IJCPS Vol. 4, No. 1, Jan-Feb 2015
www.ijcps.org
ISSN:2319-6602
International Journal of Chemical and Physical Sciences

Greywater Treatment in Pilot Plant and it's Reuse

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Abstract

The paper presents a study of a pilot plant treating light grey water for seven flats. The pilot plant combines biological treatment (RBC) with physicochemical treatment (sand filtration and disinfection). The pilot plant produced effluent of excellent quality, meeting the urban reuse quality regulations, and was very efficient in TSS turbidity and BOD removal: 82%, 98% and 96%, respectively. COD removal was somewhat lower (70–75%) indicating that the grey water may contain slowly-biodegradable organics. The RBC (attached growth biological system) was able to retain most of the solids as a result of bioflocculation; further it was proven to have very stable and reliable performance. Faecal coliforms and heterotrophic reductions were very high (100% and 99.99%, respectively) producing effluent that also met drinking water standards. The combination of low organic matter, nutrients and microbial indicators reduces the regrowth and fouling potentials in the reuse system, thus ensuring safe reuse of the treated grey water for toilet flushing.

Keywords - Biological treatment; grey water reuse; on-site; pilot plant; quality; RBC; sand filtration

Introduction

Due to increasing water scarcity in many regions around the world new water sources are developed, namely: seawater desalination and exploitation of more distant (surface water) and deeper (groundwater) sources. Not only that the cost of utilizing these sources is due to be higher than the cost of 'conventional' water sources, but they have increasing negative environmental effects. For example: seawater desalination results in increased CO2 and other pollutants emission to the atmosphere and causes disturbance to the adjacent marine environment. An alternative to the above is to enhance utilization efficiency of water, to promote water saving measures and to reuse water as an alternative resource. These measures can be implemented either in conjunction with, or prior to, the development of the new 'non-conventional' resources. On-site grey water reuse within the urban sector may have a significant role in reducing the overall urban water consumption, leading towards more sustainable urban water utilization. Domestic in-house water demand in industrialized countries consists of 30–60% of the urban water demand and ranges between 100 to 150 l/c/d (litre/capita/day), of which 60–70% is transformed into grey water, while most of the rest is consumed for toilet flushing. Grey water reuse for toilet flushing (if implemented) can reduce the in-house net water consumption by 40–60 l/c/d, and urban water demand by up to 10–25%, which is a significant reduction of the urban water demand (additional reuse for garden irrigation may further reduce the overall demand). For example, Friedler and Galil (2003a) showed that in 20 years (2023), grey water reuse for domestic toilet flushing in the urban sector could save about 50 MCM/y in Israel (projected population 10 £ 106 people) – a significant saving of about 5% of the total future urban water demand and equalling the capacity of a medium size seawater desalination plant. The estimation performed by the authors was based on about 30% penetration ratio, i.e. percentage of houses having grey water reuse units installed, and argued to be realistic and even rather conservative. Although conceived to be ‘clean’, grey water may be highly polluted, with COD concentrations of up to several hundred mg/l, and faecal coliforms of about 104–106 CFU/100 ml (Almeida et al., 1999; Diaper et al., 2001; Dixon et al., 1999; Rose et al., 1991). Further, the quantity and quality of domestic grey water presents high variability in discharge volumes and pollutant loads, both between various household appliances and between different uses of the same appliance (Friedler and Butler, 1996). Thus, grey water may pose health risks and cause negative aesthetic effects, especially in warm climates where higher ambient temperatures may increase organic matter degradation and enhance pathogen regrowth. As a result of the above, direct on-site reuse requires highly efficient and reliable conveyance, storage and treatment systems. Various treatment processes are suggested in the literature, but since on-site grey water recycling is a relatively new practice, only a few off-the-shelf systems are commercially available, and even less were tested on full scale for long time periods. Most treatment units reported in the literature (and advertised commercially) are based on physical processes (filtration þ disinfection), while the more current ones incorporate biological treatment as well (Birks et al., 2003; Diaper et al., 2001; Hills et al., 2001; Jefferson et al., 2001; Ogoshi et al., 2001; Shin et al., 1998; UK Environment Agency, 2000; Wheatley and Surendran, 2003). In rural areas, where much land is usually available, ‘natural’ treatment systems seem to be appropriate. In urban areas–where the highest water saving potential lies–due to space constraints, the treatment technologies selected should have a small footprint. The research carried out in the Technion comprises four main stages: assessment of the national realistic water saving potential (in Israel); characterization of various domestic grey water sources; pilot scale study of on-site grey water treatment and reuse and techno economical feasibility study. The first two stages were completed during the first year of the research and reported elsewhere (Friedler et al., 2002a,b; Friedler and Galil, 2003a,b).

The water saving assessment proved that on-site domestic grey water reuse has a significant water saving potential on a national level, reaching some 50 MCM/y in 20 years, time. This can be achieved even with moderate penetration ratio (see above).

The characterization study included all domestic grey water generating appliances. The study signaled the washing machine, kitchen sink and dishwasher as major contributors of most pollutants. Based on these results, on the daily grey water discharge and on the domestic daily water demand for toilet flushing, it is recommended (when possible) to treat and reuse only light grey water, i.e. grey water originating from the bath, shower and washbasin. Following the above findings, a pilot plant treating light grey water (which incorporates biological treatment) was constructed in the Technion campus, and is being operated for a long time period. This paper concentrates on the examination of the long-term performance of each treatment unit of the pilot plant and its contribution to the overall removal of pollutants. Further, the paper discusses the implications on the applicability of grey water reuse for toilet flushing.

Material & Methods

The pilot plant

An eight storey high building (six flats per storey) within the Technion campus, which accommodates married students (some with young children) was selected as the study site. In order to supply raw grey water to the pilot plant the plumbing of seven flats in this building was retrofitted separating the light grey water stream in each flat from the main wastewater stream and conveying it gravitationally to pilot plant which was constructed in the basement of the building. The treatment system consists of several units **(Figure 1)**

Fine screen (FS) – Removes gross solids, hair, etc. 1mm square shaped mesh.

Equalisation basin (EB) – Regulates between raw grey water inflows and outflows to the treatment system, and equalises the quality and temperature of the raw grey water. The volume of the EB is 330 l, with a maximum residence time of 10 hours (the EB feeds other systems too).

Rotating biological contactor (RBC) – Attached growth biological treatment unit of low energy consumption. The RBC consists of two basins in series. The volume of each basin is 15 l, it is equipped with a horizontal axis which carries circular discs of 0.22m diameter and total surface area of 1m2. The flow is perpendicular to the axis. Rotational speed of the discs is 13 rpm which corresponds to a linear velocity of 9 m/min (comparable with rotational speed of 1–1.5 rpm in a full scale RBC of 2–3m diameter). Feed discharge is 7.5 l/hr, thus the mean residence time (MRT) in each basin is 2 hours.

Sedimentation basin (SB) – The sedimentation basin is attached to the second RBC. Its volume is 7.5 l, thus its MRT is 1 hour. Sludge is removed manually (in order to study its production rate).

Pre-filtration storage tank (PFST) – The storage tank is needed to regulate between SB effluent flow (continuous) and the SF (see below) flow (intermittent). The maximum residence time is about 2.2 hours. The tank is covered to eliminate flies and mosquitoes problems.

Sand filtration (SF) – Gravity filter of 10 cm diameter and 70 cm media depth. The medium consists of quartz sand size 0 (d10 0.63 mm, d60 0.78 mm, uniformity coefficient 1.24, porosity 0.36). The filter medium is supported by 5 cm of gravel (diameter 2.2 mm). The filter is operated intermittently 11 times a day, 15 minutes each time. The filter discharge is 65 l/h. which corresponds to filtration velocity (hydraulic load) of 8.33 m/h. The filter is backwashed once a week (once every 77 filtration cycles – 1,260 l filtered).

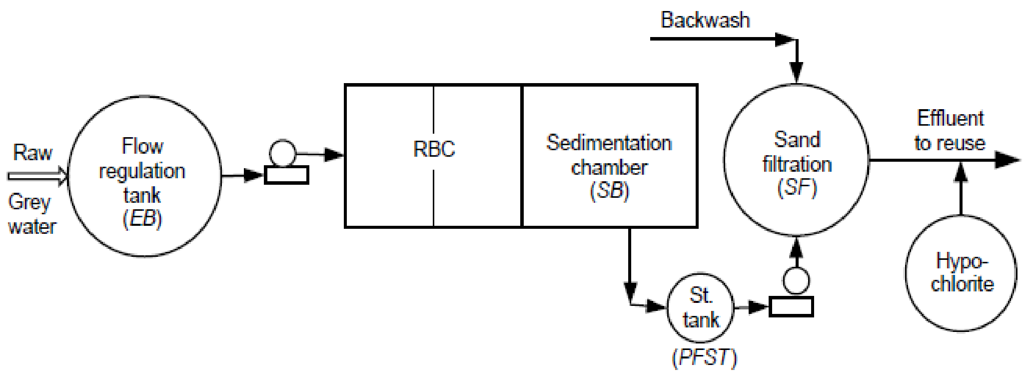

Figure 1 Schematic layout of the pilot plant

Table 1 Greywater quality and removal efficiencies – summary data

Parameter		Raw GW	RBC + SB effl.	Filter effl.	Total Removal
TSS (mg/l)	Average	43	16	7.9	
	STD	25.1	14.5	4.86	
	n	30	31	23	
	Removal (%)	–	63	50	82%
Turbidity (NTU)	Average	33	1.9	0.61	
	STD	23.2	2.30	0.379	
	n	31	32	24	
	Removal (%)	–	94	68	98%
CODt (mg/l)	Average	158	46	40	
	STD	60	19.4	13.8	
	n	33	32	20	
	Removal (%)	–	71	15	75%
CODd (mg/l)	Average	110	47	40	
	STD	54.2	27.0	22.7	
	n	31	32	22	
	Removal (%)	–	57	15	64%
BODt (mg/l)	Average	59	6.6	2.3	
	STD	29.6	9.45	2.43	
	n	17	13	11	
	Removal (%)	–	89	65	96%

Disinfection – Disinfection was carried out by chlorination (hypochlorite 0.2–0.25%) in a batch mode. Chlorine dose was calculated by chlorine demand and a requirement for 1 mg/l residual chlorine after 30 minutes, contact time.

Sampling and analyses

Samples were taken twice a week for seven months now, from five sampling points: EB, SB, PFST, SF and post-chlorinated samples. Each sample was analysed for 15 parameters (all in accordance with the Standard Methods; APHA, 1998): TSS, VSS, COD (total and dissolved), BOD (BOD5 total and dissolved), total phosphorus (TP), kjeldahl nitrogen (TKN), ammonia, nitrate and nitrite, turbidity, pH, faecal coliforms (FC) and heterotrophic plate count (HPC). SF effluent was also analysed for chlorine demand and residual chlorine.

Results and Discussion

The overall performance of the pilot plant was excellent, producing effluent of very high quality that well meets the 'excellent-quality' category set by the Israeli Ministry of Health (2003) in, their urban effluent reuse regulations. **Table 1** describes average concentrations of TSS, turbidity CODt (total), CODd (dissolved) and BODt along the treatment; specific removal efficiencies of each treatment unit and the overall removal achieved. **Table 2** presents heterotrophic plate count (HPC) and faecal coliforms (FC). Figure 2 depicts the long-term behaviour of TSS, turbidity CODt and BODt, while **Figure 3** presents the long-term overall removal of these parameters. **Figure 4a** represents the long term behavior of FC, while **Figure 4b** illustrates the specific removal efficiency of FC in each treatment stage. The overall removal efficiency (Table 1) ranged from 64% (CODd) to 98% (turbidity), with very low effluent BODt (2.3 mg/l) and turbidity (lower than turbidity limit of drink ing water; 0.61 versus 1 NTU). CODd and CODt removal (64% and 75%, respectively) was significantly lower than BODt removal (96%), implying that the grey water contains slowly/non-biodegradable organic matter, especially in a dissolved form. This falls in line with findings of Eriksson et al. (2002).

Table 2 Greywater microbial quality and removal efficiencies – summary data

Parameter	Raw GW	RBC + SB	SF	Disinfection (after 30 min)	
Faecal coliform (CFU/100 ml)					
Average	5.6×10^5	9.7×10^3	5.1×10^4	0.1	
Geometric mean	2.9×10^5	2.9×10^3	6.6×10^2	–[3]	
STD	6.5×10^5	3×10^4	1.2×10^5	3.2×10^1	
N	16	16	16	10	
Removal [1] (%)	–	98.2	–[2]	100	100
Heterotrophic plate count (CFU/ml)					
Average	1.3×10^7	1.1×10^6	1.9×10^5	1.0×10^3	
Geometric mean	6.5×10^6	5.4×10^5	1.1×10^5	3.7×10^2	
STD	1.1×10^7	1.1×10^6	2.51×10^5	1.8×10^3	
N	11	12	14	7	
Removal [2] (%)	–	91.5	82.7	99.5	99.99

1. Based on averages; 2. Negative removal; 3. In 9 out of 10 observations FC conc. was zero – not possible to calculate geometric mean

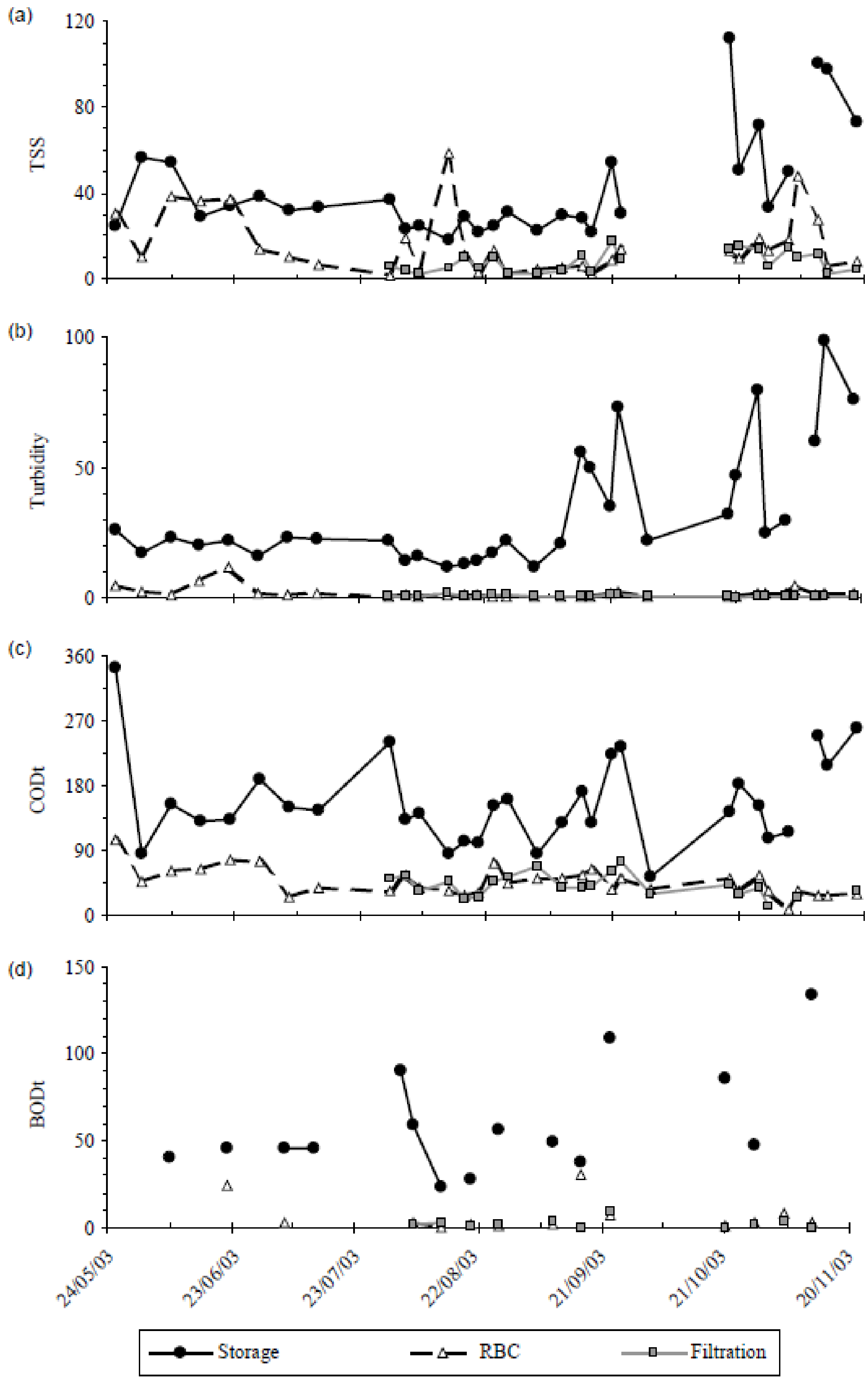

Figure 2 Concentrations of: (a) TSS (mg/l); (b) turbidity (NTU); (c) CODt (mg/l); and (d) BODt (mg/l) along the treatment train

TSS concentrations in the raw grey water ranged between 30–50 mg/l in the first four months of operation, while during the last two months their concentration was twice as high (Figure 2a). Raw grey water turbidity and BOD follow the same general trend. The RBC + SB unit successfully retained biosolids produced in the process, discharging

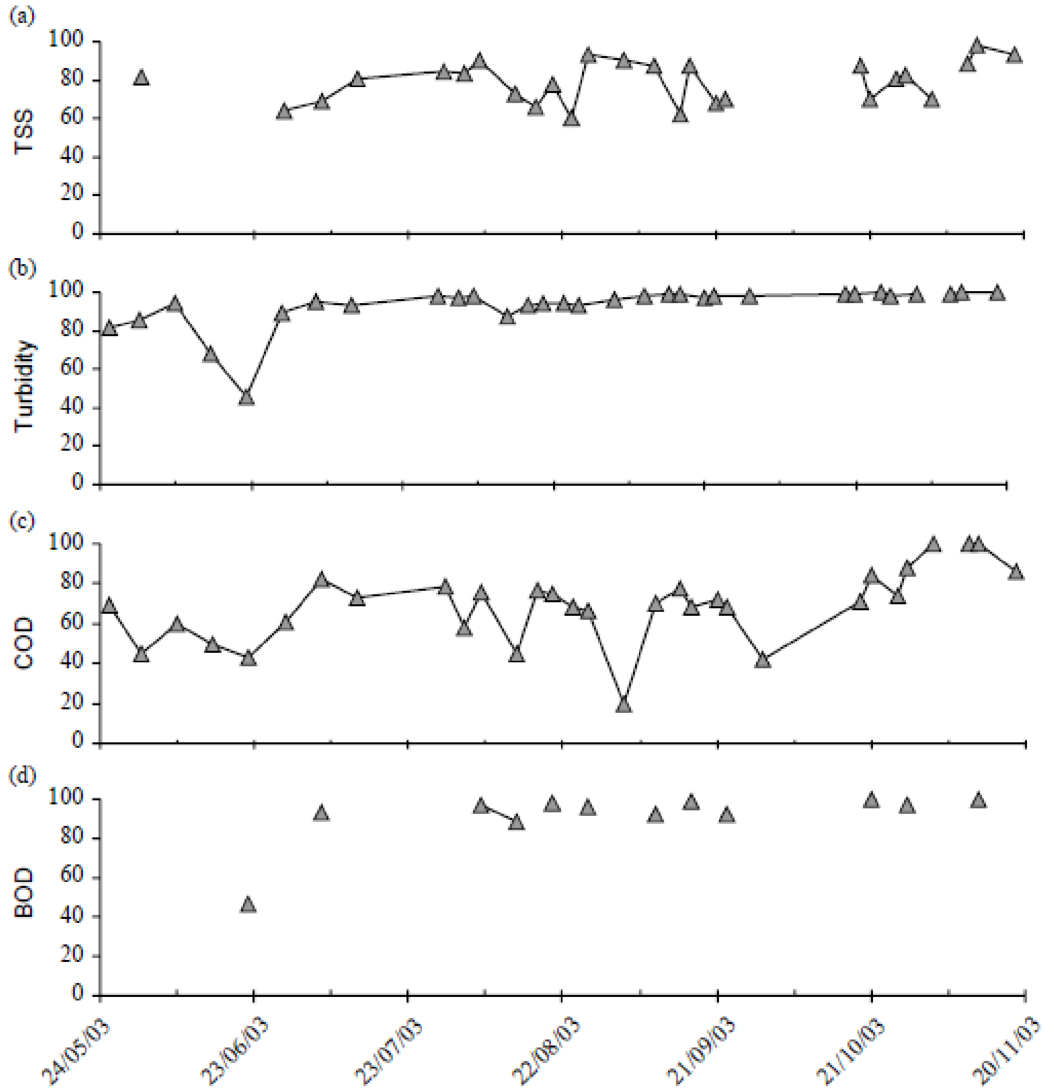

Figure 3 Overall removal efficiencies of (a) TSS; (b) turbidity; (c) COD; and (d) BOD (all in %)

Effluent with less than 20 mg/l TSS, except the initial period (June 2003) when the system was still in its start-up phase. Examination of the turbidity pattern **(Figure 2b and Figure 3b)** reveals its significant removal, from several tens of NTU to less than 1NTU in the final effluent. Most of the removal occurs in the biological treatment by the attached biomass in the RBC (turbidity of 2–6 NTU). This indicates that apart from synthesis of organic matter and production of biosolids, the process consolidates the biosolids into large flocs achieving very efficient bioflocculation. The SF has a polishing effect, usually reducing the turbidity of the effluent to less than 1NTU (upper limit of drinking water quality). Organic content (represented by CODt) in the raw grey water range between 100 and 250 mg/l (Figure 2c), its most significant reduction occurs, as expected, in the RBC. RBC performance was very stable, producing effluent with quite constant COD values. Thus, the RBC also succeeded to buffer the significant fluctuations in inflow CODt. Similar stability of the RBC was also demonstrated in BODt removal (Figure 2d), which usually produced effluent with less than 5 mg/l.

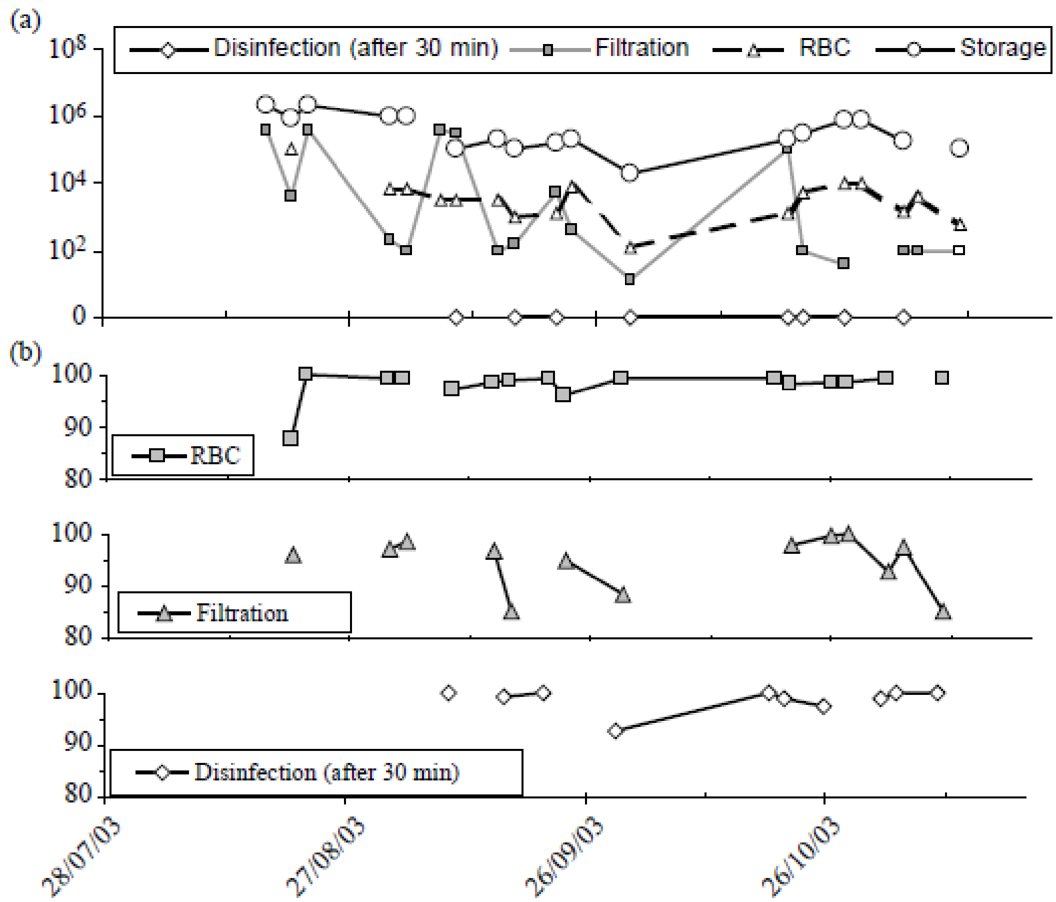

Figure 4 Faecal coliforms in the greywater treatment system: (a) concentrations along the treatment train (CFU/100 ml), (b) relative removal efficiency of each treatment unit (%)

The pilot plant successfully removed nutrients (results not shown): 58% of TP (from 4.8 mg/l in the raw grey water to 2 mg/l in the final effluent); 87% of the TKN (from 8.1 to 1 mg/l); 96% of the ammonia (from 4.9 to 0.16 mg/l) and 72% of the organic nitrogen (from 3.2 to 0.87 mg/l). Overall faecal coliform removal efficiency was 100% (more than five orders of magnitude; Table 2), with 1.8 orders of magnitude removed by the RBC + SB. The removal in the SF was negative, this is probably due to few high FC values in its effluent **(Figure 4a)**, as indicated by a much lower GM (geometric mean). Based on GM, SF average removal efficiency is 77%. The RBC (again) exhibited very stable removal efficiency

(95% or higher**; Figure 4b)**. HPC overall removal efficiency was 99.99%: a little over one order of magnitude in the RBC + SB, a little less then one order in the SF and a little more than two orders in the disinfection. Although HPC does not appear in effluent reuse regulation, it should be emphasized that the average concentration of the final effluent satisfies the limit of drinking water standards (1,000 HPC/1 ml).

IV. Conclusions

The overall performance of the pilot plant was excellent, producing very high quality effluent which meets the highest requirements of the Israeli Ministry of Health urban reuse regulations. Overall removal efficiency ranged from 64% (CODd) to 98% (turbidity), producing very low effluent BODt (2.3 mg/l) and turbidity (0.6 NTU). COD removal was much lower than BODt removal (96%), implying that the grey water may contain slowly/- non-biodegradable organics.

The RBC + SB successfully retained biosolids produced in the process, discharging effluent with less than 20 mg/l TSS. Most of the turbidity is removed in the biological treatment by the attached biomass in the RBC. This indicates that the RBC bio-process consolidates biosolids into large flocs achieving very efficient bioflocculation. The SF has a polishing effect, reducing effluent turbidity to values less than the limit of drinking water quality.

The organic content (as represented by CODt) in the raw grey water ranged between 100 and 250 mg/l, the most significant deduction occurred as expected in the RBC. COD removal in the RBC was very stable, producing effluent with steady COD concentrations. Thus the RBC also acted as a buffer of the fluctuations in inflow CODt. The stability of the RBC was also demonstrated in BODt removal (BODt of effluent less than 5 mg/l).

The pilot plant successfully removed 58%, 87%, 96% and 72% of the TP, TKN, ammonia and organic nitrogen, respectively. This produced effluent with low nutrient content which together with low BOD reduces the regrowth and fouling potential in the reuse system. 100% of the FC was removed by the pilot plant (more than five orders of magnitude). The RBC (again) exhibited very stable removal efficiency (more than 95%). HPC overall removal efficiency was 99.99%. The resulting average concentrations of both FC and HPC in the final effluent were very low with 0.1 CFU/100 ml, and $3.7E^{+2}$ CFU/ml (geo. mean), respectively.

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