Feasibility of UASB/trickling filter systems without final clarifiers for the treatment of domestic wastewater in small communities in Brazil

C. A. L. Chernicharo and P. G. S. Almeida

ABSTRACT

The paper analyses the concept and performance of different configurations of compact UASB/TF systems, without the final clarification stage, in relation to the removal of organic matter. The experiments were carried out in two sets of UASB/TF systems operating without secondary clarifiers, as follows: (i) four shallow (2.50 m height) TFs, each one filled with a different packing material; and (ii) two deep (4.20 m height) TFs, one filled with polyethylene corrugated sheets and the other with mixed polyethylene and sponge sheets. For the conditions tested (different packing material in shallow and deep TF), the UASB/TF systems had consistently complied (90 to 100% of the results) with the Brazilian discharge standards regarding to BOD, COD, and TSS parameters. The average BOD, COD and TSS effluent concentrations stayed below 40 mg BOD L^{-1}, 100 mg COD L^{-1} and 50 mg TSS L^{-1}, respectively. UASB/TF systems can constitute an attractive alternative for domestic wastewater treatment in small communities in developing countries, especially considering its operational simplicity and very low running costs.

Key words | domestic wastewater, packing media, post-treatment, small communities, trickling filter, UASB reactor, UASB/TF system

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INTRODUCTION

Trickling filters (TF) have already proven to be a successful alternative for the post-treatment of anaerobic effluents in developing countries, presenting good efficiency, very low energy consumption (even none), robustness to shock loads, and simplicity in terms of equipments, design, operation and maintenance (Mergaert *et al.* 1992; Chernicharo 2006). These factors have contributed to position the UASB/TF system as one of the main alternatives for the treatment of domestic wastewater in some regions in Brazil. In Minas Gerais State, this treatment configuration has been used for small, medium and large communities, ranging from 500 to 1 million inhabitants.

However, the improvement of system operational simplicity can be important for its application in regions where construction and operational expertise are limited. One possible and very attractive simplification is the use of UASB/TF systems *without final clarifiers*, as previously reported by Silva & Gonçalves (2004), Pontes & Chernicharo (2006) and Almeida *et al.* (2008). In this case, the typical UASB/TF flowsheet is simplified and the management of aerobic sludge is not necessary.

In previous studies carried out with shallow trickling filters operating without secondary clarifiers, Almeida *et al.* (2008) compared the compliance levels to the discharge standards of Minas Gerais State – Brazil for two operating conditions: (i) OLR of 0.43 kg BOD m^{-3} d^{-1} and HLR of 20 m^3 m^{-2} d^{-1}; and (ii) OLR of 0.24 kg BOD m^{-3} d^{-1} and HLR of 10 m^3 m^{-2} d^{-1}. High compliance levels to the discharge standards of BOD (60 mg L^{-1}), COD (180 mg L^{-1}) and TSS (100 mg L^{-1}) were attained for both operating conditions, especially for BOD and COD, although system stability and compliance levels were much higher when the TFs were operated at the lower loading rates. Based on these previous results, the present work focused on the enhancement of system performance when operating at intermediate loading rates and with different packing materials and height.

Therefore, the aim of this paper is to present the concept and performance evaluation of compact UASB/TF systems applied to the treatment of domestic wastewater, as well as a discussion regarding new packing media that have been tested. The paper also addresses a brief discussion

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regarding the effect of packing media on combined carbon oxidation and nitrification in TF without secondary clarifiers, presenting the new concept and operational strategy in order to turn the UASB/TF technology more adequate for the context of developing countries.

METHODS

Two different configurations of trickling filters (shallow and deep) were tested, both fed on effluents from UASB reactors treating domestic wastewater taken from the Arrudas wastewater treatment plant (Belo Horizonte – Minas Gerais – Brazil), after being submitted to pre-treatment for solids and grit removal. The main characteristics and operational conditions of the UASB reactors are according to Table 1.

Systems' monitoring

Samples of raw sewage, effluent of UASB reactors and effluent of both sets of trickling filters were analysed for the following main parameters: Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS). Such samples were composed over a 24-hour period, being kept under refrigeration during the whole sampling period. All analyses were performed according to APHA (2005).

Shallow trickling filters

The effluent from UASB reactor 1 was distributed on top of one 2.10 m diameter and 2.50 m height column (Figure 1), which was divided in four individual compartments, constituting four identical TFs. The four TF were operated in parallel, each one filled with a different type of packing media, as follows (Figure 2(b)): Downflow Hanging Sponge (DHS) (Machdar *et al.* 2000), pieces of corrugated plastic tubing (Tubing), blast furnace slag (Slag) and random plastic rings (Ring). All TFs were operated under the same loading conditions: hydraulic loading rate (HLR) of 10 $m^3\ m^{-2}\ d^{-1}$ and organic loading rate (OLR) varying from 0.11 to 0.37 kg BOD $m^{-3}\ d^{-1}$. The shallow TFs were monitored for a period of 91 days, although the system had already been in operation for more than 150 days before the monitoring period reported in this paper was started. The TFs were followed by secondary clarifiers (Figures 1 and 2(a)), but the results considered herein refer to samples collected before the settling units, as identified in Figure 1. The main characteristics of the trickling filters are presented in Table 2.

Deep trickling filters

As for the shallow TFs, the effluent from UASB reactor 2 was distributed on top of two trickling filters, one packed

Table 1 | Main characteristics and operational conditions of the UASB reactors

Reactor	Cross section	Height (m)	Useful volume (m^3)	HDT (h)	Upflow velocity ($m\ h^{-1}$)	OLR (kg BOD $m^{-3}\ d^{-1}$)
1	D = 2.50 m	4.50	22.1	7.0	0.65	0.87
2	1.40 m × 2.50 m	4.80	16.8	8.5	0.56	0.71

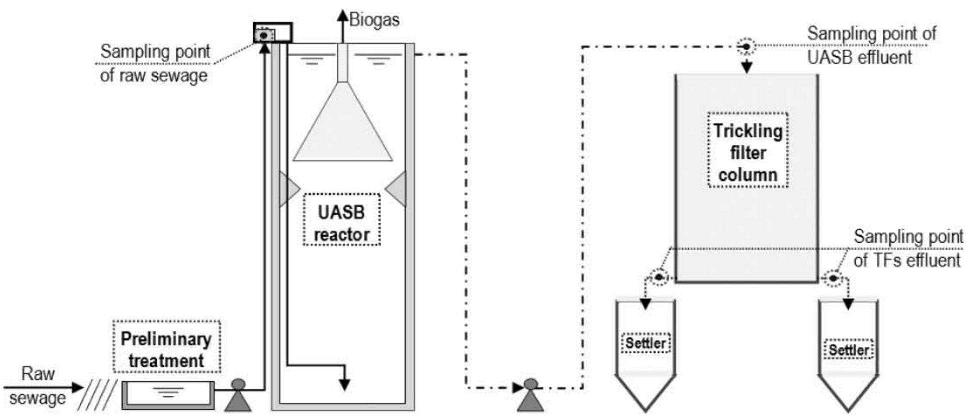

Figure 1 | Flowsheet of the experimental apparatus comprising UASB reactor followed by shallow trickling filters.

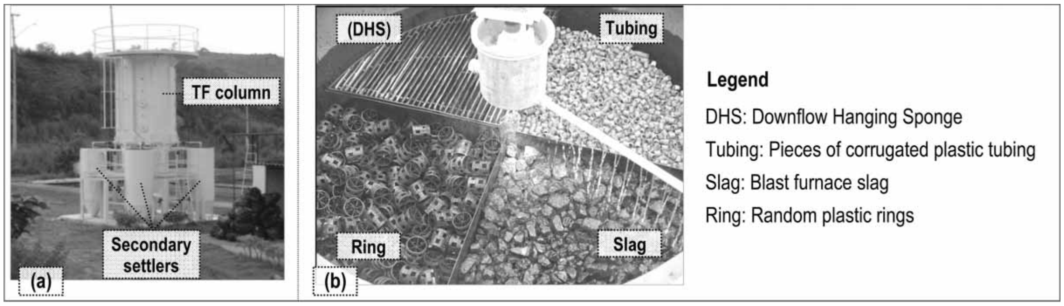

Figure 2 | View of the experimental apparatus: (a) front view of trickling filter column and four secondary clarifiers; (b) top view of the four compartments, distribution arm and media types.

Table 2 | Main characteristics of the shallow trickling filters and packing media tested

Characteristics	Overall reactor	Single compartment	Packing media (surface specific area)
Diameter (m)	2.10	–	Blast furnace slag (Slag): 60 $m^2\ m^{-3}$
Useful area (m^2)	3.46	0.87	Random plastic rings (Ring): 80 $m^2\ m^{-3}$
Useful height (m)	2.50	2.50	Downflow hanging sponge (DHS): 0.115 $m^3_{sponge}\ m^{-3}_{reactor}$
Useful volume (m^3)	8.65	2.16	Corrugated plastic tubing (Tubing): 220 $m^2\ m^{-3}$

with *Rotopack media* (polyethylene sheets) and the other with *Rotosponge media* (polyethylene and sponge sheets), as depicted in Figure 3. The TFs were divided in four vertical modules where the packing materials were installed. Both TFs were operated during 160 days under the following loading conditions: HLR between 10 and 12 $m^3\ m^{-2}\ d^{-1}$ and OLR varying from 0.10 to 0.37 kg BOD $m^{-3}\ d^{-1}$. The main characteristics of the trickling filters are presented in Table 3.

RESULTS AND DISCUSSION

Shallow trickling filters

All shallow UASB/TF systems and tested packing media presented good performance in terms of organic matter removal, reaching 100% compliance level to the discharge standards of Minas Gerais State – Brazil for BOD and COD (Figure 4(a) and (b)), and around 90% for TSS (Figure 4(c)). The average BOD, COD and TSS concentrations stayed below 40 mg BOD L^{-1}, 100 mg COD L^{-1} and 40 mg TSS L^{-1}, respectively. The corresponding overall average efficiencies were 89, 80 and 75%, for BOD, COD and TSS, respectively.

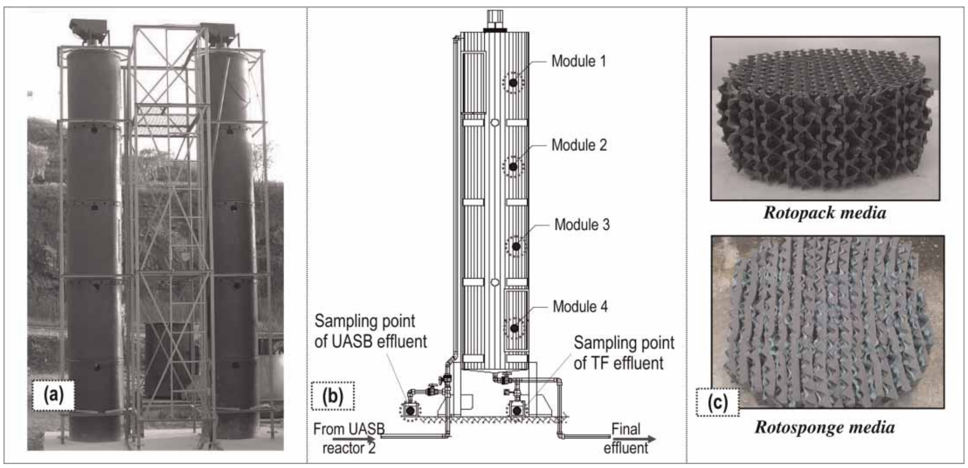

Figure 3 | Deep trickling filter experimental apparatus: (a) front view of the TFs; (b) schematics of the TFs; (c) view of the packing materials.

Table 3 | Main characteristics of the deep trickling filters and packing media tested

Characteristics	Each vertical module	Overall filter	Packing media	
Diameter (m)	0.76	0.76	Rotopack	Rotosponge
Useful area (m^2)	0.45	0.45	(Surface specific area)	(Sponge volume)
Useful height (m)	1.05	4.20	$132\ m^2\ m^{-3}$	$0.486\ m^3_{sponge}\ m^{-3}_{reactor}$
Useful volume (m^3)	0.48	1.90		

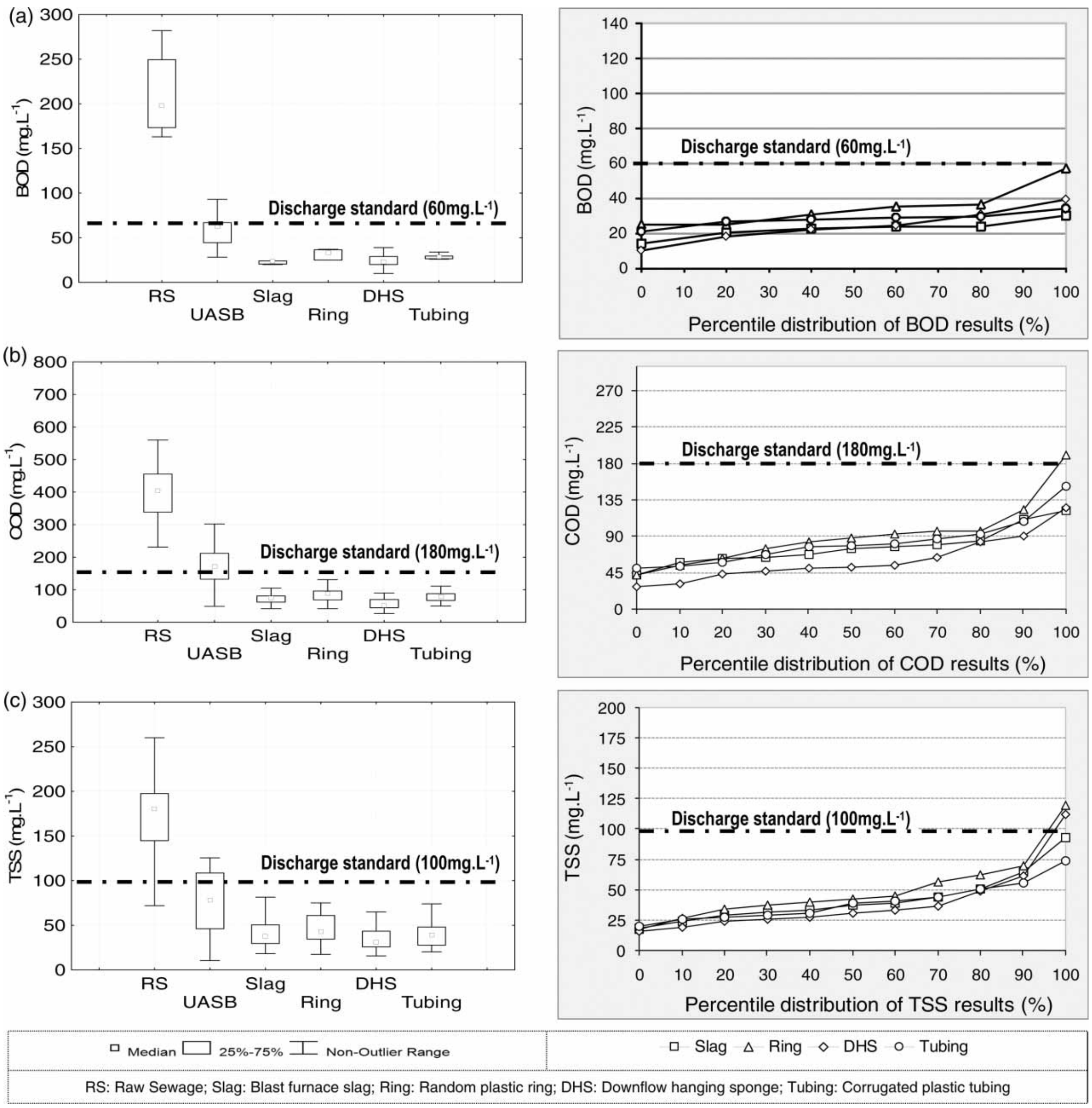

Figure 4 | Box plot and percentile distribution of BOD (a), COD (b) and TSS (c) results for the shallow TFs.

Deep trickling filters

Although the hydraulic loading rates applied to the deep TFs were slightly higher than the ones applied to the shallow filters, it was also observed a very good performance, especially for the trickling filter packed with *Rotosponge*, which reached 100% compliance level to the local discharge standards of Minas Gerais State – Brazil for BOD, COD and TSS (Figures 5(a), (b) and (c)). The average BOD, COD and TSS concentrations in the *Rotosponge* TF stayed below

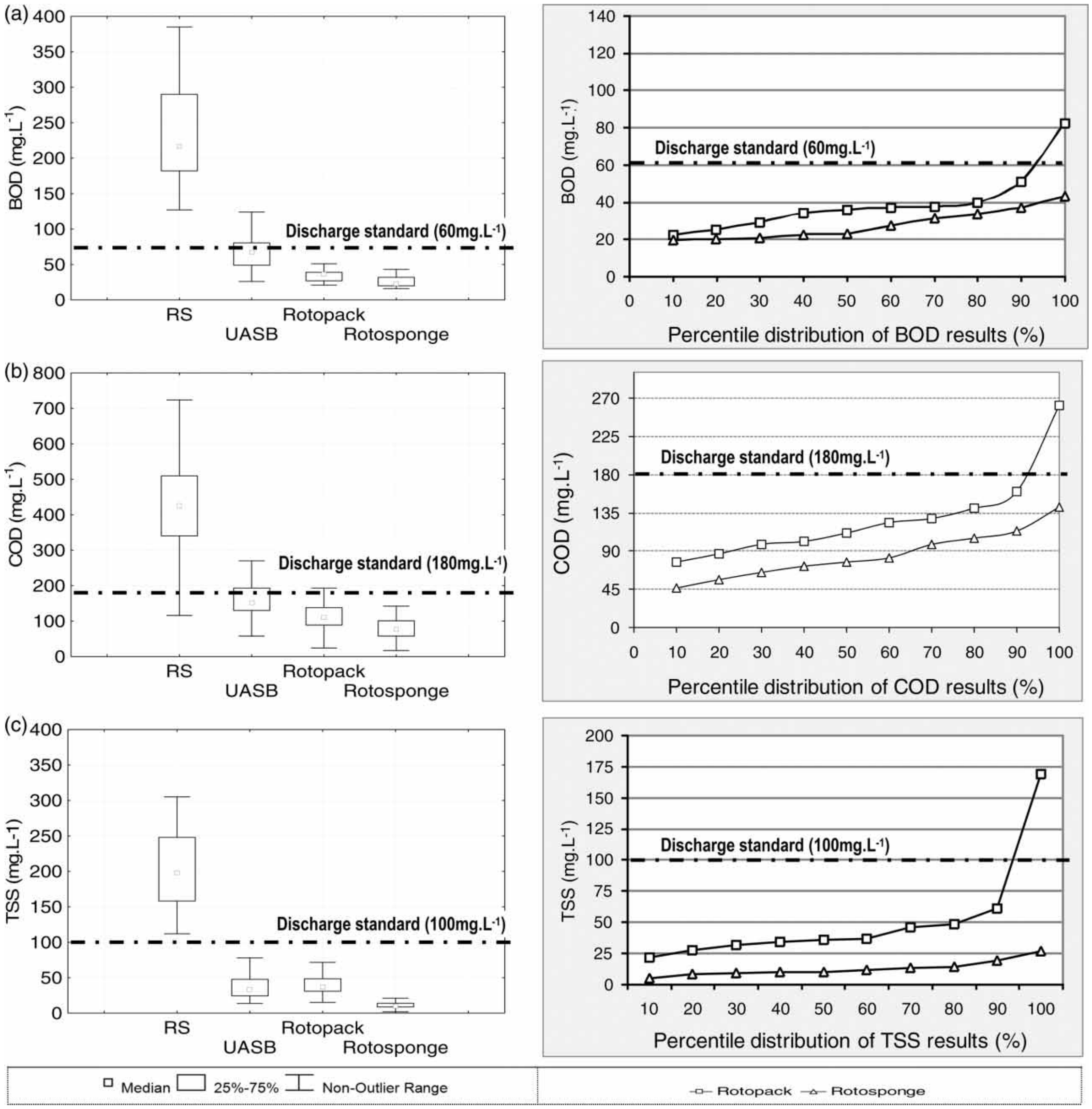

Figure 5 | Box plot and percentile distribution of the BOD (a), COD (b) and TSS (c) results for the deep TFs.

30 mg BOD L^{-1}, 100 mg COD L^{-1} and 25 mg TSS L^{-1}, respectively. The corresponding overall average efficiencies were 88, 80 and 88%, for BOD, COD and TSS, respectively.

Although the deep TFs packed with *Rotopack* and *Rotosponge* had been operated at slightly higher HLR, it was observed that the innovative materials were able to maintain the effluent concentrations at very low levels, especially the TF packed with sponge based media, which presented the best performance. These results confirm the benefits of using sponges between the corrugated plastic sheets, allowing the reduction of the TF compartment or, in some cases, contribute to enhance the nitrification in trickling filters (Tandukar *et al*. 2007). Preliminary results (not shown) related to ammonia removal in the deep trickling filters have presented the same tendency, with much higher efficiencies being observed in the filter packed with Rotosponge media.

General discussion

From previous (Almeida *et al*. 2008) and present results it becomes clear that the operation of trickling filters post UASB reactors at the lower range of conventional high rate filters (HLR between 10 and 15 $m^3\,m^{-2}\,d^{-1}$ and OLR between 0.20 and 0.30 kg BOD $m^{-3}\,d^{-1}$) influences some hydrodynamic conditions (e.g. hydraulic retention time and velocity through the media) that favours the reduction of shear forces, causing less detachment of the biofilm. In addition, the biochemical environmental conditions in these filters provided by the reduction of bulk phase substrate concentrations (low OLR applied) tend to limit the growth of heterotrophic biomass, increasing the solids retention time (SRT) and, in parallel, favouring the development of thinner and more active biofilm layers. All together, these aspects lower the volatile solids production and, therefore, the impact on BOD and COD concentrations in the final effluent is also lowered, allowing the operation of such systems without secondary clarifiers. The experience so far suggest that a mature biofilm (in terms of thickness and microbial population) is reached after 4 to 6 months of TF operation, as inferred from the operational stability of the trickling filters after 180 days of operation, even when exposed to extensive variations of organic and solids loading (results not shown). Furthermore, analyses of samples of packing media collected at different reactor heights have revealed no excessive biofilm growth (results not shown).

The main advantage attributed to operate these systems without secondary clarifiers is that the management of aerobic sludge is not necessary and, consequently, the withdrawal of the anaerobic sludge is less frequent because the aerobic sludge is not conducted to UASB for stabilization and thickening. All four shallow and two deep UASB/TF systems were able to produce effluents that could meet the local discharge standards in terms of BOD, COD and TSS, even when the OLR was around 0.40 kg BOD m^{-3} d^{-1}, however maintaining the HLR around 10 m^3 m^{-2} d^{-1}. This result is very important for regions where organic matter removal is still the main concern, as is usually the case in developing countries. Additionally, the design of trickling filters post UASB with larger volumes (low organic loading rates) can also enhance ammonia removal, especially when sponge-based packing columns are used (Machdar *et al.* 2000). Up to 50% ammonia removal was attained with TFs operating under OLR of 0.24 kg BOD m^{-3} d^{-1} and HLR of 10 m^3 m^{-2} d^{-1} (Almeida *et al.* 2008).

The apparent disadvantage of designing trickling filters to operate at lower hydraulic and organic loading conditions, implying in larger tank volumes and construction costs, can be compensated by the elimination of the secondary clarifiers, sludge scrapper and pumping station, and its corresponding operational costs. Considering the construction costs related to full-scale UASB/TF in operation in Brazil, the construction costs of secondary clarifier represents around 70% of trickling filter's costs. Thus, these resources can be used to compensate the investment directed to construct larger trickling filters.

Technology transfer

Based on the results obtained with shallow and deep trickling filters post UASB reactors, the Sanitation Company of Minas Gerais decided to adopt compact UASB/TF systems without final clarifiers for the treatment of wastewater in small communities located in a low income region of Minas Gerais State, where there is a need for low cost and easy operation treatment systems.

Specifications containing guidelines for the design and construction of such systems were developed, as a way of warrantee that all manufacturers of compact treatment systems could offer their products with the same characteristics. The specifications were made for five types (modules) of compact UASB/TF systems (Table 4).

The compact treatment systems incorporate the following main units and features:

- UASB reactor;
- Trickling filter without final clarifier;
- Device for biogas collection and flaring;
- Devices for sludge sampling and withdrawal;
- Device for scum removal from the inside of the three-phase separator;
- Non-mechanized device for distribution of the anaerobic effluent on top of the trickling filter;
- Sludge drying beds.

For the trickling filters without secondary clarifiers, the following design criteria and parameters were established:

- Average hydraulic loading rate ($HLR_{average}$): ≤ 10 m^3 m^{-2} d^{-1}.
- Maximum hydraulic loading rate (HLR_{max}): ≤ 15 m^3 m^{-2} d^{-1}.

Table 4 | Modulation and main characteristics of the prefabricated compact UASB/TF systems

Type	Population equivalent (inhabitant)	Design flowrates (m^3 d^{-1}) Mean	Design flowrates (m^3 d^{-1}) Maximum	Influent organic loads (kg d^{-1}) BOD	Influent organic loads (kg d^{-1}) COD
1	250	1.1	1.8	11.3	22.5
2	500	2.2	3.5	22.5	45.0
3	1,000	4.4	7.1	45.0	90.0
4	2,000	8.8	14.1	90.0	180.0
5	3,000	13.2	21.2	135.0	270.0

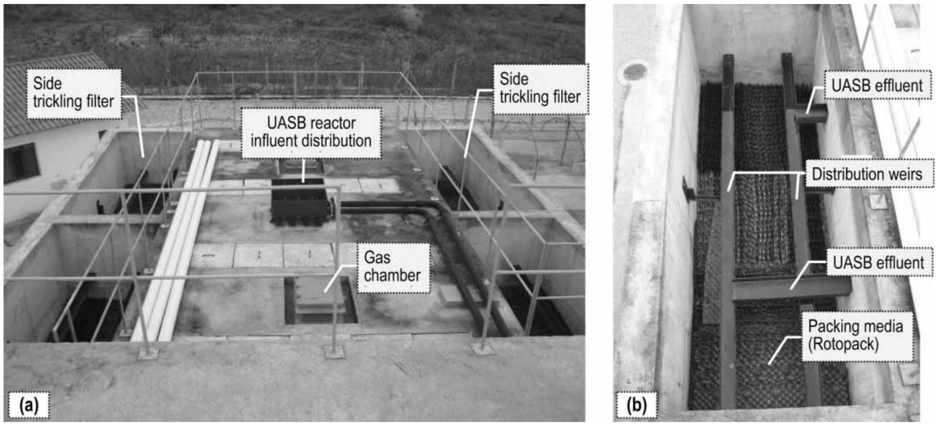

Figure 6 | (a) Top view of an UASB/TF system for 3000 inhabitants; and (b) top view of one side tricking filter.

- Average organic loading rate (OLR) $\leq$0.4 kg BOD m^{-3} d^{-1}.
- Packing media height: $\geq$3.00 m.

Figure 6 illustrates one of the several compact UASB/TF systems implemented by the Sanitation Company of Minas Gerais States, some constructed in concrete (Figure 5) and others in fibreglass, polyethylene and steel.

CONCLUSIONS AND FUTURE PERSPECTIVES

All shallow (2.50 m height) and deep (4.20 m height) UASB/TF systems without final clarifiers presented very high compliance levels with the discharge standards of Minas Gerais State – Brazil (100% compliance for BOD, 90–100% for COD and 90–100% for TSS). The average BOD, COD and TSS effluent concentrations stayed below 40 mg BOD L^{-1}, 100 mg COD L^{-1} and 50 mg TSS L^{-1}, respectively. These results were obtained for trickling filters operating at HLR between 10 and 12 m^3 m^{-2} d^{-1} and OLR between 0.10 and 0.37 kg BOD m^{-3} d^{-1}.

Some enhancements to increase nitrification in these systems are still necessary. For that, other strategies should be more investigated, such as the use of higher sponge-based packing columns, in order to create longer sludge retention times for autolysis of sludge in the system itself and suitable environmental conditions for the development of nitrifiers. Additionally, it is possible that also denitrification can be achieved, since large amounts of organic matter and biomass are retained in the interstices of the sponge layers located on top of the TF. For this, the strategy of final effluent recirculation shall be tested.

The results of the present study substantiate that UASB/TF systems operating without final clarifiers can constitute an attractive alternative for domestic wastewater treatment in small communities in developing countries, especially considering its operational simplicity and very low running costs. The key factor for the success of this treatment configuration is the maintenance of BOD and TSS concentrations in the influent of the trickling filter below around 100 mg L^{-1}, for both parameters, what can be accomplished in well operated UASB reactors. The technology was adopted by the Sanitation Company of Minas Gerais State to attend several small villages in regions where technical expertise and economical resources are scarce.

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