tests on the SUMB1 and SUMB2 soakaways

The infiltration tests performed at laboratory scale under controlled conditions (SUMB1 and SUMB2) aimed to confirm the results obtained from the pilot scale soakaways operating with the Septic Tank (ST) and UASB reactor effluents to determine the variation in infiltration flow ($L.min^{-1}$) during the test periods of 60 minutes.

The physicochemical and infiltration tests results were statistically treated by determining the dispersion and central tendency. The results were also submitted to:

- descriptive statistics;
- analysis of variance (ANOVA), single factor at the significance level of 5% (SOKAL & ROHLF, 1981).

Phase II studies

In the second phase, raw sewage was pumped via a wet well from the eastern wastewater interceptor of the city using a submersible pump (1/4 hp) to an equalization reservoir with a capacity of 1,000 L and finally pumped intermittently (using a timer control), to the pilot-scale domestic wastewater treatment systems (DWTS), to simulate a household flow patterns with an average total flow of 270 $L.d^{-1}$. The DWTS was composed of two types of units. The first was a brick built septic tank (ST) with a working volume of 1,500 L and the second, a UASB reactor made of fiberglass with an operational volume of 355 L. Both systems were followed by brick soakaways (Figures 1A and 1B).

Infiltration tests with pilot scale soakaways SUM1 and SUM2

The pilot scale experimental soakaways (SUM1 and SUM2) were respectively fed with treated effluent from the ST and UASB reactors with an average flow of 270 $L.day^{-1}$. The infiltration tests were performed in two stages. During the first stage, 90 L of effluent were applied to the soakaways daily during a 60 minutes period for 10 days. In the second phase, infiltration tests were performed weekly between December 2011 and March 2012. The soakaway feed zone (SFZ) had a built length of 25 cm, a width of 100 cm and a 100 cm depth, with useful volume of 250 L. The Soil Infiltration Zone (SIZ) had a built length of 70 cm, a width of 100 cm, and a depth of 100 cm. It was packed with a basal layer of gravel/aggregate (No. 19) and an upper infiltration layer of sand 50 cm deep.

During the infiltration tests, variations of recovered infiltrated volume and the infiltration rates ahead of the soakaways, through a pipeline set, were monitored.

The actual infiltration tests involved applying the effluents (90 L), to each of the soakaways, and measuring the time for filling and discharging the accumulated infiltrated volume (liter by liter), over the 60 minutes test period. Figure 1 presents the construction features of both DWST [TS+SUM1 (a) and UASB+SUM2 (b)] and of the laboratory bench scale confirmatory experiments (c).

Physicochemical analyses

Analyses of solids and their fractions were made weekly during the 15 days of laboratory scale experiments and during a period of nine months (July 2011 to April 2012) for COD and solids and their fractions for the pilot scale systems experiments using the methodology according to APHA, AWWA and WPCF (1995).

RESULTS AND DISCUSSION

Infiltration rates

Using the results obtained at pilot scale, it was possible to create a profile of filling and discharging effluents in the SFZ, as well as the infiltration volume profile for the SIZ during the 60 minutes period. The effective volume (V_{ei}) of infiltrated effluent through SUM1 and SUM2 was given by Equation 2:

$$V_{ei} = [(L_i - L_f).\ 0.25 \times 0.96] \times 1000 \quad (2)$$

Where:
V_{ei}: Volume effectively infiltrated and discharged through the soakaways (liters);
L_f: Final wastewater level in the SFZ piezometer (meters);
L_i: Initial wastewater level in the SFZ piezometer (meters).

The infiltration flow rate of the soakaways was calculated through Equation 2, while the infiltration rate in the SFZ's was given by Equation 3:

$$Q_i = (\Delta_i - \Delta_f)/(\Delta t_i - \Delta_{tf}) \quad (3)$$

Where:
Q_i: Infiltration effluent flow rate in the experimental soakaways ($L.min^{-1}$);
Δ_i: Initial recovered volume (Liters);
Δ_f: Final recovered volume (Liters);
Δ_t: Accumulated time for initial volume recovery (minutes);
Δ_{tf}: Accumulated time for final volume recovery (minutes).

$$T_i = (L_i - L_f)/(\Delta t_i - \Delta_{tf}) \quad (4)$$

Where
T_i: Infiltration rate in the experimental soakaways ($cm.min^{-1}$);
L_f: Final wastewater level in the SFZ piezometer (meters);
L_i: Initial wastewater level in the SFZ piezometer (meters);
Δ_{ti}: Accumulated time for initial volume recovery (minutes);
Δ_{tf}: Accumulated time for final volume recovery (minutes).

Figure 2 shows the correlation between VSS accumulation and the infiltration rate in both soakaways SUM1 and SUM2, as well as between the infiltrated volumes and VSS accumulation in both soakaways SUMB1 and SUMB2. The infiltration rate variations, as well as the infiltration profile of the effluent´s edge inside SFZ of SUM1 and SUM2, are presented in Figure 3, while Figure 4 shows failure predictive modeling for SUM1, SUM2, SUMB1 and SUMB2 soakaways.

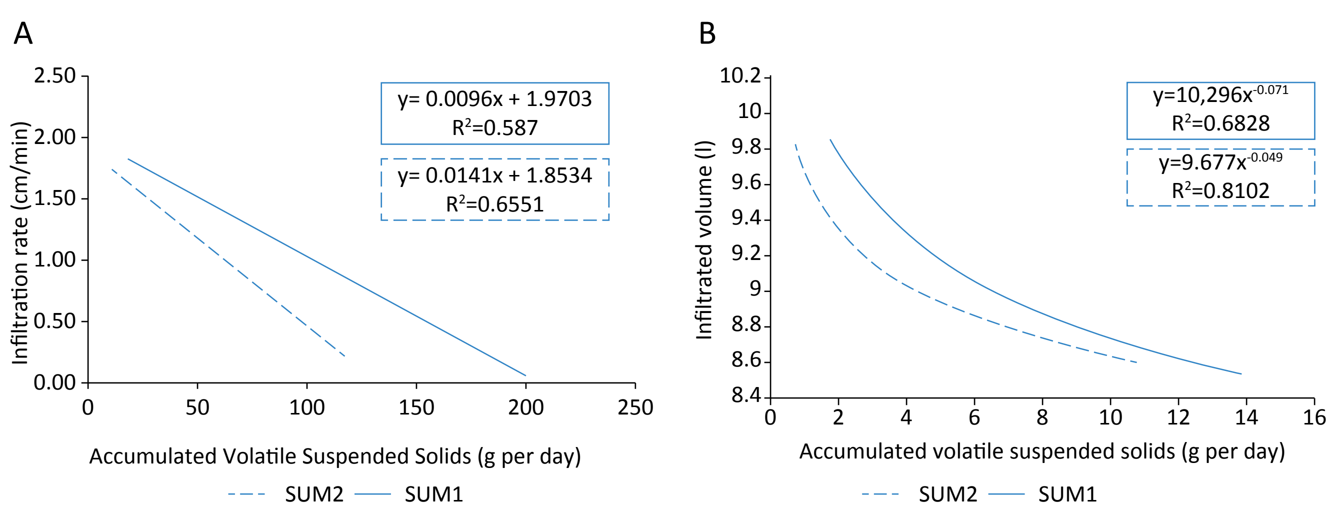

Figure 2 – Infiltration rate against accumulation of VSS in SUM1 and SUM2 soakaways (A) and infiltration volume against VSS accumulation in SUMB1 and SUMB2 laboratory scale soakaways (B).

Variations in COD and solids in the DWTS effluents

The concentration of COD, TSS and VSS of the pre-treated effluents prior to soil infiltration plays an important role in the magnitude of soil infiltration failure (LEVERENZ; TCHOBANOGLOUS; DARBY, 2009; PAVELICK *et al.*, 2011).

The ST and UASB reactors produced effluents with average COD concentrations of 183 $mg.L^{-1}$ and 171 $mg.L^{-1}$, respectively, which were not significantly different (p=0.333).

The DWTS were fed with raw sewage (RS) with a concentration of total suspended solids (TSS) varying between 62 and 216±45 $mg.L^{-1}$. The average concentrations of TSS in the TS and UASB effluents were 32±11 $mg.L^{-1}$ and 20±7 $mg.L^{-1}$ respectively. Analysis of variance showed no significant difference between concentrations of TSS in RS and ST effluent (p=0.07258). In contrast, the reduced TSS concentration in the UASB effluent was significantly different (p=0.0463). In terms

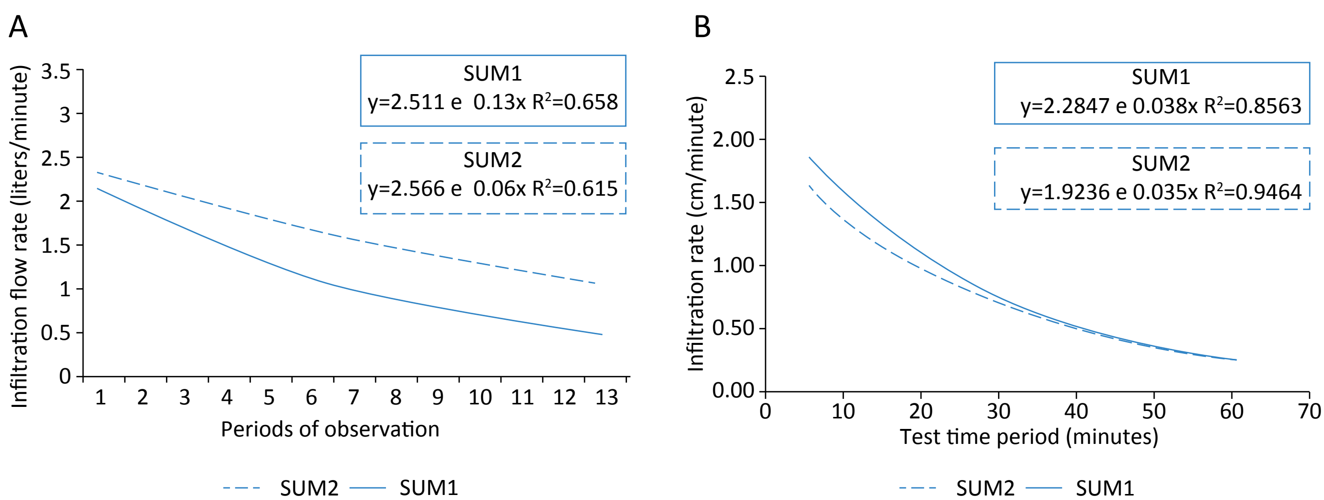

Figure 3 – Infiltration flow rate plotted against period of operation (A) and the infiltration rate profile during the 60 minute test period (B) of the experimental soakaways SUM1 and SUM2.

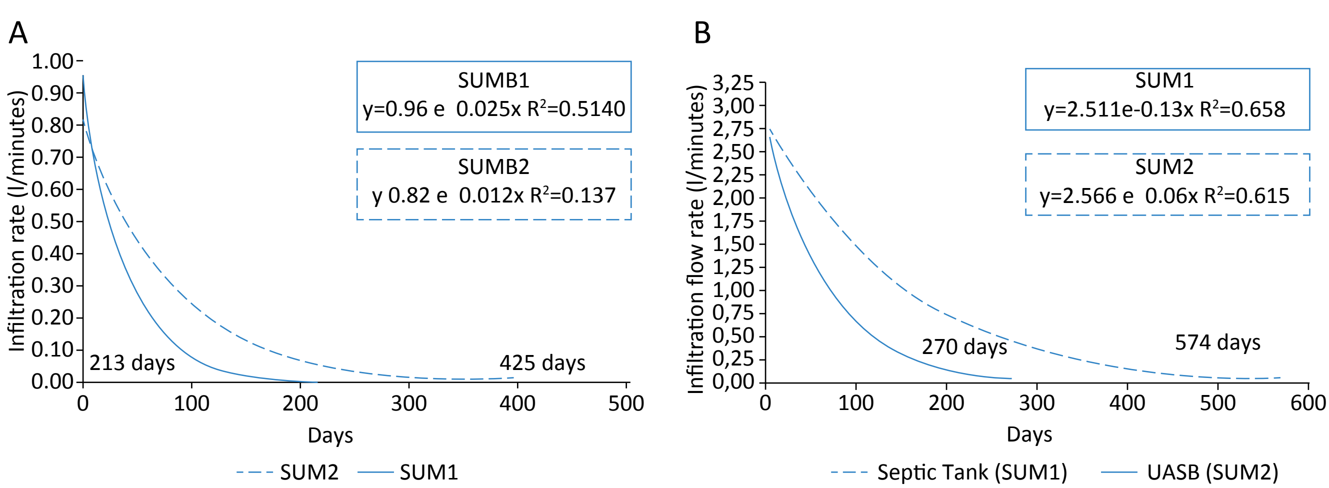

Figure 4 –Failure modeling of experimental soakaways SUM1, SUM2 (A) and SUMB1 and SUMB2 (B).

of VSS concentrations, the final effluents of the two DWTS, were significantly different (p=0.000118) with average concentrations for SUM1 of 29±9 mg.L^{-1} and 19±6 mg.L^{-1} for SUM2.

Pedescoll *et al*. (2011) demonstrated a significant correlation between hydraulic conductivity reduction and the accumulated suspended solids loading rate. The correlation between the infiltration rate and the volatile suspended solids accumulation in the soakaways SUM1, SUM2 (Figure 2A) confirmed the influence of volatile suspended solids accumulation in hydraulic conductivity reduction. (OKUBO & MATSUMOTO, 1983; VIVIANI & LOVINO, 2004; BEAL *et al*., 2006; PEDESCOLL *et al*., 2011). The good correlation between the decrease of infiltrated volume in time and the volatile suspended solids accumulation in the soakaways SUMB1 and SUMB2 also confirmed the same influence (Figure 2B).

Performance of experimental soakaways (SUM1 and SUM2)

During test's carrying out, the infiltration rate and the recovered volume had been monitored and presented a tendency to decrease as long as liquid percolation capacity reduced as a result of the continual decrease of hydraulic conductivity.

Variations in infiltration volumes and rates

The difference between the averages recovered infiltration volumes of 39.62 and 62.87 L, respectively (p=3.10^{-5}), for SUM1 and SUM2 was significant. This suggests a greater clogging tendency for SUM1. Okubo and Matsumoto (1983) evaluated the influence of suspended solids (SS) concentration due to synthetic effluent infiltration in sand columns, showing that the increase of SS concentration reduced significantly the accumulated volume over successive days of infiltration.

Figure 3A shows the correlation between the infiltration flow rate and the operation period, with each observation carried out for nine days in SUM1 and SUM2, along with the infiltration SIZ profile in SUM1 and SUM2 soakaways (Figure 3B).

The infiltration flow rate measured in terms of percolated volume variation over time in SUM1 and SUM2 soakaways (Figure 3A) showed significant difference with average values, respectively, of 1.26 and 1.97 L.min^{-1} (p=0.016). Taking into account the average loaded quantity of VSS in SUM1 and SUM2 soakaways, respectively of 19.15 and 12.38 g.day^{-1} with significant difference (p-value=0.019), it can be suggested that clogging tendency observed in TS soakaway may be related to the most substantial amount of VSS in SUM1 when compared to SUM2 accumulated VSS which has been fed with UASB effluent. The infiltration rate calculated observed in SIZ piezometer, varied between 0.22 cm.min^{-1} (13.45 cm.h^{-1}) and 2.23 cm. min^{-1} (127.74 cm.h^{-1}) in SUM1 and from 0.20 cm.min^{-1} (11.80 cm.h^{-1}) to 1.73 cm.min^{-1} (103.78 cm.h^{-1}) in SUM2.

Performance of SUMB1 and SUMB2 soakaways

The infiltration flow rate observed in SUMB1 and SUMB2 had maximum and minimum values respectively of 0.85–0.62 L.min^{-1} and 1.01–0.59 L.min^{-1}, with average values of 0.717 and 0.755 L.min^{-1}. The infiltration failure modeling of SUMB1 and SUMB2 (R^2=0.613 and 0.514 respectively), confirmed the tendency of SUMB1 to clog before SUMB2.

Hydraulic failure modeling

Estimates of infiltration failure were modeled for the pilot scale soakaways and confirmed by the LRE's tests using empirically adjusted models. Equations 5 and 6 were used to model clogging for SUM1 and SUM2, while Equations 7 and 8 were used for SUMB1 and SUMB2 respectively.

$$T_i = 2.511 .e^{-0.13t} \quad (5)$$

$$Ti = 2.566 .e^{-0.06t} \quad (6)$$

$$Ti = 0.8200 .e^{-0.0128t} \quad (7)$$

$$Ti = 0.965 .e^{-0.0248t} \quad (8)$$

Where:

Ti: Infiltration rate (L.min^{-1});

t: Time of operation (days);

e = invariable number of the exponential function, equal to 2,71828182845904.

Based on Equations 5 and 6, infiltration failure prediction for SUM1 and SUM2 shown in Figure 4A was, respectively, of 270 and 574 days, with significant difference between these soakaways (p=0.016). However, the application of Equations 7 and 8 showed a prediction a little lower than that presented formerly in Equations 5 and 6. The prediction of failure for SUMB1 and SUMB2 was, respectively of 213 and 425 days (Figure 4B). Results suggest confirmation of gradual soil matrix obstruction in SUM1, probably due to significant effluent amount of TSS and VSS, considering that effluent organic load is reported as responsible for a superficial bio zone formation which may reduce hydraulic conductivity by 1-3 orders of magnitude (BUMGARNER & MCCRAY, 2007).

Results obtained by applying experimental data to the Leverenz, Tchobanoglous and Darby (2009) predictive model (Equation 4) confirmed the data of both bench and pilot scale soakaway studies. The absolute difference between all the tested experimental soakaways was around 3% and 0.91% when applying the results to the Leverenz, Tchobanoglous and Darby (2009) model.

The experimental data that suggested failure due to relative clogging gave the relative difference between SUM1 and SUM2 of 53%. Whilst using the Leverenz, Tchobanoglous and Darby (2009) model, the relative difference was 58%. Likewise, at laboratory scale, the experimental results for SUMB1 and SUMB2 gave relative differences of around 50% against 57% when applying the Leverenz model to the soakaway data.

The greater observed values for predictive hydraulic failure of the pilot scale soakaways can be explained by the greater capacity of hydraulic conductivity recovery and its corresponding infiltration rate, due to non-controlled experimental conditions, e.g., direct solar radiation, temperature variation and wind convective effects at the experimental site (PAVELICK *et al*., 2011).

CONCLUSIONS

The effluents produced from a household sized UASB reactor and a single household septic tank achieved similar COD_{total} removals (p=0.1533) which may not have played an important role regarding the differences between soakaway clogging processes.

The low concentration of VSS, at a significance level of 5% (p=0.000118), in the UASB effluent compared to that of ST effluent, with respective averages of 29±9 mg.L^{-1} and 19±6 mg.L^{-1} could account for the lower clogging tendency of the UASB soakaway during the infiltration tests.

Infiltration flow rates in the pilot scale soakaways SUM1 and SUM2 showed significant differences with respective mean values of 1.26 and 1.97 L.min^{-1} (p=0.016).

Infiltration rates of the laboratory scale soakaways SUMB1 and SUMB2, operated under controlled conditions, has predicted the hydraulic infiltration failure of SUMB1 before SUMB2.

The increased clogging tendency of SUMB1 over SUMB2 confirmed the pilot scale studies with SUM1 and SUM2, suggesting that soakaways constructed to treat the effluent from household ST's at real scale in sandy soils will tend to clog 50 to 58% faster than those treating household UASB effluents.

Prediction modeling of the clogging of soakaways in sandy soil, taking into account the influence of organic load in terms of COD, SS and also hydraulic loading rate, and daily dosing regimens (LEVERENZ; TCHOBANOGLOUS; DARBY, 2009) confirmed the clogging rates based on experimental data.

The good correlation found between the average infiltration rate, the number of days of operation, and the increased clogging rate (58%) obtained for the pilot scale soakaway treating ST effluent predictions, suggests that the household UASB reactor is a promising alternative to septic tanks for treatment prior to effluent soil disposal in household decentralized wastewater treatment systems.

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