

Treatment of domestic greywater by geotextile filter and intermittent sand filtration bioreactor

Sebastian Ignacio Charchalac Ochoa, Ken Ushijima, Nowaki Hijikata and Naoyuki Funamizu

ABSTRACT

Intermittent sand filtration (ISF) is an efficient system for treatment of greywater; however, the high quality of effluent and the simple set-up contrast with the high failure rate due to clogging of surface layers. The efficacy of several polypropylene non-woven geotextiles (apparent opening size from 0.10 to 0.18 mm) used as primary treatment filters to remove suspended particles from domestic greywater and the effects of this pretreatment in the performance of fine and small media size (0.3 and 0.6 mm) ISFs was examined. Results showed geotextile achieved suspended solids (SS) removal rates from 25 to 85% and chemical oxygen demand (COD) from 3 to 30%; although the portion larger than 75 µm was removed at higher rates (55–90%), particles smaller than the nominal pore size of the filter were also captured. Geotextile used as pretreatment resulted in improvement of lifetime of the ISFs over an experimental run of 60 days. The vertical profile of volatile organic matter in the ISFs was evaluated at the end of the experiment and it showed a clear reduction in the accumulation of organic material on the top layer of the ISFs, effectively avoiding its early failure by accumulation of solids.

Key words | geotextile, greywater, intermittent sand filter, water reuse

Sebastian Ignacio Charchalac Ochoa
(corresponding author)

Graduate School of Engineering,
Hokkaido University,
Kita 13, Nishi 8, Kita-ku,
Sapporo,
Hokkaido 060-8628,
Japan
E-mail: scharchalac@eng.hokudai.ac.jp

Ken Ushijima
Nowaki Hijikata
Naoyuki Funamizu
Faculty of Engineering,
Hokkaido University,
Kita 13, Nishi 8, Kita-ku,
Sapporo,
Hokkaido 060-8628,
Japan

INTRODUCTION

Decentralized reclamation and reuse of domestic wastewater is considered as one of the alternatives to alleviate the water availability issues for agricultural irrigation and reduce the health risks associated with lack of improved sanitation in rural communities of developing countries, which heavily depend on agricultural production (Morel & Diener 2006). Reclamation of domestic greywater is of particular interest for water reuse in domestic gardens or small-scale irrigation systems since it generally contains lower concentrations of organic matters and pathogens compared to mixed wastewater (Eriksson *et al.* 2002; Gajurel *et al.* 2003; Friedler & Hadari 2006).

The Onsite Wastewater Differentiable Treatment System is an ecological sanitation alternative based on the 'don't mix' and 'don't collect' principles that proposes source separation and treatment of reduced volume

blackwater (excreta and urine), higher load greywater (HLGW) and lower load greywater (LLGW) (López-Zavala *et al.* 2002). Typically, HLGW includes greywater from kitchen sinks, laundry (totally or partially) and dishwashers, while LLGW is formed by effluents from showers, baths and hand basins. Treatment of blackwater through a dry bio-toilet was proposed for production of compost to be used as fertilizer. The separation of greywater into two types is based on the assumption that greywater from different sources varies in volume and concentration of pollutants (Almeida *et al.* 1999; Funamizu *et al.* 2002; Friedler 2004), thus reducing the treatment required for certain effluents. LLGW was intended to be treated by natural soil infiltration systems and HLGW by onsite conventional systems and discharged afterwards. In this sense, the treatment of HLGW by membrane bioreactors (MBRs) for

urban non-potable reuse (Huelgas & Funamizu 2010) and by slanted soil system for reuse in irrigation (Ushijima *et al.* 2013) has been explored. However, the complexity of these systems, added to the frequent maintenance, requirement of qualified labor and energy requirements (in the case of the MBR) may still be a barrier for wide implementation in low- and medium-income developing countries.

On the other hand, intermittent sand filtration (ISF) is one of the simplest and most efficient methods to treat wastewater; this technology combines physical and biological aerobic processes, enhanced by the aeration given by the intermittent load of influent, as in the case of domestic greywater discharge (Reed *et al.* 1995). High quality effluents in terms of organic matter and suspended solids (SS) can be achieved with shallow depths (Darby *et al.* 1996; Rodgers *et al.* 2010), depending on the physical configuration of the system and the hydraulic loading rate (HLR). However, the weak point of this system is the relatively high failure rate due to clogging (Leverenz *et al.* 2009).

The reasons for the porosity reduction that causes clogging have been widely discussed, including simple accumulation of solids or fibers (Langergraber *et al.* 2003; Spychala & Blazejewski 2003; Zhao *et al.* 2009), biofilm growth (Rodgers *et al.* 2004), bacterial production of slimes (Spychala & Blazejewski 2003), precipitation of chemicals (e.g. CaCO₃), mechanical compaction of media (Rolland *et al.* 2009) and others. Nevertheless, clogging is not caused by only one of these reasons, but rather due to a complex combination of all these processes (Leverenz *et al.* 2009; Hua *et al.* 2010). Compared to the accumulation of solids, biofilm growth is an inherent process to bioreactors since they rely on biological degradation and is therefore controllable to a certain extent by avoiding overloading and allowing enough resting time between loads (Darby *et al.* 1996). High loads and the particle size distribution of SS have been suggested to influence the clogging rate of ISFs (Winter & Goetz 2003); these loads can be significantly affected by lack of or inefficient primary treatment, which has been stressed as the main reason for failure in practical use of ISFs and other similar systems (Morel & Diener 2006).

We propose the use geotextile fabric filters as pretreatment for domestic greywater prior to treatment by simple ISF systems as a measure of protection to overload of SS.

Geotextile fabrics and similar materials have been used as the primary treatment for removal of SS and lint from domestic greywater (Christova Boal *et al.* 1996), municipal wastewater (Kotha 2001), combined runoff and sewage (Marino 2006), surface waters (Mulligan *et al.* 2009) and rainwater (Silva Vieira *et al.* 2013); as media for a recirculating bioreactor for treatment of domestic wastewater (Roy *et al.* 1998); and as biofilm attachment filters for municipal wastewater treatment (Korkut 2003). These materials, particularly non-woven needle-punched geotextiles, have been shown to be efficient in trapping SS and other large materials (Marino *et al.* 2006), given their complex fiber structure compared to simple strainers. Additionally, they may have some capacity in removal of pathogens (Keraita *et al.* 2008), especially helminthes. The main mechanisms for capture of particles by geotextiles are sieving and cake filtration (Korkut 2003); consequently, capture of particles will be more influenced by their size rather than density or the flow rate of the influent; this could be an advantage if compared to traditional grease traps, given the typical unsteady flow of domestic greywater sources. However, geotextiles and ISFs could be especially sensitive to oils and fats, therefore, kitchen sink greywater is excluded from treatment in this study; thus the target influent of this study is a mixture of LLGW plus laundry greywater and is referred in this paper only as greywater.

The aim of this paper is to evaluate the ability of different geotextiles to remove SS from greywater and extend the lifetime of simple ISFs by controlling the accumulation of particles. Two features are discussed: first, the lifetime and efficiency of geotextiles to remove SS and chemical oxygen demand (COD) from greywater and second, the effects of using this pretreatment on the permeability and accumulated materials on the surface of ISFs fed with greywater.

MATERIALS AND METHODS

Evaluation of geotextiles

Six geotextile materials (provided by Toyobo Co. and Mexi-chem S.A.B. de C.V.) were selected to evaluate their capability as single-layer direct filters to remove SS and

Table 1 | Characteristics of geotextile fabrics

Type	Manufacturer	Model	AOS [mm]	Permeability [cm s^{-1}]	Thickness [mm]	Weight [g m^{-2}]
NP	Toyobo	4061N	0.14	0.150	1.00	83
NP	Toyobo	4101N	0.12	0.200	1.40	106
NP	Toyobo	4161N	0.10	0.250	2.00	171
TBNP	Mexichem	NT 1800	0.18	0.040	1.70	144
TBNP	Mexichem	NT 2000	0.18	0.042	1.90	174
TBNP	Mexichem	NT 3000	0.15	0.042	2.10	235

AOS: Apparent opening size (pore).

NP: Needle-punched.

TBNP: Thermal-bonded needle-punched.

COD from greywater (Table 1). All the materials were polypropylene non-woven needle-punched geotextiles with apparent opening size (AOS) ranging from 0.10 to 0.18 mm and thickness from 1.4 to 2.3 mm. Samples of each material were cut from a roll (2×20 m or 1×20 m) of geotextile provided as is in general distribution.

To evaluate the reduction in permeability of the geotextiles, a device designed according to ASTM D4491–99a (American Society for Testing and Materials (ASTM) 2004) requirements was constructed with PVC pipes and accessories. The procedure was as follows: a sample of geotextile was cut in a circular shape and installed in the device sample holder. The effective diameter was 5 cm. Then, permittivity was measured three consecutive times using water and the arithmetic average was calculated. After that, a batch of 50 cm of greywater was loaded to the geotextile sample and the filtrate collected. Permittivity was measured again with water. The process of loading batches and measuring permittivity was repeated until permittivity was under 10% of the original and it was considered as clogged.

The quality assessment of influent greywater and collected filtrates was done in terms of SS and COD. The material with the best performance, i.e. higher removal of SS and COD, was subsequently examined for a more detailed analysis regarding the particle size distribution of SS in the effluent. Fractions of SS by size were determined by filtering enough volume (5–6 L) of the filtrate through US Standard steel mesh sieves number 100, 200, 400 (nominal pore size of 150, 75 and $32 \mu\text{m}$, respectively) and glass fiber filter ADVANTEC GB-140 (pore size $0.40 \mu\text{m}$) and

measuring the individual SS concentration of each filtrate. The load and sampling of greywater was done using a similar method as the preliminary experiment in batches of 50 cm.

Evaluation of intermittent sand filters

Four ISFs were constructed with acrylic Lucite plastic tubes with 0.05 m inner diameter and 1.32 m length (Figure 1). Media depth was 1 m, leaving 0.16 m between the sand surface and the geotextile filter to avoid mix-up and interference between the clogging either in sand surface or in the geotextile. Two filters (each constructed with and without geotextile) contained sand with an effective size (d_{10} , i.e. size of screen opening through which 10% by weight of sand passes) of either 0.30 mm (fine) or 0.60 mm (medium). The sand was obtained from a company that supplies the material typically used in large sand filters of local wastewater treatment plants; it was washed, dried, sieved (mesh nominal opening sizes: 0.125, 0.3, 0.425, 0.60, 0.85, 1.20, 2.0 mm) and then graded. The uniformity coefficients, calculated as d_{60}/d_{10} , were 1.4 and 1.66 for fine and medium sand, respectively. The inclusion of only fine and medium size media was also intended to observe more clearly the effects of deposited solids, since the porosity is supposed to be smaller than in coarser media and therefore more susceptible to clogging.

Sampling ports of 2.5 cm diameter were installed at depths 0.1, 0.2, 0.4 and 0.6 m from the media surface to determine the COD and linear alkyl benzene sulfonates (LAS) removal efficiency in the ISFs. These ports were

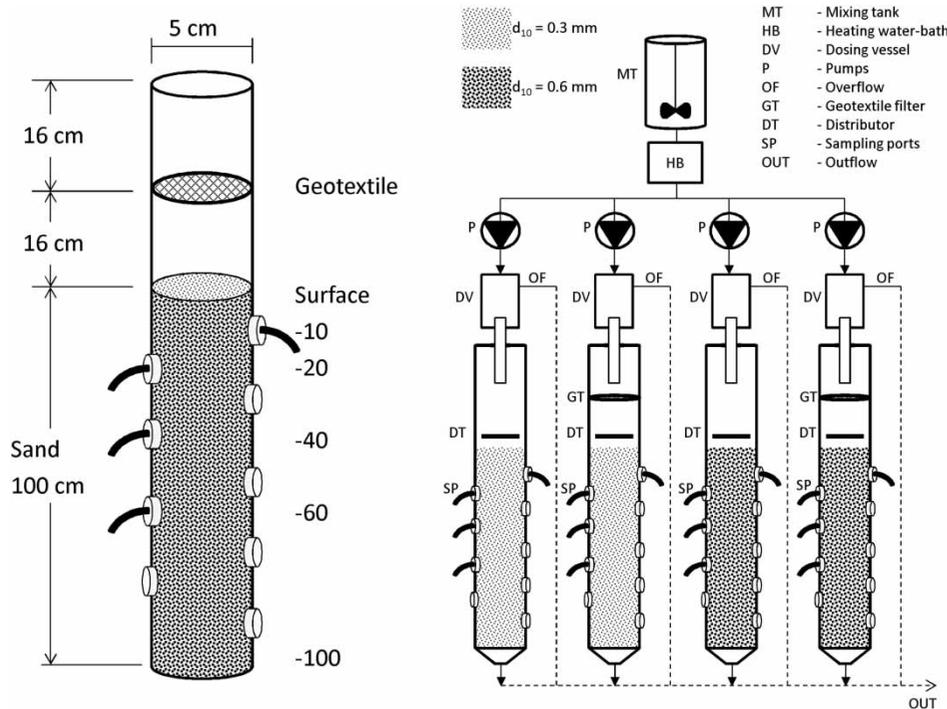


Figure 1 | Individual ISF and experimental set-up.

used only in the last 2 weeks to avoid any disturbance to the ISFs and when the microbial populations had likely already stabilized. The ISFs were operated for 60 days. The conditions were set such as to be able to observe clear differences due to overloading of SS. For the first 6 weeks, effluent was collected only at the bottom of each ISF. Since the greywater volume of each discharge was small, only one port was opened in each sampling, starting from depth 0.6 and going upwards; this took a week for evaluation at all depths.

The geotextile filter for pretreatment was installed in two of the ISFs through a stainless steel ring equipped with rubber seals to ensure the flow of greywater would go only through the material; the inner diameter of the steel ring was 0.05 m. The geotextile filter was replaced every time it became clogged (i.e. incomplete infiltration after 24 h), which occurred every 7–10 days.

A greywater HLR of 16 cm d^{-1} was applied based on the recommendation of Darby *et al.* (1996). SS and COD loading rates were 16 and $57 \text{ g m}^{-2} \text{ d}^{-1}$, respectively. The total daily volume was split into three equal single-time discharges during daytime (9 AM, 12 PM and 6 PM), corresponding

to a theoretical morning, noon and evening time peak water use (Funamizu *et al.* 2002).

Effects of the geotextile filters on ISF performance were measured by two factors: permeability of surface (in terms of infiltration time of a single given greywater dose) and effluent quality. To use a conventional permeability test was deemed impractical since this could cause disturbances to the normal accumulation of SS and the natural development of the ISF biofilm under greywater loading. Therefore, the permeability of media was measured by the total time in seconds that it took for a single morning discharge of 5.66 cm to completely infiltrate (i.e. no water line observed above sand) the surface. Additionally, post experiment weight loss on ignition (LOI) of sand layers at different depths (three samples were taken from each depth: 0.025, 0.075, 0.15, 0.25, 0.35, 0.5, 0.7 and 0.9 m, respectively) were performed to determine the difference in organic material accumulated as an indicator of physical clogging (Rodgers *et al.* 2004). Samples for LOI were first evaluated for moisture content and subsequently burned in a muffle furnace at 550°C for 2 hours. Difference between initial dry weight and burnt weight in percentage was calculated as LOI.

Greywater characteristics

Composition of greywater was a mixture of shower, laundry and hand basin sources (65:30:5 in volume) with the characteristics summarized in Table 2. Shower and washbasin greywater was collected from a domestic household to include the organic waste originated from the human body. Constituents included common brand shampoo (5 g 30 L⁻¹), conditioner (5 g 30 L⁻¹), body soap (5 g 30 L⁻¹), toothpaste (3 g 30 L⁻¹) and hand soap (3 g 30 L⁻¹). Prior to preparation of greywater, each constituent was weighed in separate plastic containers with precision of 0.01 g. Then a shower was taken by one person using the contents of the plastic containers. The shower drain was connected to semitransparent container tanks previously marked to the desired volume (20 L each), so the volume of accumulated greywater was visible and was collected with relative accuracy.

Laundry greywater was prepared by washing four pieces of used clothes in a washing machine using 12.5 g of detergent (Unilever OMO) per 40 L of water; this detergent was chosen since LAS are the active surfactant. LAS have been estimated to be the most widely used synthetic anionic surfactants and may have a negative impact on the environment (Mungray & Kumar 2009). LAS can exist in high concentrations in greywater and thus it is a useful indicator compound for greywater treatment systems that aim for reuse of effluent.

After preparation, both types of greywater were transported, mixed in the volume ratio indicated and stored in refrigerator at 3–4 °C under constant stirring to maintain a

homogeneous particle suspension. Fresh greywater was prepared every 5 days. Typical temperature of greywater is in the range of 18–38 °C (Eriksson *et al.* 2002); therefore, the influent was passed through a water bath that heated it to a temperature of 20 °C before being supplied to the ISFs. In general, the quality of the experimental greywater (SS and COD) was in the low to middle range for raw greywater (Almeida *et al.* 1999; Morel & Diener 2006), but higher than usual influents from septic tanks or pond effluents loaded to ISFs (Darby *et al.* 1996).

Sample analysis

Permittivity of geotextiles was evaluated using the ASTM D4491–99a Falling Head Method; normalized values were used for a better comparison. Influent and effluent samples were analyzed for suspended and dissolved solids (SS and DS), total and dissolved COD (TCOD and DCOD), total phosphorus (TP), total nitrogen (TN) and LAS. Standard analytical methods were used for SS and DS (American Public Health Association *et al.* 1985). HACH kits were used for COD, TN and TP (Method 8000, Method 10071 and Method 8190, respectively) with the HACH DR2800 Spectrophotometer.

Concentration of LAS (C10–C14) was determined using liquid chromatography mass spectrometry (LC-MS) based on Ushijima *et al.* (2013). The column used was Wakopak[®] WS-Aqua (4.5 × 250 mm) and mobile phase was 0.2 mM ammonium acetate and 100% acetonitrile, ratio 63:37 at 0.3 mL min⁻¹ in isocratic mode. Samples for solid phase extraction were spiked with recovery standard C8 surrogate and then diluted to a concentration in the range of the limit of detection (0.01–0.25 mg L⁻¹). Solid phase extraction was performed according to Managaki *et al.* (2005) as follows: the pH was adjusted to 3 ± 0.05 with 10% HCl solution and loaded to a BOND ELUTE[®] PPL cartridge previously conditioned with 10 mL of methanol and 10 mL of pure water adjusted to pH 3 ± 0.05. LAS were eluted from the cartridge with 10 mL of methanol and subsequently filtered with a 0.2 µm PTFE Dismic filter and aliquots were loaded to the LC-MS vials. Standard LAS solution (C10–14) and recovery standard C8 reagent were obtained from WAKO Industries (>99% purity). Recovery rates were 92, 90, 87, 75 and 64%, respectively.

Table 2 | Influent characteristics

	Average	Min.	Max.
TCOD [mg L ⁻¹]	357	210	505
DCOD [mg L ⁻¹]	187	65	335
SS [mg L ⁻¹]	100	75	124
DS [mg L ⁻¹]	240	196	272
TN [mg L ⁻¹]	7.5	4.1	13.7
TP [mg L ⁻¹]	7.5	5.2	10.0
LAS [mg L ⁻¹]	25		

TCOD: Total chemical oxygen demand.

DCOD: Dissolved chemical oxygen demand.

DS: Dissolved solids.

TN: Total nitrogen.

TP: Total phosphorus.

RESULTS

Performance of geotextiles

As shown by the range in Table 2, the SS and COD concentration in greywater fluctuated significantly each time despite following the same recipe for greywater in each preparation; this is probably due to the alternate type of clothes used for laundry greywater as well as the variability of the load of human waste that depends on personal habits and activities.

The permeability of the geotextiles, indirectly estimated in terms of permittivity, followed a steep reduction over the course of loading greywater (Figure 2). From the six models evaluated, only model 4061N showed a slower reduction of permeability, just 20.99% loss after 300 mL cm⁻² of greywater were loaded. At the same point, all the other models were already below 10% of original permittivity. The materials captured by geotextile included hair, cloth fibers and small clumps of particles or biofilm.

Differences in removal rate of SS were negligible in the initial conditions, but generally, after loading 100 cm it was possible to observe difference in the behavior of the materials (Figure 3). Overall, only the geotextile models with density above 170 g m⁻² (4161N, NT2000 and NT3000) achieved removal rates above 50% of the SS. Table 3 shows the average SS and TCOD removal by geotextiles, where the maximum value of the range refers to the last measured removal before the permittivity value was below 10% of the original.

For the filter experiment, geotextile NT3000 was chosen due to its ability to capture more SS compared to other

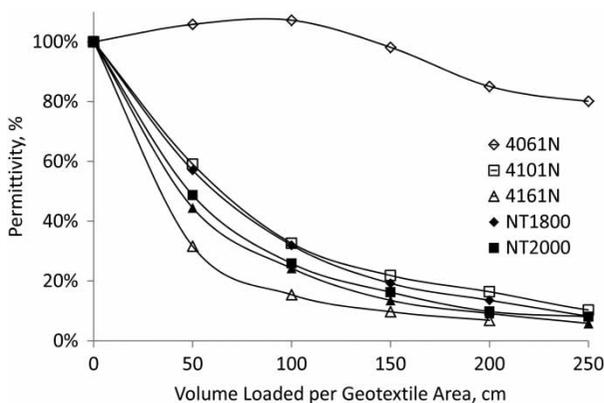


Figure 2 | Permittivity reduction in geotextiles.

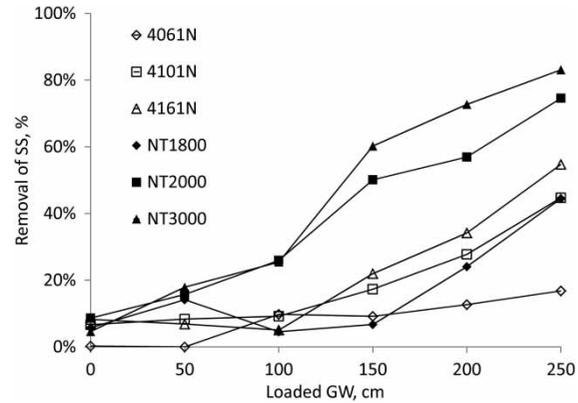


Figure 3 | SS removal by geotextiles.

Table 3 | SS and COD removal by geotextiles

Geotextile	SS		COD	
	Removal [%]	Range [%]	Removal [%]	Range [%]
4061N	8.1	0.0–16.8	3.0	0.0–5.4
4101N	19	6.7–44.7	10.3	2.0–20.5
4161N	21.8	5.0–54.7	11.3	2.9–26.0
NT1800	16.6	4.5–44.5	6.7	1.0–15.4
NT2000	38.6	8.6–74.5	20.3	5.2–32.0
NT3000	44	4.6–83.1	19.6	7.5–34.2

models. Since the quality of greywater is variable, several samples of NT3000 were individually assessed regarding the specific size of the particles removed; this is of importance since the size of deposited particles has been cited as one possible factor in ISF clogging. Figure 4 shows fractionated removal of SS by geotextile NT3000 for one sample batch test when greywater had a SS concentration of 143 mg L⁻¹, from which 77 mg L⁻¹ were solids larger than 0.075 mm. SS removal had a high initial value and sustained increase in quality, from 79 to 85%, the remaining SS in the filtrate being mostly solids smaller than 0.032 mm. Although the pore size of NT3000 is 0.15 mm, the material was able to remove SS in smaller fractions. Permeability was significantly reduced after only 150 cm.

Performance of ISFs and geotextile filters

The performance of the geotextile was slightly different compared to the first experiment. In this longer-term operation,

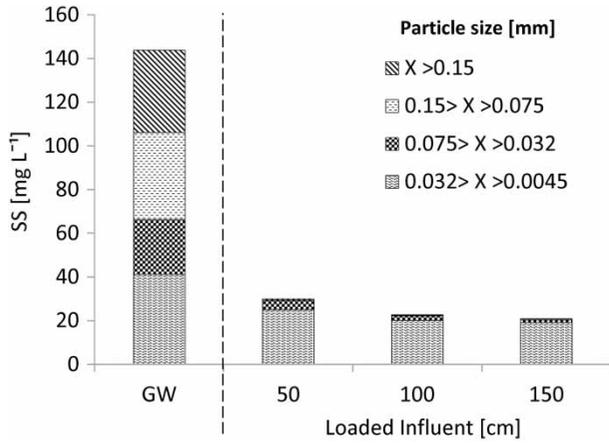


Figure 4 | Particle size distribution of SS in GW treated by NT3000.

insects and other random materials were occasionally observed, in addition to the previously mentioned greywater contents. The geotextile filter had to be replaced every 7–10 days, which means it only filtered 112–160 cm, compared to the 250–300 cm observed in the preliminary tests. Some type of slime was observed on the surface of the geotextile but not measured in any way; this could, however, indicate some bacterial activity.

Figure 5 shows the progression in infiltration time for a single dose (5.66 cm) on the surface layer of the ISF, as an indirect measurement of its hydraulic permeability. A clear increase in infiltration time was observed for three of the cases (0.30 mm with and without geotextile and the 0.60 mm without geotextile). Differences started to be noticeable after just 2 weeks. The ISF without geotextile and fine sand was clogged after 29 days, after an almost exponential increase in the infiltration time in its last

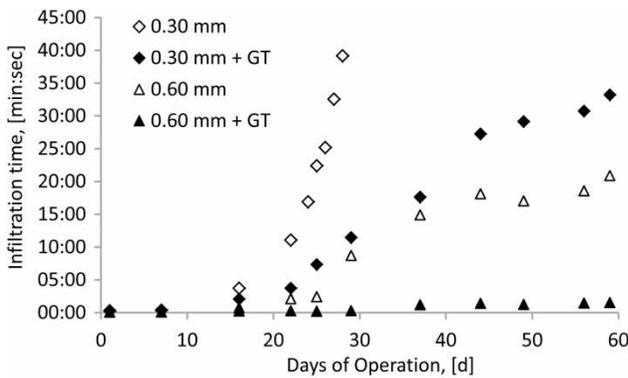


Figure 5 | Infiltration time of a single dose of GW in ISFs.

week. On day 28 the total daily dose of 16 cm did not completely infiltrate from the previous day; the column was stopped at the end of day 29, letting it rest for one more day and then proceeded to disassembling. The LOI test was performed immediately. The ISF with same media but also with geotextile did experience sustained increase in infiltration time, although at a slower rate.

For the case of 0.60 mm sand with geotextile pretreatment, the decrease in permeability was the least severe, increasing from 17 seconds in the initial day to 92 seconds on day 60. Although there was an increment in the infiltration time, the increase rate was significantly slower compared to the case without geotextile.

The remaining three ISFs were dismantled after 60 days of operation and the LOI tests were performed. Figure 6 shows the difference in weight loss in each of the layers. The most notable difference is observed in the top layer (0–0.05 m depth). The ISF of media 0.60 mm with geotextile had a weight loss of only 0.49%, whereas the one without the filter was 0.77%. ISFs with media 0.30 mm with and without geotextile had 0.89 and 0.92% weigh loss. The LOI values from below the surface were similar for all ISFs.

Furthermore, following experiments showed that after operating for more than 8 months in similar conditions, no clogging was observed in media size $d_{10} = 0.60$ mm

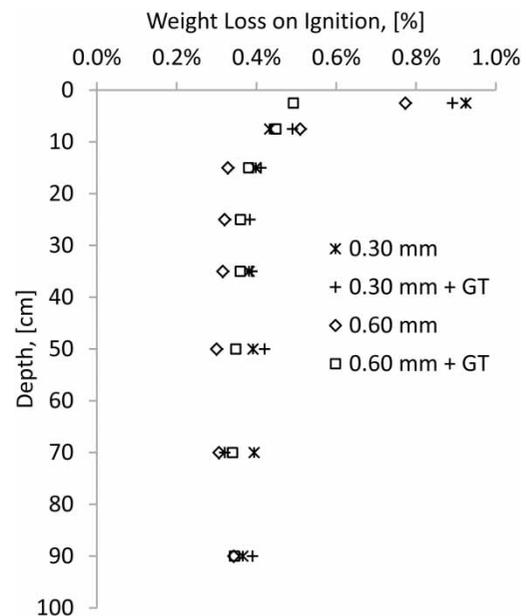


Figure 6 | Accumulation of organic material in ISFs.

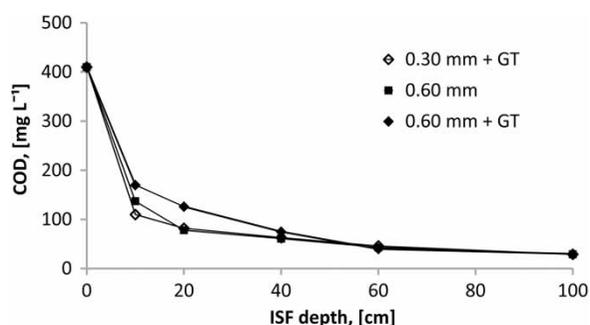
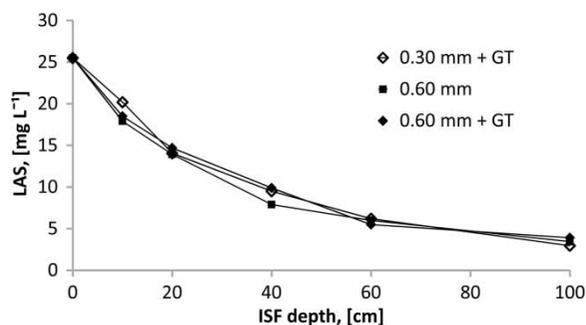
Table 4 | Effluent quality

	GW	0.30 mm	0.30 mm + GT	0.60 mm	0.60 mm + GT
COD [mg L^{-1}]	357.4 ± 72.0	30.5 ± 18.9	27.5 ± 16.2	32.6 ± 14.2	33.7 ± 18.9
SS [mg L^{-1}]	99.9 ± 14.7	< 1	< 1	< 1	< 1
TN [mg L^{-1}]	7.5 ± 2.9	1.9 ± 1.4	2.9 ± 2.4	3.5 ± 1.5	3.0 ± 1.9
TP [mg L^{-1}]	7.5 ± 1.5	1.2 ± 0.2	1.2 ± 0.3	1.1 ± 0.2	0.9 ± 0.1
LAS [mg L^{-1}]	25	3.0 ± 1.2	3.0 ± 1.5	3.5 ± 1.0	3.9 ± 1.2

(data not shown). This confirms the ability of geotextile to extend the lifetime of ISFs over a continuous usage.

At depth 100 cm, the quality of effluent from ISFs was high in terms of both SS (less than 1 mg L^{-1} in all cases) and organic matter (COD removal over 90%). The quality of the effluents did not significantly vary between the columns of same media size (Table 4).

The profile obtained in the last 2 weeks for the three remaining columns through samplings in the ports provided information about the degradation of organic components (Figure 7 and 8). COD reduction was drastic in the upper

**Figure 7** | COD reaction in ISFs.**Figure 8** | LAS reaction in ISFs.

10 cm, whereas LAS removal had a more linear relationship to depth, reaching overall efficiencies of 88% and 84–86% for fine and medium sand, respectively.

DISCUSSION

As shown in the results from the first phase, the geotextiles have a remarkable ability to remove SS and COD in particulate form. Moreover, the particle size can be controlled. In the case of a traditional sedimentation tank, the removal of SS depends on the retention time, something difficult to control in the case of sudden and intermittent discharges. In addition, the lack of maintenance in such systems can cause a sharp increase in SS exiting the chamber, a common occurrence. Geotextile filtration appears to be a good option to control the size of particles, although the maintenance required for the current method of use seems a downside. In a previous study by Marino (2006), a geotextile was evaluated in removal of organic particles under horizontal flow, the material was able to separate the large elements and when the flow stopped, the retained material subsequently slurred, giving an idea of the geotextile working as a simple mesh and separating particles of a given size; however, the nature of particles in greywater is different in the sense that particles attach to the fibers of the geotextile, giving little chance to reuse the filter under the current usage conditions. The inclusion of geotextile in a self-cleaning backwash system set-up as shown in Silva Vieira et al. (2013) could enhance its lifetime and reduce the frequency of maintenance. In that scheme the geotextile was installed in an inverted siphon set-up, performing an up-flow filtration rather than top to bottom as in this study. This set-up allowed the retained SS to settle in the bottom of the siphon after the

influent stopped being loaded. Furthermore, a magnetic valve located in the bottom part of the siphon opened under certain head pressure, allowing automatic backwash when the accumulated liquid equilibrated the strength of the magnet. Although the influent in that study was rainwater, the same principle applied for a greywater system could be a good option to be examined for a longer lifetime of the geotextile.

The thermal-bonded side of geotextile materials NT1800, 2000 and 3000 seemed to be beneficial on the initial sieving capture of SS and certainly the structure of the geotextile was more robust since the fibers were bonded together. Besides this characteristic, another important factor in removing particles seems to be the density of the materials. Despite having a theoretical smaller AOS and similar thickness, the model 4161N performance in removal of SS and COD was slightly below models NT2000 and NT3000, and above NT1800, an order which correlates to the densities shown in [Table 1](#).

The improvement in performance over the course of loading greywater to geotextiles is undoubtedly due to the accumulation of trapped particles in the fibers of the filter and a logical reduction of porosity, as well as the formation of a cake layer. This is clearly shown when the SS load of larger particles was higher ([Figure 4](#)). The removal rates jumped to near 80%, although with a reduced lifetime.

The effect of the geotextile on the permeability of the ISFs was evident, although the experimental conditions were somewhat near worst case scenario for the two columns without pretreatment. However, it was clear that the short term clogging was avoided by pretreatment. The geotextile reduced the SS load, thus reducing the particulate accumulation on the surface, which was not only important regarding the total volume but also the type and size of particles trapped; the geotextile removed not only particles, but also fibers originated in clothes, which had previously been suggested by [Spychala & Blazejewski \(2003\)](#) to contribute to the acceleration of clogging in sand filters. These types of SS probably have a higher chance to breakthrough a sedimentation tank, most likely if those are low density synthetic fabrics, which adds the complication of no biodegradation. Geotextile has a remarkable ability to trap such materials and similar (hair) within its complex array of fibers, compared to a simple metallic mesh. In the long run this process could extend the lifetime of a sand filter.

The quality of effluent in the ISFs did not show any significant difference and, as expected, the top layer of the filters was the most important for the removal of COD and SS, mainly due to the capture of the particulate portion by sieving. The near linear pattern in LAS concentration to depth shows that removal may be initially influenced by the adsorption process followed by biodegradation.

Biofilm growth is a process inherent to this type of bioreactor, but if the system works under appropriate conditions and resting times are allowed periodically, the system can have a stable performance for long periods of time. Clogging by deposition of large and non-degradable materials on the other hand is an avoidable process.

CONCLUSIONS

The study showed geotextiles were able to remove more than 50% of SS in greywater. Moreover, the removal of specific particles goes below the theoretical AOS. Reduction of large particles by pretreatment not only reduces the amount of accumulated particles but showed the potential to remove COD up to 30%. The materials with one side thermal-bonded as well as higher density showed the best performance. The materials were able to filter an overall maximum of 200–250 cm of greywater before failure in continuous use, and only 112–160 cm in the intermittent set-up, meaning that if used in the same area ratio to the ISF surface, a large amount of geotextile would need to be replaced often. Using a geotextile filter as pretreatment did not affect significantly the overall quality of ISF effluent and positively reduced the accumulated volatile solids in the top layers of the media, effectively avoiding early clogging in fine media and decreasing permeability in medium sand during the experimental period.

The results of the experiment show that geotextile filters may have potential for extending the initial lifetime of ISFs. The downside is the periodic maintenance and the material expense needed every 7–10 days in the current usage form. It is recommended to explore alternative usage techniques to address this matter. Promising alternatives could be the usage of layered packed geotextile and/or the up-flow layout shown in some rainwater oriented systems, but a

cost-effectiveness assessment is needed to evaluate the real value of integrating such pretreatment in ISF systems.

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REFERENCES

- Almeida, M. C., Butler, D. & Friedler, E. 1999 [At-source domestic wastewater quality](#). *Urban Water* **1**, 49–55.
- Christova Boal, D., Eden, R. E. & McFarlane, S. 1996 [An investigation into greywater reuse for urban residential properties](#). *Desalination* **106**, 391–397.
- Darby, J. L., Tchobanoglous, G., Asri Nor, M. & Maciolek, D. 1996 [Shallow intermittent sand filtration: performance evaluation](#). *The Small Flows Journal* **2**, 3–14.
- Eriksson, E., Auffarth, K., Henze, M. & Ledin, A. 2002 [Characteristics of grey wastewater](#). *Urban Water* **4**, 85–104.
- Friedler, E. 2004 [Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities](#). *Environmental Technology* **25**, 997–1008.
- Friedler, E. & Hadari, M. 2006 [Economic feasibility of on-site greywater reuse in multi-storey buildings](#). *Desalination* **190**, 221–234.
- Funamizu, N., Mizukubo, T., Zavala, M. A. L. & Takakuwa, T. 2002 [Fractioning gray-water in the differentiable onsite-wastewater treatment system](#). In *Proceedings of XXVIII Congreso Interamericano de Ingeniería Sanitaria y Ambiental*, Cancún, México.
- Gajurel, D. R., Li, Z. & Otterpohl, R. 2003 [Investigation on the effectiveness of source control sanitation concepts including pre-treatment with Rottebehaelter](#). *Water Science and Technology* **48**, 111–118.
- Hua, G. F., Zhu, W., Zhao, L. F. & Huang, J. Y. 2010 [Clogging pattern in vertical-flow constructed wetlands: insight from a laboratory study](#). *Journal of Hazardous Materials* **180**, 668–674.
- Huelgas, A. & Funamizu, N. 2010 [Flat-plate submerged membrane bioreactor for the treatment of higher-load greywater](#). *Desalination* **250**, 162–166.
- Keraita, B., Drechsel, P., Konradsen, F. & Vreugdenhil, R. C. 2008 [Potential of simple filters to improve microbial quality of irrigation water used in urban vegetable farming in Ghana](#). *Journal of Environmental Science and Health, Part A: Environmental Science and Engineering & Toxic and Hazardous Substance Control* **43**, 749–755.
- Korkut, E. N. 2003 [Geotextiles as biofilm attachment baffles for wastewater treatment](#). PhD Dissertation. Faculty of Civil Engineering, Drexel University.
- Kotha, K. K. 2001 [Modification of waste water treatment using geotextiles](#). MSc Thesis. Faculty of Civil Engineering, Texas Tech University.
- Langergraber, G., Haberl, R., Laber, J. & Pressl, A. 2003 [Evaluation of substrate clogging processes in vertical flow constructed wetlands](#). *Water Science and Technology* **48**, 25–34.
- Leverenz, H. L., Tchobanoglous, G. & Darby, J. L. 2009 [Clogging in intermittently dosed sand filters used for wastewater treatment](#). *Water Research* **43**, 695–705.
- López-Zavala, M. A., Funamizu, N. & Takakuwa, T. 2002 [Onsite wastewater differentiable treatment system: modelling approach](#). *Water Science and Technology* **46**, 317–324.
- Managaki, S., Kojima, S., Harada, A., Nanada, N., Tanaka, H. & Takada, H. 2005 [Development of analytical method of linear alkylbenzenesulfonates and their degradation intermediates by high performance liquid chromatography equipped with tandem mass spectrometry and its application to major Japanese rivers](#). *Journal of Japan Society on Water Environment* **28**, 621–628.
- Marino, R. J. 2006 [Geotextile filter treatment of combined sewer discharges](#). PhD Dissertation. Faculty of Civil Engineering, Drexel University.
- Marino, R. J., Walton, J., Cheng, S. C. & Martin, J. P. 2006 [Geotextile behavior relevant to filtering low density suspended organic particles](#). *Proceedings from the 8th International Geosynthetics Conference*, Yokohama, Japan, Millpress, Rotterdam, The Netherlands.
- Morel, A. & Diener, S. 2006 [Greywater Management in Low and Middle-Income Countries, Review of Different Treatment Systems for Households or Neighbourhoods](#). Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Dübendorf, Switzerland.
- Mulligan, C. N., Davarpanah, N., Fukue, M. & Inoue, T. 2009 [Filtration of contaminated suspended solids for the treatment of surface water](#). *Chemosphere* **74**, 779–786.
- Mungray, A. K. & Kumar, P. 2009 [Fate of linear alkylbenzene sulfonates in the environment: a review](#). *International Biodeterioration and Biodegradation* **63**, 981–987.
- Reed, S. C., Crites, R. W. & Middlebrooks, E. J. 1995 [Natural Systems for Waste Management and Treatment](#). McGraw-Hill, USA.
- Rodgers, M., Mulqueen, J. & Healy, M. G. 2004 [Surface clogging in an intermittent stratified sand filter](#). *Soil Science Society of America Journal* **68**, 1827–1832.
- Rodgers, M., Walsh, G. & Healy, M. G. 2010 [Different depth intermittent sand filters for laboratory treatment of synthetic wastewater with concentrations close to measured septic tank effluent](#). *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering* **46**, 80–85.
- Rolland, L., Molle, P., Liénard, A., Bouteldja, F. & Grasmick, A. 2009 [Influence of the physical and mechanical characteristics](#)

- of sands on the hydraulic and biological behaviors of sand filters. *Desalination* **248**, 998–1007.
- Roy, C., Auger, R. & Chénier, R. 1998 Use of non woven textile in intermittent filters. *Water Science and Technology* **38**, 159–166.
- Silva Vieira, A., Weeber, M. & Ghisi, E. 2013 Self-cleaning filtration: a novel concept for rainwater harvesting systems. *Resources Conservation and Recycling* **78**, 67–73.
- Spychala, M. & Blazejewski, R. 2003 Sand filter clogging by septic tank effluent. *Water Science and Technology* **48**, 153–159.
- Standard Methods for the Examination of Water and Wastewater* 16th edn 1985 American Public Health Association, American Water Works Association, Water Environment Federation, Washington, DC, USA.
- Standard D4491–99a (Reapproved 2004) *Standard Test Methods for Water Permeability of Geotextiles by Permittivity*. American Society for Testing and Materials, USA.
- Ushijima, K., Ito, K., Ito, R. & Funamizu, N. 2013 Greywater treatment by slanted soil system. *Ecological Engineering* **50**, 62–68.
- Winter, K. J. & Goetz, D. 2003 The impact of sewage composition on the soil clogging phenomena of vertical flow constructed wetlands. *Water Science and Technology* **48**, 9–14.
- Zhao, L., Zhu, W. & Tong, W. 2009 Clogging processes caused by biofilm growth and organic particle accumulation in lab-scale vertical flow constructed wetlands. *Journal of Environmental Sciences (China)* **21**, 750–757.

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