Drawer Compacted Sand Filter: A new and innovative method for on-site greywater treatment

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Abstract

In this paper, results of a new sand filter design were presented. The Drawer Compacted Sand Filter (DCSF) is a modified design for a sand filter in which the sand layer is broken down into several layers, each of which is 10 cm high and placed in a movable drawer separated by a 10 cm space. A lab-scale DCSF was designed and operated for 330 days fed by synthetic greywater. The response of drawer sand filters to variable hydraulic and organic loading rates in terms of BOD₅, COD, TSS, pH, EC and *E.coli* reductions were evaluated. The Hydraulic Loading Rate (HLR) was studied by increasing it stepwise from 72 to 142 L m⁻² day⁻¹ and Organic Loading Rate (OLR) was studied by increasing it from 24 to 30 g BOD₅ m⁻² day⁻¹ while keeping the HLR constant at 142 L m⁻² day⁻¹. Each loading regime was applied for 110 days. Results showed that DCSF was able to remove > 90% of organic matter and Total Suspended Solids for all doses. No significant difference was noticed in terms of overall filter efficiency between different loads for all parameters. Significant reduction in BOD₅ and COD (P<0.05) was noticed after water drained through the third drawer in all tested loads. The paper concludes that DCSF would be appropriate for use in dense urban areas as its footprint is small and is appropriate for a wide range of users because of its convenience and low maintenance requirements.

Key words: synthetic greywater, hydraulic load, organic load, permeability test, drawer compacted sand filter

1. Introduction

Greywater reuse is a sustainable and attractive option to cope with global water shortages. It can save 40-70% of freshwater by reusing it for toilet flushing and irrigation (Jamarah *et al.* 2008). However, studies have revealed clearly that reuse of greywater without any prior-treatment would increase soil salinity and the concentration of Sodium in the soil profile which ultimately cause deterioration of the soil texture (Palmquist *et al.* 2005; Eriksson *et al.* 2002). Studies have also observed that high organic matter and surfactants concentration in raw greywater would cause hydrophobic soil phenomena (Dalahemeh *et al.* 2011).

Based on Dalahmeh *et al.* (2012), Nolde E. (2005), Ghaitidak *et al.* (2013), Abu Ghunmi *et al.* (2011) and Domenech *et al.* (2010), appropriate greywater treatment option should fulfill the following criteria:

- Technically sound: efficient in organic matter, solids and bacterial removal. The treatment must be able to produce water quality which complies with the national or international standards for greywater reuse.
- Reliability: minimal break downs or down-time and does not produce offensive odours.
- Low land footprint: the treatment unit should not require a large land area.
- Minimal installation and maintenance requirements: the treatment should be user-friendly and the maintenance can be accomplished by the user after minimal training.
- Economically-feasible: the treatment should be cost effective. The pay-back period for the treatment unit should be reasonable.
- High potential for scaling up and being used successfully in other communities and countries.
- Environmental tolerance: the unit can work in different weather conditions (i.e. high capacity to tolerate unfavorable environmental conditions) and tolerate the fluctuations in chemical and biological components of greywater.
- Aesthetics: the unit should not be aesthetically problematic and have an acceptable appearance.
- Operational and hygienic safety: all components of the unit should be safe to handle, have low potential for mosquito and fly reproduction, and should not allow any direct human contact with the greywater.
- Socially-accepted: on-site greywater management is a critical issue that not only depends on the technical feasibility of the treatment system, but also depends on human issues such as public perceptions and their participation. The success or failure of any decentralized wastewater management program depends significantly on public involvement, acceptance and feelings of ownership

After critical reviewing for current greywater treatment options, it was found that none of them fully matched these criteria. Some of treatment units were found to be technically efficient but economically unfeasible such as the Membrane Biological Reactor and Rotating

Biological Contactor (Nolde E. 1999; Abdel-Kader A. 2013) while others were efficient but not user-friendly such as the Sequencing Batch Reactor (Kraume *et al.* 2010; Lamine *et al.* 2007) and Electro coagulations (Pidou *et al.* 2008; Lin *et al.* 2005) due to the complexity of controlling the dose of dissolved oxygen and chemical coagulants. Up-flow Anaerobic Sludge Blanket (UASB) units were also tested for greywater and found to be ineffective in organic and pathogens removal (ElMitwally *et al.* 2007; Leal *et al.* 2011). Constructed wetlands have been used widely for greywater, but due to the high footprint required for installation (Dallas *et al.* 2004, Boufaroua *et al.* 2013) it is not seen as an appropriate option in crowded areas.

Intermittent Sand Filters have been used successfully in water and wastewater treatment for more than a century. They consist of a multi-layer series of beds filled with a particular medium, such as washed graded sands, gravel, crushed glass or peat (USEPA guidelines, 2002). The water percolates through the filtering media after being fed onto the upper surface of sand. The distribution of wastewater usually occurs via well-designed manifold lines placed over the upper sand surface. However, aerobic and anaerobic treatment process prevail in Intermittent Sand Filter i.e. a biofilm develops on the sand particles in the upper sand levels which, in turn, absorbs soluble organic matter as it percolates over the sand surface; and anaerobic bacteria develops in the lower sand layers, where the oxygen level is substantially lesser (Torrens *et al.*, 2009; Leverenze *et al.*, 2009, USEPA guidelines, 2002, Metcalf & Eddy, 1991). Maintaining aerobic conditions in the sand filter is considered essential to achieving high treatment efficiency. Clogging problems (Chris *et al.* 2009), a large land footprint, emission of bad odors due to anaerobic conditions in the lower levels of the sand beds and excavation difficulties in some regions of the sand filter are the main problems associated with using the conventional design of intermittent sand filters (table 1).

Table 1: Design parameter for the conventional intermittent sand filter according to USEPA and Metcalf &Eddy

Design parameter	unit	Typical Design values	
		Metcalf & Eddy (1991)	USEPA guidelines (2002)
Filter medium			
Material		Washed durable granular material	Durable, washed sand/gravel with rounded

			grains
Effective size	mm	0.25-0.5	0.25-1.00
Depth	cm	45-90	60-90
Underdrain			
Type		Washed durable gravel or crushed stone	Washed durable gravel or crushed stone
Size	cm	7-9	7-9
Hydraulic loading	L/m ² .day	16-40	40-80
Organic loading	mgBOD ₅ /m ² .d	2441-9765	< 22750
Dosing frequency		Minimum of 30 minutes	12-24 times per day

The aim of this paper is to suggest and optimize a new method of greywater treatment. The Drawer Compacted Sand Filter (DCSF) is a modified design for a sand filter in which the sand layer is broken down into several layers, each of which is 10 cm high and placed in a movable drawer separated by a 10 cm space (figure 1-a). This unit is hypothesized to have three main features:

1. Aerobic treatment in all layers

Drawer Compacted Sand Filter (DCSF) through dividing the sand depth into several layers and allowing air space between layers would ease the diffusion of oxygen between different layers (Rodgers et al. 2004; Leverenze et al. 2009) so that the filter will function with fully aerobic conditions, thus enhancing the aerobic biological treatment of greywater. The choosing of 6 drawers with 10 cm of sand depth in each drawer was based on Metcalf & Eddy (1991) who reported that 60 cm for the whole sand depth is required for a conventional intermittent sand filter.

2. Clogging is no longer serious problem

One of the most prominent problems in conventional sand filtration is what is known as surface clogging (Rodgers *et al.* 2004). Surface clogging is a consequence of a reduction of pore space by suspended and dissolved solids and a biomass buildup on the upper surface of the sand layer (Leverenze *et al.* 2009; Seigrist 1987). In the DCSF unit, it is hypothesizing

that sliding out the drawer, mixing up the media and then keeping the drawer off-line for 24-48 hours would restore the filtering media without stopping the whole system. This maintenance procedure is very convenient compared to the laborious procedure in a conventional intermittent sand filter where the whole filter must be stopped and the first 5-10 cm of a quite big surface area must be skimmed off (Assayed *et al.* 2010; Chris *et al.* 2009).

3. Low land footprint

The surface area of an intermittent sand filter is a function of the flow rate and the hydraulic and organic load of the influent (Abu Ghunmi *et al.* 2008). Based on the Metcalf & Eddy design criteria (Table 1), using a conventional intermittent sand filter for treatment of 200 L/day with 350 mg/l BOD₅ requires 14 m². This high requirement of land is not applicable in dense urban areas, where the houses are crowded together and land is expensive and not always available. Reducing the land required for a conventional intermittent sand filter can be seen an option to cope with crowded areas. However, this will significantly increase the number of clogging events and therefore require laborious maintenance more often. In contrast, the DCSF only requires 1m² of land area, which can be easily found in the backyard or on the rooftop of a house. In DCSF, the sand layers are placed in movable drawers that are easily to be removed and cleaned. Therefore, the DCSF combines convenient and easy maintenance together with a low land footprint.

This research paper seeks to answer two questions:

- How do variations in hydraulic loading affect the performance of a DCSF?
- How do variations in organic loading affect the overall performance of a DCSF?

These questions are answered through the construction and testing of a laboratory based DCSF which was used to treat synthetic greywater over three 110 day periods of operation (330 days as a whole).

2. Material and Methods

2.1 Drawer Compacted Sand Filter Fabrication

A DCSF unit for testing and optimizing the design under laboratory conditions was constructed. A metal framework of 80 cm x 80 cm x 160 cm was designed and fabricated in a metal workshop located in Amman, Jordan. Six PVC drawers with dimensions of 75 cm x 75

cm x 14 cm were obtained and placed on the frame (Figure 1-a&b). Each drawer –except the lowest drawer (number 6) – was perforated with holes of the dimensions and sizes listed in table 2 (Figure 1-b). A distribution manifold (Figure 1-c) was designed and placed over the top drawer and a submersible pump was used to pump synthetic greywater from a small storage tank placed next to the DCSF to this distribution manifold (Figure 1-d). This pump was controlled by digital timer to give 12 doses per day. Table 2 shows all design details of the laboratory DCSF.

Table 2: Design parameters of the laboratory DCSF.

Dimension of each drawer	75 cm x 75 cm x 14 cm
Filter medium:	
Drawer 1	Gravels; effective size 2.5 mm
Drawer 2	Silica; effective size 1.2 mm
Drawer 3	Silica; effective size 0.7 mm
Drawer 4	Silica; effective size 0.7 mm
Drawer 5	Silica; effective size 1.2 mm and 0.7 mm.
Drawer 6	Granular activated carbon
Depth of media	10 cm (for each drawer)
Perforation - for each drawer- except the lowest one- (figure)	Orifice size = 4 mm
	Orifice spacing = 10 cm
	Number of orifices = 36
Distribution system (figure 1-c)	Orifice size = 3 mm
	Orifice spacing= 10 cm
	Lateral spacing=11 cm
Hydraulic loading	<u>Variable</u> L/m ² .day
Organic loading	<u>Variable</u> mgBOD ₅ /m ² .d
Dosing frequency	8 times / day
Dosing tank volume	120 L

Figure 1: (a) Schematic diagram for metal frame (b) Dimensions of each drawer (c) Schematic diagram for distribution manifold (d) laboratory DCSF unit.

2.2 Filter materials

Small gravels and silica sand, of two different sizes, were used as treatment materials. These were obtained from local building materials suppliers. Small gravels were obtained from the Jordan River valley¹, whereas the silica sand was obtained from the *Naqab* area in Jordan². The gravel and sand were sieved according to the methodology suggested by ASTM (1998). The grain size distribution for gravels ranged from (0.15- 4.75) mm, the effective grain size (D_{10}) was 2.6 mm. The grain size distribution for the two silica samples ranged from 0.4-2.36 and 0.15-2.36 and the effective size were 1.2 mm and 0.7 mm, respectively. Silica of 1.2 mm effective size was given the code S1 and the other silica sample was given code S2. Each drawer was lined with 2 mm fiber mesh to prevent treatment material from slipping out through the holes in the drawers. Small gravels were placed in drawer number 1, S1 was placed in drawer 2, and S2 was put in drawers 3 and 4. Drawer number 5 was filled with 5 cm of S1 and 5 cm with S2 and 5 cm of granular activated carbon ($D_{10}= 2$ mm) was used in drawer number 6.

2.3 Synthetic greywater

Synthetic greywater was prepared so that the DCSF could be tested and optimized using greywater of consistent quality. The synthetic greywater was prepared by mixing 0.16g of dishwashing solution (Golden, manufactured in Jordan), 0.16g hair shampoo (Sunsilk brand), 0.16g washing powder (Persil brand), 0.1g of maize oil, 4-5% (v/v) of raw wastewater from the inlet pipe of *Abu Nsair* domestic wastewater treatment plant in North Amman to inoculate it with an indigenous bacterial flora and 1 L of tap water. *Abu Nsair* domestic wastewater treatment plant serves the upstream residential houses with average flow rate of 2600 m³/day and average BOD₅ 552 mg/l (Ammary, 2007). This mixture gives a composition similar to that of natural greywater which excludes kitchen water, as reported in Eriksson *et al.* (2002) and Winword *et al.* (2008). An electronic mixer with 90 rpm was used continuously to obtain a homogeneous solution. The synthetic greywater was prepared on daily basis and stored at room temperature.

2.4 Experimental set-up

The DCSF was operated for 330 days. For the first period of 110 days the unit was running under a flow rate of 40 L/day and organic matter content of 160 mg/l BOD₅ (**hydraulic load 72 L.m⁻².d⁻¹ and organic load of 12 g BOD₅.m⁻² d⁻¹**). For the second 110 day test period the

¹ *Manaseer* crusher company.

² The Middle East company for Silica.

unit was running with a flow rate of 80 L/day and organic matter content of 160 mg/l BOD₅ (**hydraulic load 142 L.m⁻².d⁻¹ and organic load of 23 g BOD₅.m⁻² d⁻¹**), while for the final test period the unit was running with a flow rate of 80 L/day and organic matter content of 210 mg/l BOD₅ (**hydraulic load 142 L.m⁻².d⁻¹ and organic load of 30 g BOD₅.m⁻² d⁻¹**). The hydraulic behavior of the materials in drawers 1, 2, 3 and 4 were studied using soil permeability tests at the beginning and end of each load. It is worth mentioning here that after each experiment of 110 days, a new batch of treatment materials were installed in the drawers. Table (3) describes the operation variables for each load.

Table 3: The values of flow rate, hydraulic and organic loads in the three operation periods

Exp. number	Period Days	Flow rate L/day	BOD ₅ concentration mg/l	Hydraulic load L.m ⁻² .d ⁻¹	Organic load g BOD ₅ .m ⁻² d ⁻¹	No. of doses per day	Discharge per dose (L)
1	110	40	160	72	12	8	5
2	110	80	160	142	23	8	10
3	110	80	210	142	30	8	10

2.5 Soil hydraulic conductivity

Hydraulic conductivity is a measure of how easily water moves through the soil profile (Beach *et al.* 2005). It is a function of pressure, texture, the length of the soil column and the area through which the water moves. It was calculated by using equation 1:

$$K = \frac{V.L}{T.H.A} \quad (1)$$

Where K is the conductivity (cm/hr), V is the amount of water collected in the designated time, T is the time needed to collect the water, H is the height of water from the top of the core, L is the length of the soil core and A is the area of soil core.

2.6 Sampling and Analysis

Samples of influent and effluent greywater from the different loads were collected at regular intervals during the experimental period and analyzed for BOD₅, COD, TSS, *E.coli*, pH and EC. The tests were performed according to standard methods presented in table 4.

Table 4: Parameters analyzed, frequency of analysis and methods

Parameter	Frequency of testing for each load	Method	Reference no. in Standard Method
BOD ₅	Weekly	5-Day BOD Test	5210 A
COD	Monthly	Open Reflux, Titrimetric Method	5220 C
TSS	Weekly	Total Solids Dried At 103–105°C	4500-H ⁺
pH	Weekly – biweekly	pH Method	2520
EC	Weekly – biweekly	Electrical Conductivity Method	2540
<i>E.coli</i>	Twice during each experiment	Multiple-tube fermentation technique for members of the Coliforms Groups.	9221 F

The efficiency of reduction for the various parameters analyzed was calculated using equation. 2:

$$E = \frac{C_{out} - C_{in}}{C_{out}} \times 100\% \quad (2)$$

Where E is the efficiency (percent), *C_{in}* the influent concentration (milligram per liter) and *C_{out}* the effluent concentration (milligram per liter).

2.7 Mechanism of treatment in DCSF

The greywater was pumped using a submersible pump and transferred via well-designed manifold lines placed over the upper surface of the sand layer of drawer number 1. The water then percolates through the filtering media placed in drawer number 1 to drawer 2 and passively passes through the filtering media in all drawers. The dosing frequency is controlled by using a digital timer to supply 8 doses per day (dose/3 hours). The water, which comes out from the last drawer, is accumulated to be sampled and tested.

3. Results

3.1 Feed characteristics

For experiments 1 and 2, the synthetic greywater contained BOD₅ (n=13) 160 ±80 mg/l, TSS (n=13) 66 ±3, COD (n= 6) 304 ±66. The proportion of raw wastewater inoculums was an estimated 4% to produce 10⁴-10⁵ CFU/100 ml of *E.coli*, which has been reported for the greywater in Jordan (Halalshe *et al.* 2007). For experiment number 3, the synthetic greywater contained BOD₅ (n= 10) 210 ±70, TSS (n=10) 169 ±51, COD (n =6) 483 ±115. The proportion of raw wastewater used for experiment number 3 was 5%. Though the synthetic greywater was prepared on daily basis, fluctuation in organic and solids content was clearly noticed. This was attributed according to Dalahmeh *et al.* (2012) to fluctuation in water and ambient temperatures, quality of raw wastewater inoculums and mixing time. The BOD₅/COD ratio ranged from 0.43-0.52 which indicates that about half of organic load is bioavailable for degradation. This ratio is also similar to what has been reported by Halalsheh *et al.* (2007) and Assayed *et al.* (2010) for greywater in Jordan.

3.2 Filter performance

3.2.1 Experiment number 1

In all doses, Electrical Conductivity (EC) increased slightly in the treated greywater, whereas the pH values remained very similar to that of the influent. No significant variations were noticed in pH and EC between several drawers (Table 5). Calculating the efficiency for each drawer showed that 97%, 94%, and 97% of BOD₅, COD, and TSS removal was obtained after the water passed through the first 3 drawers, while no significant reduction was noticed after passing through other drawers (Figure 2-a, b &c). The faecal indicator bacteria i.e. *E.coli*, was reduced by 3 logs leaving 2.2 x 10³ CFU/100 ml of *E.coli* in the treated greywater.

Table 5: Influent characteristics and treatment performance (mean ± standard deviation) of the different drawers at HL= 72 L.m⁻².d⁻¹ and OL = 12 g BOD₅ m⁻² d⁻¹

Parameter	Concentration in influent ^a	Concentration reduction in effluent ^b					
		Drawer 1	Drawer 2	Drawer 3	Drawer 4	Drawer 5	Drawer 6
pH (SD)	8.00 ±0.6	7.65±0.25	7.86±0.38	7.79±0.21	7.76±0.27	8.00 ^c	7.8±0.13

EC ($\mu\text{S cm}^{-2}$)	1419 $\pm$ 260	1703 $\pm$ 413	1605 $\pm$ 386	1775 $\pm$ 445	1353 $\pm$ 26	1389	1556 $\pm$ 300
BOD ₅	160 $\pm$ 49	109	22 $\pm$ 7.0	3.4 $\pm$ 1.4	5.0 $\pm$ 4.0	2.7 $\pm$ 2.7	1.8 $\pm$ 1.4
COD	304 $\pm$ 66	223	44 $\pm$ 15	18 $\pm$ 2	19 $\pm$ 5	15 $\pm$ 4	7 $\pm$ 2
TSS	104 $\pm$ 37	55	13 $\pm$ 8.0	3.5 $\pm$ 2.0	5.5 $\pm$ 2.6	3.3 $\pm$ 1.7	2.5 $\pm$ 2.0
<i>E.coli</i> (CFU/100 ml)	4.3E+06	NA	NA	NA	NA	NA	2.12E+03

^a All units are in milligram per liter unless otherwise stated.

^b Percentage reduction is not valid for pH and EC. Concentrations measured in the effluent are shown in the table.

3.2.2 Experiment number 2

Likewise in the first experiment, no significant variations were noticed in pH and EC between influent and effluent between the different drawers; pH ranged from (7.6-7.85) and EC values fluctuated between (1300 – 1390 $\mu\text{S cm}^{-1}$) for all doses (Table 6). About 91% of TSS removal was achieved after passing through drawer number 3 (Figure 2-b). However, 90% of BOD₅ and COD removal was obtained only after the water had passed through all the drawers i.e. drawers 1- 6 (Figure 2- a & c). *E.coli* also reduced 3 logs after the water had passed through all drawers leaving 3.4×10^3 in the treated greywater.

Table 6: Influent characteristics and treatment performance (mean $\pm$ standard deviation) of the different drawers at HL= 142 L.m⁻².d⁻¹ and OL = 23 g BOD₅ m⁻² d⁻¹

Parameter	Concentration in influent	Concentration reduction in effluent					
		Drawer 1	Drawer 2	Drawer 3	Drawer 4	Drawer 5	Drawer 6
pH (SD)	7.70 $\pm$ 0.035	7.56 $\pm$ 0.045	7.75 $\pm$ 0.15	7.80 $\pm$ 0.10	7.90 $\pm$ 0.27	7.9 $\pm$ 0.235	7.84 $\pm$ 0.005
EC ($\mu\text{S cm}^{-2}$)	1294 $\pm$ 20	1295 $\pm$ 75	1324 $\pm$ 30	1296 $\pm$ 75	1350 $\pm$ 26	1348 $\pm$ 43	1364 $\pm$ 27
BOD ₅	169 $\pm$ 61	72 $\pm$ 29	34 $\pm$ 18	26 $\pm$ 24	29 $\pm$ 24	11 $\pm$ 9.0	8.0 $\pm$ 4.0
COD	333 $\pm$ 1.0	146 $\pm$ 10	128 $\pm$ 38	89 $\pm$ 27	66 $\pm$ 23	50 $\pm$ 22	30 $\pm$ 17
TSS	77 $\pm$ 3.0	19 $\pm$ 8.0	11 $\pm$ 3.0	7.2 $\pm$ 4.3	3.75 $\pm$ 1.25	5.0 $\pm$ 2.90	4.3 $\pm$ 2.71
<i>E.coli</i> (CFU/100 ml)	4.3E+06	NA	NA	NA	NA	NA	3.4E+03

3.2.3 Experiment number 3

No significant variations were noticed between influent and effluent in pH and EC as a result of the water passing through the drawers (Table 7). A 93% reduction of BOD₅ and a 94% reduction of COD were achieved after the water had passed through the third drawer (Figure 2- a & c). Likewise in the previous experiments, a 3 logs reduction in *E.coli* was achieved when the water passed from drawer number 6.

Table 7: Influent characteristics and treatment performance (mean $\pm$ standard deviation) of the different drawers at HL= 142 L.m⁻².d⁻¹ and OL = 30 g BOD₅ m⁻² d⁻¹

Parameter	Concentration in influent	Concentration reduction in effluent					
		Drawer 1	Drawer 2	Drawer 3	Drawer 4	Drawer 5	Drawer 6
pH (SD)	7.73 $\pm$ 0.11	8.01 $\pm$ 0.27	7.4 $\pm$ 0.01	7.62 $\pm$ 0.16	7.65 $\pm$ 0.15	7.74 $\pm$ 0.04	7.73 $\pm$ 0.26
EC (μ S cm ⁻²)	1372 $\pm$ 116	1494 $\pm$ 159	1495 $\pm$ 140	1411 $\pm$ 179	1532 $\pm$ 114	1534 $\pm$ 154	1489 $\pm$ 178
BOD ₅	208 $\pm$ 70	77 $\pm$ 34	36 $\pm$ 9	14 $\pm$ 2	7 $\pm$ 2	4.3 $\pm$ 2.5	4.8 $\pm$ 1.1
COD	438 $\pm$ 115	154 $\pm$ 43	46 $\pm$ 10	29 $\pm$ 6	13	4	NA
TSS	169 $\pm$ 51	54 $\pm$ 18	16 $\pm$ 9	7 $\pm$ 4.5	1.5 $\pm$ 1.5	2.8 $\pm$ 2.7	8 $\pm$ 3
<i>E.coli</i> (CFU/100 ml)	6.50E+05	NA	NA	NA	NA	NA	8.0E+02

(a)

(b)

(c)

Figure 2: (a) BOD% removal for the three experiments (b) TSS % removal for the three experiments (c) COD % removal for the three experiments.

3.3 Sand hydraulic conductivity (permeability test)

Hydraulic conductivity was measured for the sand in drawers 1, 2, 3 and 4. The test was conducted two times i.e. at the beginning and at the end of each experiment. As shown in figures 3, 4 & 5 the ability of sand to convey water decreases in time due to biofilm growth and solids build up on the upper surface which leading to a decrease in free pore spaces.

There was no clear trend in hydraulic conductivity fluctuation between the three experiments. The slight difference in hydraulic conductivity between drawers in the three experiments can be attributed to the changes in greywater contents in terms of BOD₅ and TSS concentration. Using chemical tracers is recommended for further studies to investigate the hydraulic behaviors of sand in drawers.

Figure 3: Variation in soil hydraulic conductivity before and after greywater application for the experiment no. 1.

Figure 4: Variation in soil hydraulic conductivity before and after greywater application for the experiment no. 2.

Figure 5: Variation in soil hydraulic conductivity before and after greywater application for the experiment no. 3.

4. Discussion

Sand filtration is probably the most widely used method for water treatment, particularly for greywater, but the problems of clogging and high land footprint, in addition to anaerobic conditions in the lower parts of the filter bed are considered prominent challenges for this treatment method. In the present study, a new design of sand filtration was suggested and tested under laboratory conditions. The new design of sand filter was based on the idea of placing filtering media in movable drawers thus enabling oxygen movement and easing maintenance procedures without sacrificing treatment efficiency.

4.1 Filter performance

4.1.1 Variations of hydraulic loading vs. filter performance

Two different hydraulic loads (Experiments 1 and 2) were used to find out the impacts of various hydraulic loads on the overall filter performance while BOD_5 concentration was kept constant for both experiments. However, given that organic load is directly correlated with hydraulic load (Abu ghunmi *et al.* 2008), the organic load for the second experiment was essentially doubled. Nonetheless, the rest of design parameters shown in table 2 were kept constant during testing the two loads. Each load was tested for 110 days and fed by synthetic greywater on a daily bases.

The ANOVA test was carried out to find out the statistically significant differences between different variables in the two experiments (Table 8 & 9). No significant differences in filter

performance were noticed in either experiment ($P>0.05$). More than 90%, of BOD₅, 95% of COD and 95% of TSS removal were achieved in the two experiments (i.e. 70 L.m⁻².day⁻¹ and 142 L.m⁻².day⁻¹) when water was drained from drawer 1 to drawer 6, leaving less than 5 mg/l of BOD₅; 10mg/l of COD and 5 mg/l of TSS in the effluent. This was in agreement with sand filter performance for greywater treatment in different areas using a conventional design (Table 1). Assayed (2010) reported 90%, 95% and 95% of BOD₅, COD and TSS removal from greywater when using intermittent sand filters. Also, Tyagi *et al.* (2009) reported 85% of BOD₅ and 77% of COD and 89% removal of TSS when using sand filtration for treatment of UASB effluent.

For both experiments 1 and 2, significant pollutant removal was noticed after the water passed from the drawers 1, 2 and 3 ($P<0.05$) (Table 8 & 9). More than 85% of BOD₅ and TSS removal was achieved after the water drained from drawer number 3. This finding was in agreement with what was concluded by Rodgers *et al.* 2004 who stated that the significant treatment of sand filtration occurs in the uppermost surface of the sand layers.

Log₁₀ removals of indicator bacteria i.e. *E.coli* with the two different hydraulic loads are slightly different to those reported previously for greywater treatment. Three logs of *E.coli* reduction were achieved for both hydraulic loads tested. This was not the case for Torrens *et al.* (2009) and Stevik *et al.* (1999) who found *E.coli* reduction is inversely correlated with hydraulic loads and directly related with the media depth. However, the constant reduction of *E.coli* in all loads might be attributed to the small dose size (5 – 10L) which according to Stevik *et al.* (1999) is an important factor for bacterial removal rather than the daily dosing rate. Further investigation is required to find out more on the *E.coli* and other pathogens removal in the drawer sand filter.

4.1.2 Variations of organic loading vs. filter performance

The drawer compacted filter was subject to two different organic loads i.e. 20 g BOD₅.m⁻².d⁻¹ and 30 g BOD₅.m⁻².d⁻¹. The hydraulic load was kept at 142 L.m⁻².d⁻¹ and each experiment lasted 110 days.

Likewise in the previous experiments, no significant variations in pollutant reduction occurred when testing the two loads ($P>0.05$). The reduction in BOD₅, COD, and TSS was more than 90% for two loads after water emerged from the filter. However, more than 85% of pollutants were removed after the water passed from drawer number three ($P<0.05$). As

noticed in the previous experiments, three logs in E.coli reduction were achieved when the water passed through all drawers regardless of the variations in organic loads, which was expected, as the microbial load was not significantly changed across various organic and hydraulic loads.

Table 8: The BOD₅ correlations between drawers for all experiments.

		Correlations						
		Inf.	D1	D2	D3	D4	D5	Eff.
Inf.	Pearson Correlation	1	.366	.328	.319	.203	.083	.352
	Sig. (P value)		.298	.232	.312	.548	.798	.198
	N	17	10	15	12	11	12	15
D1	Pearson Correlation	.366	1	.234	.492	.390	.356	.227
	Sig. (P value)	.298		.514	.149	.299	.347	.528
	N	10	10	10	10	9	9	10
D2	Pearson Correlation	.328	.234	1	.763**	.663*	.795**	.759**
	Sig. (P value)	.232	.514		.004	.026	.002	.002
	N	15	10	15	12	11	12	14
D3	Pearson Correlation	.319	.492	.763**	1	.942**	.875**	.911**
	Sig. (P value)	.312	.149	.004		.000	.000	.000
	N	12	10	12	12	11	11	12
D4	Pearson Correlation	.203	.390	.663*	.942**	1	.796**	.942**
	Sig. (P value)	.548	.299	.026	.000		.003	.000
	N	11	9	11	11	11	11	11
D5	Pearson Correlation	.083	.356	.795**	.875**	.796**	1	.781**
	Sig. (P value)	.798	.347	.002	.000	.003		.005
	N	12	9	12	11	11	12	11
Eff	Pearson Correlation	.352	.227	.759**	.911**	.942**	.781**	1
	Sig. (P value)	.198	.528	.002	.000	.000	.005	
	N	15	10	14	12	11	11	16

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level.

Table 9: COD correlations between drawers for all experiments.

		Correlations						
		Inf.	D1	D2	D3	D4	D5	Eff.
Inf.	Pearson Correlation	1	-.151	.187	.005	.231	.176	.042
	Sig. (P value)		.746	.688	.991	.709	.739	.921
	N	10	7	7	7	5	6	8
D1	Pearson Correlation	-.151	1	-.617	-.204	-.635	-.335	-.613
	Sig. (P value)	.746		.267	.698	.365	.665	.272
	N	7	7	5	6	4	4	5
D2	Pearson Correlation	.187	-.617	1	.880**	.921**	.901*	.903**
	Sig. (P value)	.688	.267		.009	.009	.014	.002
	N	7	5	8	7	6	6	8
D3	Pearson Correlation	.005	-.204	.880**	1	.952**	.760	.965**
	Sig. (P value)	.991	.698	.009		.003	.136	.000
	N	7	6	7	8	6	5	7

D4	Pearson Correlation	.231	-.635	.921**	.952**	1	.905*	.991**
	Sig. (P value)	.709	.365	.009	.003		.035	.000
	N	5	4	6	6	6	5	6
D5	Pearson Correlation	.176	-.335	.901*	.760	.905*	1	.853*
	Sig. (P value)	.739	.665	.014	.136	.035		.031
	N	6	4	6	5	5	6	6
Eff	Pearson Correlation	.042	-.613	.903**	.965**	.991**	.853*	1
	Sig. (P value)	.921	.272	.002	.000	.000	.031	
	N	8	5	8	7	6	6	10

** Correlation is significant at the 0.01 level.
* Correlation is significant at the 0.05 level.

4.1.3 Filtered vs. Total BOD₅

Filtered BOD₅ (fBOD₅) refers to the amount of dissolved food available for microorganisms in the water being treated (Metcalf & Eddy, 1991). It is tested in the water that has been filtered in the standard total suspended solids test. Subtraction of filtered BOD₅ from total BOD₅ (tBOD₅) will give suspended BOD₅ (sBOD₅). Table 10 shows the fBOD₅/tBOD₅ ratio for all experiments (Standard method, 1995).

Table 10: fBOD₅/tBOD₅ ratio for the influent synthetic greywater for all loads.

Experiment number	fBOD ₅ mg/l	tBOD ₅ mg/l	fBOD ₅ /tBOD ₅	Notes
1	69	125	0.56	44% of organic compounds are suspended and the rest are soluble.
2	63	169	0.37	63% of organic compounds are suspended and the rest are soluble.
3	69	207	0.33	67% of organic compounds are suspended and the rest are soluble.

Looking at table (10) in conjunction with Figure (3- a, b & c), one can conclude that drawer number one had been working more effectively during the experiments 2 and 3, than it was working during experiment 1, i.e. 60% of BOD₅ removal occurred in this drawer during experiments 2 & 3, whereas about 30% of BOD₅ removal was achieved by the same drawer in experiment 1, which is essentially related to fBOD₅/tBOD₅ ratio. This is, however, quite similar to what was demonstrated by Dalahmeh *et al.* 2011; Assayed *et al.* 2010; Halalshe *et al.* 2007, who found that when wastewater has high SBOD₅ then physical pre-treatment is required to improve the quality of greywater being treated.

4.2 Sand hydraulic conductivity (permeability)

Sand hydraulic conductivity is closely related to the organic and hydraulic loading being used (Roadgers *et al.* 2004, Beach *et al.* 2006). Sand hydraulic conductivity dramatically decreased when water goes further through the drawers. This was noticed in all experiments at all doses. In the present filter design, restoring some of the sand hydraulic conductivity has been easily achieved by sliding out the drawer and leaving it to rest for 24-48 hours after mixing up the media inside. This implies that the filter at these times would have been working without one of the drawer which might have impacts on the overall performance, which was not tackled during this research. However, spare drawers could be added to the system and used alternatively with clogged drawers if needed. This was in consistent with Torrens *et al.* 2009, Leverenze *et al.* 2009 who found that giving rest periods for 3-7 days could be efficient to improve permeability and restore some of hydraulic conductivity of sand.

4.3 General discussion

The results of the laboratory trials showed that DCSF was suitable for greywater treatment with high efficiency and minimal maintenance requirements. The oxidation of organic matter for all tested doses (represented by BOD₅ and COD) was found to be more than 90%, assuring the availability of oxygen for organic matter degradation. The majority of organic matter oxidation ($\approx 90\%$) in all dose trials was achieved after water passed through the drawer number three. This was consistent with Leverenze *et al.* 2009, Torrens *et al.* 2009 and Rodgers *et al.* 2004 who found that the aerobic oxidation of organic matter in sand filtration mainly occurs on the upper surface of sand where oxygen is available in enough quantities to oxidize most of organic matters. In DCSF, the sand is placed in movable drawers with only 10 cm depth and is exposed to air from above and below; this facilitated oxygen movement within and between the sand layers, thus oxidation occurs in all layers with no chance of oxygen depletion. This compares to conventional intermittent sand filters where 60 to 90cm is bulked in one single bed, either under or above ground, and thus causes anaerobic conditions in the lower parts which in most cases leads to unpleasant odors and poor performance (Assayed *et al.* 2010).

DCSF was tested and operated under high hydraulic and organic load conditions. According to Metcalf & Eddy (1991), the maximum hydraulic and organic load for an intermittent sand filter is $40\text{L}/\text{m}^2\cdot\text{d}^{-1}$ and $9\text{gBOD}_5/\text{m}^2\cdot\text{d}^{-1}$, respectively. The DCSF was tested in this research

with a hydraulic load of $142 \text{ L/m}^2 \cdot \text{d}^{-1}$ and organic load of $30 \text{ gBOD}_5/\text{m}^2 \cdot \text{d}^{-1}$, thus exceeding the Metcalf & Eddy design guidelines by 3.5 times for the hydraulic load and 3.3 times for the organic load. This high hydraulic and organic load, according to Leverenz *et al.* (2009), would substantially increase the clogging incidences and the overall filter failure. However, clogging was not experienced in the DCSF with any of the doses regimes. This was attributed to the concept of movable drawers, which allowed the user to slide out the sand layer and mix up the media then leave it to rest for 24-48 hours. This was sufficient to restore the sand media and delay the clogging occurrence and was consistent with Rodgers *et al.* 2004, Torrens *et al.* 2009 and Leverenze *et al.* 2009

Three logs of *E.coli* reduction were achieved for all hydraulic and organic loads tested. This exceeded the removal of faecal coliforms reported by Jenkins *et al.* (2011) who applied river water augmented with raw wastewater onto two fine sand size layers ($D_{10} = 0.17$ and 0.52 mm) placed under three hydraulic heads (10, 20, and 30 cm). The maximum faecal coliforms removal as reported in the Jenkins *et al.* (2011) experiment was 1.4 logs. However, effective sand size, pausing time and increase residence time emerged as highly beneficial for improving the removal of pathogens from water when using sand filtration (Stevik *et al.* 1999; Bauer *et al.* 2011; Cuyk *et al.* 2001). The satisfactory performance in terms of *E.coli* removal by using DCSF can be understood by looking at the findings of Stevik *et al.* (1999) who observed that 99% of *E.coli* removal takes place in the upper 10 cm of sand media, which according to Vavai (2010) is attributed to biofilm growth and solids build up on the upper surface, leading to a decrease in the free pore spaces, thus increasing the capability of straining and trapping the bacteria. Given the good aeration in all drawers at all levels in the DCSF, biofilm and solids accumulation occurs on the upper surface for all drawers (as shown in the permeability test); therefore, DCSF, through the concept of drawers, provides several subsequent barriers for bacteria.

Fully aerobic conditions seemed to be dominant in DCSF, as water flowed downward from one drawer to another and did not accumulate in the lower parts of the sand media. Although the dominance of aerobic conditions was not investigated by the laboratory analyses (i.e. measuring the dissolved oxygen, levels of nitrification or concentration of H_2S), no bad smells were noticed emerging from the unit during the whole period of operation. This was in contrast to what has been reported for conventional intermittent sand filters where emission of bad smells have been one of the main shortcomings identified (Assayed *et al.* 2010).

5. Conclusions

The DCSF was found able to overcome the problems commonly associated with conventional sand filter design, such as clogging and the need for a large land area to house the filter.

Several conclusions can be drawn from this research:

1. No significant difference was noticed in terms of overall filter efficiency between different loads for all parameters. 90-95% of organic matter removal was achieved for all doses at all loads. A significant reduction in BOD₅ and COD ($P < 0.05$) was noticed after water drained through the third drawer in all tested loads.
2. The drawer filter with a minimum 3 drawers and 75cm*75cm*14cm dimension for each drawer is sufficient for efficiently treating up to 80 L/day and ≤ 210 mg/l of BOD₅ with minimal maintenance requirements. Sliding the drawer out and mixing up the media inside is sufficient to restore the filtering media and delay clogging occurrence.
3. Intermittent sand filters could be designed in a rather different way to what is mentioned in Metcalf & Eddy and EPA guidelines. The essence of the new suggested design is placing filtering media in movable drawers rather than bulking out the media in underground excavation.
4. This new compact design would allow sand filters to be used in locations where space is at a premium, such as dense urban areas, and the low maintenance requirements mean that a wide range of users could easily operate a DCSF.
5. This research article provides preliminary perspective on DCSF. Further investigation is required to cover several aspects of this new filter design such as: responses to different hydraulic and organic loads, the performance when using different media with different sizes, using different drawers' dimensions, the impacts of this new design on the mechanism of bacterial removal, responses to different media depth and finding out the mechanism of water movement through each drawer by using chemical tracers.

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