Greywater treatment and recycling for toilet flushing: comparison of low and high tech treatment approaches

El Hamouri B., Bey I., Ait Douch A., Ghazi N. and Regelsberger* M.

Department of Rural Engineering, Institut Agronomique et Vétérinaire Hassan II (IAV), Rabat, Morocco ;
*AEE INTEC, Feldgasse 19, Gleisdorf, Austria. b.elhamouri@iav.ac.ma

Abstract: Greywater (GW) from the showers of a sport club was treated following two approaches: adapted low-cost and advanced technologies. The low-cost unit consisted of a gravel-horizontal-flow constructed wetland planted with Phragmites followed by a vertical-flow-multilayer sand filter. For the comparison, two high-tech units were also used: a membrane bioreactor (MBR) with a net capacity of 550 L/d and a sequencing batch reactor (SBR) with a net capacity of 600 L/d and a built-in UV lamp. Performances of the low cost unit were satisfactory: turbidity was reduced from 28 to 2 NTU while removal efficiencies for COD and BOD5 were 75 and 80% respectively. Also, 50% of nitrogen was nitrified and 50% of phosphorus was removed. Anionic surfactants removal efficiency reached 90 %. On the contrary, FC removal did not exceed 1 Log Unit out of an initial concentration of 1.3 105 FC/100 mL. UV disinfection was necessary to bring the counts to 10 units/100 mL. On the other hand, the performance of the MBR and the SBR unit were excellent with effluent quality respecting recycling standards for toilet flushing. Helminth eggs found in the raw greywater were found at a concentration of 1 egg/6L of Hymenolepis sp. (rodent origin probably from the collection system) ; No eggs were found in 6L of the effluent of any of the treatment units tested. The effluent from the low-cost unit was recycled for toilet flushing for fifteen continuous months. We report the absence of any anaesthetic aspect and smell emanation and the acceptance of the approach by the toilet users.

Keywords: Greywater treatment; constructed wetland; MBR; SBR; toilet flushing; helminth eggs.

Introduction
The generalisation of the western way of life in urban areas of developing countries experiencing water scarcity is leading to an increasing stress on water supplies. Demand management is now a dominating approach with the long term research objective being that of closed loop recycling. Following this trend, rainwater-harvesting (Nolde, 2007) and greywater (GW) recycling for site specific, non-potable urban uses such as toilet flushing are becoming more and more attractive. Large-scale projects were recently developed. In the Millennium Dome in the UK, about 7200 m^3 run-off from hand washing basins were collected in the year 2000 and recycled to help satisfying the flushing demand of the 646 WCs and the 191 urinals, which represent 48% of the Dome daily needs (Hills and English, 1999; Hills et al., 2001). In Japan, legislation was introduced to force buildings of a certain size in the metropolitan areas to implement greywater collection and recycling (Stephenson et al., 2000). GW consists of waters from washbasins, showers, baths and washing machines. In developed countries, these volumes represent from 30% in households to 60% in commercial buildings (Shouler et al., 1998). Some authors include water from the kitchen and dish washing machines (dark GW) some do not. GW only contains low concentrations of nutrients: 5 to 22 mg/L of nitrogen and 0.2 to 3.9 mg/L of phosphorus. Its content in FC is rather low (Fittschen and Niemczynowicz 1997; Jefferson et al., 2001). By comparison, black water (water from toilets) contains most part of organic matter, 90% of nitrogen, 80% of phosphorus, 90% of potassium and faecal bacteria. For these reasons, GW is easy to treat and is much safer to recycle for various water usages that do not need potable water quality. Innovative high-tech systems with or without membrane systems (Stephenson et al., 2000) are often adopted for GW treatment in developed countries. These technologies could also find applications in developing countries and offer alternative approaches to low-cost units in some circumstances.

This paper presents the results obtained in recycling GW from the showers of a sport club for toilet flushing in a public building. The same GW was also treated using an MBR and an SBR to test the possibility of introducing such technologies in tourist developments where land is expensive and often just not available.

Material and methods
Setup of the GW recycling system
The Club of the “Association Culturelle et Sportive de l’Agriculture” (ACSA) and the Campus of IAV Hassan II in Rabat lie next to each other. GW from the showers was segregated allowing the collection of 8 m$^3$/d. An underground reservoir was installed outside the gym room to collect GW which was pumped to the wastewater treatment facility located inside the IAV Campus (figure 1).

Figure 1. GW System at the ACSA / IAV.

Greywater treatment
Greywater was treated in parallel in a planted-gravel/sand filter, in an MBR and an SBR unit.

Planted gravel-sand filter plus UV disinfection
The unit was constructed in reinforced concrete and had the following characteristics: length 2.25 m, width 2.0 m, depth 0.8 m, cross sectional area 1.6 m$^2$ and bottom slope 2%. The bed filling material was limestone aggregates with an effective diameter of 5.5 mm. The uniformity coefficient ($U_C$; $d_{60}/d_{10}$) was 1.61, the porosity 47%, and the clean Darcy’s hydraulic conductivity, $K$, was 60 $10^{-3}$ m/s. The bed was planted with reed; *Phragmites australis* (figure 2). The hydraulic loading rate was 1.8 m/d with an organic load of 210 g COD/ (m$^3$*d).
Figure 2. Planted gravel filter and multilayer sand filter followed by a UV disinfection unit.

The second step consisted of a vertical multilayer sand filter also made in reinforced concrete and having the same dimensions as the first step. Five sand layers of 0.14 m thickness each with particle sizes from 0.55 to 6 mm were used. The measured clean Darcy’s hydraulic conductivity, $K$, of the unit was $25.1 \times 10^{-3}$ m/s.

**UV disinfection**

GW was disinfected in an UV Tspa Teflon system (Iritech Finmeccanica, Italy). GW was forced upward in a Teflon pipe placed in an aluminum box with dimensions of 0.20 m x 1.70 m x 0.20 m. The Teflon pipe was surrounded by four 0.90 m long low-pressure mercury tubes of 30 Watts each emitting at 253.7 nm and placed around the tube at a distance of 0.03 m. The contact time was adjusted to 6.35 s leading to a dose of $400 \text{ mJcm}^{-2}$.

**GW recycling for toilet flushing**

GW treated in the low-cost unit was disinfected and stored in a black polyethylene reservoir. This reservoir is connected to the building of the Department of Rural Engineering (DRE) to feed four toilets at the ground floor. A dual pipe network was adopted with the valve of drinking water staying permanently closed except when GW is not available. Also and to prevent GW from flowing back into the drinking water network, a gap of 4 cm was left between the drinking water pipe and the highest water level in the flushing reservoirs (figure 3, where the drinking water valve was open for the purpose of the picture). Four similar toilets, located on the first floor of the DRE building, were flushed with potable water for comparison.

Figure 3. Dual network (greywater recycling /potable water) for toilet flushing (see material and methods for explanation).
The MBR technology combines activated sludge process, for the removal of biodegradable pollutants, and membrane filtration for solid/liquid separation. The equipment used is from Busse, Germany, type MF-GW-HKA 4 (one reservoir). The membrane is a 5 m² "frame and plates" made of polyelectrolyte complex (Kubota, Japan) with a nominal pore size of 0.4 µm. The operating conditions were as follows: cycle duration 3 h (8 cycles/d); contact time 25 min (treatment aeration) then intermittent aeration (10 min every one hour); flow 675 L/d and HRT 19.5 h. After some time, the cycle was reduced to 2h, (12 cycles/d) to treat 980 L/d at HRT of 13.5 h. The purchase of the large unit was preceded by bench-pilot experiments (see (Merz et al., 2007). The COD load was decreased from 0.16 to 0.14 g COD/ (g VSS*d) when the cycle was reduced from 3 to 2 hours.

The SBR is an activated sludge unit in which the biomass grows inside small floating foam cubes. The unit used is an Aquacycle 900 from Pontos, Germany. It includes 3 reservoirs, two for the treatment and the third for storing the UV-disinfected effluent. Operating conditions were as follows: Cycle duration 3 h, i.e. 8 cycles/d; (3min aeration and 5 min rest) followed by 20 min settling period corresponding to 850 L/d and 16.5 h as HRT. The settled material was pumped out every 4 days. The operating conditions were later changed to a cycle of 2 hours i.e., 12 cycles/d (3 min aeration and 5 min rest) followed by 20 min settling period corresponding to 1100 L/d and 13 h as HRT. The COD load was 0.2 g COD/ (g VSS*d) for the 2-hour cycle.

**Sampling and analysis**

Samples for GW characterisation were taken during the two daily peak flow periods (11:00 and 20:30). In this period, GW does not stay more than 30 min in the collection reservoir and the conveying pipe together. Fresh GW was also collected right at the outlet of the segregation pipe before the contact with the reservoir content and the conveying network. Samples to assess recycled GW quality were also taken from the toilet flushing cisterns. Water analyses were performed following Standard Methods (APHA, 2005). All FC figures are MPN except when stated. Membrane filtration was used with Tergitol 7 TTC medium (NF, 2000). Helminth eggs analyses were done following the method described by Arther et al., (1981) on a 6 L-sample.

**Results and discussion**

**GW characterisation**

Table 2 shows that the values of the main pollution parameters of GW were within the range reported by other authors. Turbidity values never exceeded 40 NTU and had an average of 30; settleable solids were entirely organics representing 5% of total solids. Nitrogen and phosphorus contents were low. Almost 80% of nitrogen in the influent consisted of ammonia.

Average FC contamination was 1.3 \(10^5\) units/100 mL. Conflicting FC contents were reported with figures ranging from \(10^2\) to \(10^5\) (Lazarova et al., 2003). Such a large span might be explained by socio-cultural or technical reasons. We noticed large differences depending on the point of sampling inside the collection manhole. FC counts were lower when the samples were taken at the outlet of the GW collection pipe. Those taken in the collection reservoir were systematically two orders of magnitude higher. This difference might be due to a subsequent FC growth during the residence time of GW in the collection reservoir and inside the conveying pipe. Storage of raw GW resulted in a dramatic increase of FC content. We found that FC counts were multiplied by a factor of 100 within the first 48 hours at laboratory temperature when conserved in ceramic containers similar to those of toilet flushing cisterns. An intriguing fact, however, was the large population of cockroaches (black beetles) living inside the collection manhole, where they freely circulate between black water and GW boxes. The existence of these insects could explain the difference in FC counts discussed above. Cross contaminations are likely to take place particularly when segregation and conveying systems are placed side by side as this was the case in this study.

**Low-cost unit performance**

The performance of the two-step gravel/sand filtration unit was quite satisfactory. The effluent turbidity was reduced from 28 to 2 NTU. Removal rates of COD and BODs were 75 and 80% respectively. Half of the nitrogen was nitrified during the filtration process. Removal rate of phosphorus was almost 50% while anionic surfactants were removed at a rate of 97 %. On the contrary, the gravel/sand filter performance in FC removal was low and did not exceed one Log Unit.
Recycled GW quality

The effluent quality inside the flushing reservoirs was of good quality. The difference of FC counts, before and after disinfection, was 3 Log Units leading to a quality that complies with common, international standards for domestic recycling (Table 1). Very little changes occurred in the recycled GW following disinfection except for the doubling of the electrical conductivity. This increase could be explained by the evaporation that takes place in the black reservoir feeding the recycle network.

<table>
<thead>
<tr>
<th>Water quality standards and criteria suitable for domestic water recycling (after Smith &amp; Dudley, 1998).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total coliforms Count/100 mL</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>USA, NSF Federal Minimum</td>
</tr>
<tr>
<td>USA, EPA</td>
</tr>
<tr>
<td>Australia</td>
</tr>
<tr>
<td>UK (BSIRA)</td>
</tr>
<tr>
<td>Japan</td>
</tr>
<tr>
<td>WHO*</td>
</tr>
<tr>
<td>2006/7/EC**</td>
</tr>
</tbody>
</table>

* suggested as appropriate for domestic water recycling, BSIRA: Building Services Information and Research Association (according to Jefferson et al., 2001); Bathing EC directives Intestinal Enterococci (cfu/100 ml) for water of Excellent quality.

Impact on flushing equipment and perception by the toilets users

The recycling system was checked daily and compared with the toilets of the first floor connected to potable water only. The check protocol included the following aspects: visual quality of water, smell perception, and impact on flushing equipment such as marks on the ceramic reservoirs or failure of the flushing mechanism. On all these aspects there were no differences between GW and potable water toilets except the development of a slim light-yellow line of biofilm on the inner wall of the greywater reservoirs (figure 2). However, this film did not have any consequences moreover; it was easily removed upon washing up.

MBR performances

Performances of the MBR in greywater treatment are satisfactory and confirm those reported by other authors (Jefferson, 2001). The remarkable reduction operated in both TSS and COD allow the production of an effluent of excellent quality (figures 4 and 5 and Table 2). These figures also show that the switch cycle from 3 to 2 hours did not produce any change on the TSS effluent content. This is not the case for the COD where a slight increase was observed bringing the effluent COD from less than 20 to around 30 mg/L. Figure 6 demonstrates that the organic load was limiting the biomass production. Reducing the cycle to 2 h led to the immediate increase of the reactor biomass.
Figure 4. TSS removal by an MBR operated at a cycle of 3 than 2 hours.

Figure 5. COD removal by an MBR operated at a cycle of 3 than 2 hours.

Figure 6. Change in TSS and VSS concentration following the reduction of the operation cycle from 3 to 2 hours for the MBR unit.
Table 2. Quality of treated GW on the three systems chosen and inside the toilet flushing reservoirs. Temperature 18.7°C for low-cost; 25°C for MBR and SBR.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tur.</th>
<th>pH</th>
<th>COD</th>
<th>BOD₅</th>
<th>TKN</th>
<th>N-NO₃⁻</th>
<th>Pt</th>
<th>TSS</th>
<th>AS*</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>NTU</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>µg/L</td>
<td>U/100 ml</td>
</tr>
<tr>
<td>Raw GW</td>
<td>28</td>
<td>7.4</td>
<td>120</td>
<td>51</td>
<td>15.2</td>
<td>0.1</td>
<td>1.6</td>
<td>42.5</td>
<td>299</td>
<td>1.3 10⁵</td>
</tr>
<tr>
<td>Low-cost +</td>
<td>2</td>
<td>6.9</td>
<td>25</td>
<td>10</td>
<td>9.0</td>
<td>4.5</td>
<td>0.7</td>
<td>17.6</td>
<td>24</td>
<td>1.10⁴</td>
</tr>
<tr>
<td>Flushing reservoirs**</td>
<td>2</td>
<td>6.9</td>
<td>28</td>
<td>10</td>
<td>10.6</td>
<td>2.8</td>
<td>0.9</td>
<td>31</td>
<td>0***</td>
<td></td>
</tr>
<tr>
<td>MBR 3h</td>
<td>0.8</td>
<td>7.7</td>
<td>13.7</td>
<td>6.7</td>
<td>2.9</td>
<td>-</td>
<td>1</td>
<td>0.3</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>MBR 2h</td>
<td>0.7</td>
<td>7.7</td>
<td>29</td>
<td>11.5</td>
<td>3.5</td>
<td>9.2</td>
<td>0.9</td>
<td>0.3</td>
<td>-</td>
<td>0***</td>
</tr>
<tr>
<td>SBR** 3h</td>
<td>0.9</td>
<td>7.6</td>
<td>22.6</td>
<td>11.8</td>
<td>3.4</td>
<td>-</td>
<td>0.9</td>
<td>15</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>SBR** 2h</td>
<td>1.5</td>
<td>7.7</td>
<td>36</td>
<td>16.5</td>
<td>4</td>
<td>10.1</td>
<td>0.7</td>
<td>17.6</td>
<td>-</td>
<td>5***</td>
</tr>
</tbody>
</table>

Tur: Turbidity; *Anionic surfactants as LAS; TSS: Total suspended solids; VSS: volatile suspended solids; FC faecal coliforms (MPN). UV disinfected Effluent. ***Membrane filtration of 100 mL.

Removal efficiency of COD in the SBR was similar to that of the MBR; however, the SBR did not succeed in producing an effluent of low TSS content nor an effluent without any FC when operated at the 2 hour-cycle. Here also, an increase in the effluent COD was observed when the cycle changed from 3 to 2 hours (figure 7 & 8). The electric power consumption for the aeration (without any pumping of influent) was metered for both equipments and giving 2.2 and 2.9 kWh/m³ respectively for the MBR and the SBR.

Figure 7. TSS removal by an SBR operated at a cycle of 3 than 2 hours.

Figure 8. COD removal by an SBR operated at a cycle of 3 than 2 hours.
One drawback, however, was that the power of the inbuilt UV lamp of the SBR was not sufficient to kill all the FC. This may be due to the high remaining TSS. Improvements to the process in order to increase the efficiency of TSS reduction are under way.

Finally table 2 shows the comparison of the effluents of the three treatment units tested namely the horizontal-flow CW plus sand filtration, the MBR and the SBR. The low-cost unit achieved performances close to those of the advanced systems on the side of COD and TSS removal aspects.

**Conclusion:**

Preliminary results indicate that toilet flushing using recycled greywater collected from the shower of a sports club is technically easy to implement. Low-tech, environmental friendly systems (planted gravel and sand filtration) can provide an adequate treatment. However, residual faecal bacteria counts necessitated the adoption of a disinfection step in order to comply with toilet flushing quality standards table 1. In this respect, UV disinfection was tested and found satisfactory. After fifteen months of continuous recycling, a positive perception is dominating as well as the acceptance of the practice by the users. Advanced technologies, MBR and SBR, were also tested. They have very low footprints, gave excellent performance and produced stable effluent quality. Their power consumption for aeration was moderate. Overall both techniques are considered viable solutions for greywater recycling in circumstances where a small footprint outweighs higher investment and operation cost, especially in tourism facilities, possibly also in densely populated urban areas.

**Acknowledgements**

The authors would like to thank the Commission of the European Union (MEDA water program) for funding the project Zer0-M and the Ministry of Agriculture for its support to the IAV Hassan II. The authors wish to thank Dr. Matthias Kraume and Eng. René Scheumann from the Technical University of Berlin (TUB) and Dr. Erwin Nolde (Nolde and partners). Parasitological analyses were performed by Dr Khallayoune (IAV Hassan II).

**References**


NF, French norms, en IS 9308 (September 2000). Qualité de l'eau Recherche et dénombrement des Escherichia coli et des bactéries coliformes. Partie 1 méthode par filtration.
