Characterisation and biological treatment of greywater

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Abstract Characterisation of greywater was conducted in two different greywater streams in the Netherlands (Groningen and Sneek). The concentrations of macropollutants and nutrients measured were very different in both streams; in particular the COD was 425 mg/L in Groningen's water whereas in Sneek it was 1,583 mg/L.

The aerobic treatment of greywater in a fed-batch reactor led to a 90% removal of COD at different organic loading rates. Anaerobically, the removal reached 40% COD removal on average, the possible reason being the high amount of surfactants present in the influent.

Keywords Greywater composition; greywater treatment; water reuse

Water Science & Technology **Vol 56 No 5 pp 193–200**

Introduction

The critical importance of water to sustainable development is clearly recognised in the Millennium Development Goals. Freshwater is a fundamental requirement for human survival and socio-economic development and must therefore be wisely managed. Reducing the needs for fresh water can be achieved by reusing waste water. Greywater (water discharges from laundry, shower, bath, sinks and kitchen) has great potential for reuse due to its availability (around 70% of domestic waste water) and its low concentration of pollutants compared with combined household waste water.

Greywater can vary significantly in composition; wide ranges of values for macropollutants and nutrients have been published; for instance, COD has been reported between 13 and 550 mg/L; BOD_5 90–360 mg/L; total nitrogen 0.6–74 mg/L and total phosphorus 4–14 mg/L (depending on the use of detergents with or without phosphate) (Eriksson *et al.*, 2002).

This paper describes the initial results from the characterisation of the grey waste water from an eco-village in Groningen and a demonstration project in Sneek, both in The Netherlands. Such a characterisation of greywater is essential to determine a treatment scheme.

Furthermore, this paper shows some results of the operation of a UASB (up-flow anaerobic sludge blanket) reactor and an aerobic fed-batch reactor to treat this greywater. Waterland is an ecological housing settlement comprising 150 houses and situated in Groningen in The Netherlands (Figure 1). The production of wastewater is 125 L/p·d, of which 80% is considered greywater (Dijk, 2000). Greywater is discharged into the local environment after treatment by two horizontal, constructed wetlands. It must be said that these constructed wetlands have a large footprint (9 m^2 per person in this case) and the treatment performance during winter is poor.

In May 2006, a demonstration project of a separation at source sanitation was started in Sneek (Figure 2), The Netherlands. Thirty-two houses were equipped with

doi: 10.2166/wst.2007.572

Figure 1 Waterland, eco-village in Groningen

Figure 2 DESAR project Sneek

vacuum toilets. The concentrated toilet water is treated on site and greywater is not treated but discharged to the sewer. First results from the project indicate a water consumption of about 70 L/p·day, which is very low compared to the Dutch average of 134.1 L/p·d (Wijst and Groot-Marcus, 1998).

Our aim is to design a compact treatment system combining biological and physical–chemical processes for the reuse of greywater for gardening, recreation, as secondary household water or infiltration. Attention will be given to micro-pollutants such as heavy metals and xenobiotic organic compounds present in greywater. A biological process has been selected as a first treatment step, to be followed by the physical–chemical process required to remove the persisting micro-pollutants. In this article, two lab-scale reactors for aerobic and anaerobic treatment are briefly presented. Only limited information has been published on the anaerobic (pre)treatment of greywater (Imura *et al.*, 1995); it is therefore one of the goals of this project to assess the feasibility of this treatment.

Methodology

The sampling period for Groningen greywater was from 18th–31st October 2005. Samples were taken daily every 1.5 h and collected in separate vessels. The sampling point was in the entrance of the greywater collection tank. The automatic sampler was taking 100 mL water every 10 min from the submerged sampling vessel in the tank. pH, conductivity, temperature and dissolved oxygen were measured continuously. The samples (104 samples) were analysed for macro-pollutants (total, suspended and dissolved COD, TOC), nutrients, volatile fatty acids, trace elements, metals, chloride, nitrite and nitrate concentrations.

A less thorough characterisation was conducted on the water from the demonstration project in Sneek. Ten samples have been taken in the period from July to November 2006 during the morning. The sampling point was an inspection pit, since there was no greywater storage tank installed.

A UASB lab-scale reactor (see Figure 3) with a capacity of 3.6 and 5 L was used to treat sampled greywater; the first one from May to September, and the latter during September and November. The inoculum used was flocculent anaerobic sludge (mixed primary and secondary sludge) from the municipal WWTP in Leeuwarden, The Netherlands. The hydraulic retention time ranged from 12 to 24 h. The reactor temperature ranged between 20–30 °C.

On day 129 of operation, the UASB reactor was spiked with acetate to achieve an influent concentration of 1 g/L; this test was conducted to verify if there was methanogenic activity in the sludge. For the aerobic treatment, a reactor of 3.6 L was used; the inocculum was activated sludge from WWTP in Leeuwarden.

From May to July the UASB was running with greywater taken from Groningen, from July until November both reactors were treating greywater from Sneek.

Characterisation of greywater

In Groningen's greywater, the mean values for conductivity, pH, dissolved oxygen and temperature were 7.52 mS/m, 7.12, 16.5 °C and 8.9 mg/L, respectively. The average

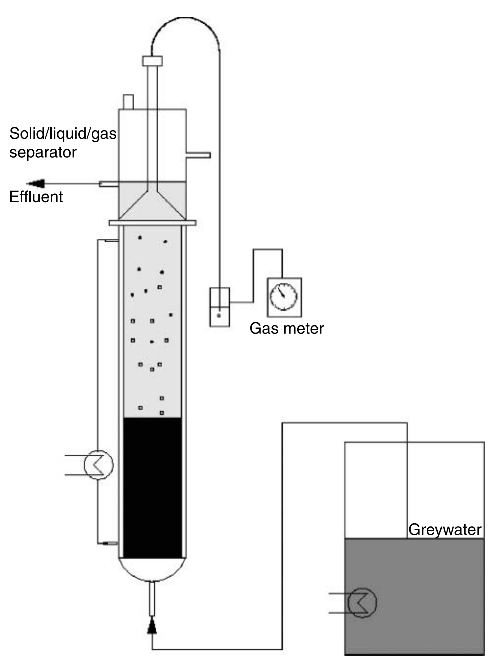

Figure 3 UASB reactor scheme for grey water treatment

values of macro-pollutants and nutrients for both greywater streams are shown in Table 1. For Groningen's wastewater the ratio of BOD/COD is approximately 0.50 which indicates good potential for biological treatment. The concentrations of nutrients show no apparent nutrient limitation for a biological process, as has been assumed for greywater (Jefferson *et al.*, 2001).

There is a large difference in the quality of greywater coming from Sneek and Groningen, especially concerning the COD. The organic load of Sneek's water lies outside the ranges reported in literature for greywater. Although it has been mentioned that the water consumption in Sneek was lower than average, these high COD values cannot be fully explained.

In The Netherlands, the average chemical oxygen demand discharged into greywater is 48.6 g COD/p·d (Wijst and Groot-Marcus, 1998). Considering a greywater generation of 100 L/p/d in Groningen and 60–70 in Sneek, the expected COD would be 486 mg/L in Groningen and 694–810 mg/L in Sneek. In the case of Groningen, the difference between the calculated value and the actual value is not very significant. However, in the case of Sneek, the difference is very high and difficult to attribute to a specific source. It is suspected that most samples were taken at the moment of a laundry discharge, with high concentrations of detergents; this still has to be investigated by a more representative sampling campaign in Sneek.

Table 2 shows the concentration of some elements in greywater, along with limit values recommended for reclaimed water to be used in irrigation purposes. Many of the metals measured (As, Au, Cd, Cr, Ce, Co, Hg, Li, Mn, Mo, Ni, Pb, Sn, Ti and Zn) were below detection limits (0.05 mg/L) and have not been included in Table 2.

With the exception of boron and aluminium, none of the streams analysed contained concentrations above recommended limits, which indicates that after treatment this effluent will represent no risk with respect to these metals. For the greywater originating in Sneek, boron and aluminium could pose a risk if the stream were to be used directly in agriculture. Boron is included in the formulation of some detergents, as it acts as a bleaching agent (Tai 2000). Apparently, the use of detergents containing boron is higher among the inhabitants of Sneek than those of Groningen, or laundry water was sampled in too high an amount in relation to the other wastewater streams from the household. It is not clear what the source of high aluminium concentrations in Sneek's greywater is, but attention should be given to it.

Greywater treatment in a UASB reactor

Figure 4 shows the general data describing the performance of the UASB reactor during a period of 6 months. The COD removal fluctuated considerably between 0 and 80%, with an average value of 40%. The most significant changes during the UASB operation were the

Table 1 Macro-pollutants and nutrients' concentrations in greywater

	Groningen mg/L	Std. dev mg/L	Sneek mg/L	Std. Dev. mg/L
TOC	114	28	254.5	
COD total	425	107	1,583	382
COD ss	115	106	605	412
COD diss	175	48.7	576	146
BOD_5	215	102		
Total N	17.2	4.7	47.78	27.06
NH_4-N	7.2	3.7	16.35	6.78
Total P	5.7	2.6	9.86	8.48
PO_4-P	2.3	1.3	2.25	0.26
K	11.2	2.3	23.28	8.49

Table 2 Metal concentrations in greywater

	Groningen mg/L	Std. Dev. mg/L	Sneek mg/L	Std dev mg/L	Limit long term irrig (Feigin and Shalhevet, 1991) mg/L
Ca	60.79	8	65.53	29.34	
Mg	6.15	0.71	30.55	34.43	
Na	86.35	18.9	159.75	44.96	
Fe	0.11	0.06	1.28	0.36	5
Cu	0.08	0.04	0.12	0.20	0.20
B	0.42	0.15	0.87	0.49	0.75
Si	11.97	1.52	21.43	6.67	
Al	0.49	0.31	7.35	6.07	5
P	4.17	2.64	5.85	0.86	
S	19.00	5.04	33.18	21.38	
Zn	0	0	0.13	0.11	2

addition of sludge on day 57, the change to Sneek's greywater on day 59, the change of reactor from 3.6 L to 5 L with a gas meter on day 129, the addition of acetate to the reactor on day 146 to check activity of sludge and the new start up on day 150 with new sludge and diluted influent. Despite these modifications made to the process during the operation of the reactor, there was no significant improvement in the COD removal.

Greywater originating from washing activities is expected to contain high concentrations of surfactants and some surfactants are persistent in anaerobic conditions (Ying, 2006). Moreover, the presence of surfactants has also been reported to have a negative effect in the anaerobic processes (Elmitwalli *et al.*, 2001).

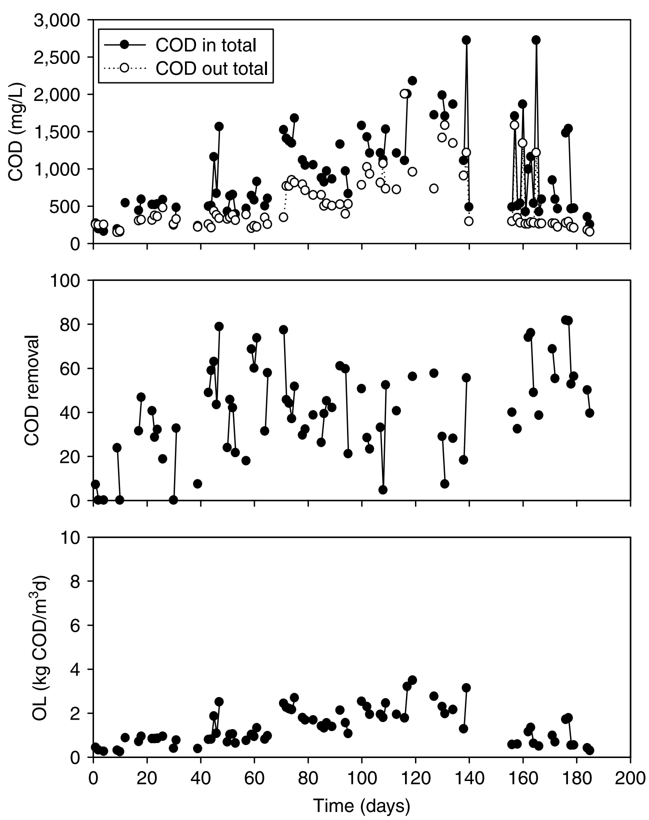

Figure 4 Performance data for UASB reactor

The removal of suspended COD was 56% on average, whereas for colloidal and dissolved COD it was 33 and 25% respectively. The highest removal was shown in the suspended fraction of the COD, which indicates the physical removal of solids in the UASB reactor. Figure 5 shows the influent and effluent concentrations of suspended COD, and it can be observed that the effluent concentration remains stable throughout the operation of the reactor.

The most interesting aspect is that the colloidal COD was removed in a higher extent than the dissolved fraction (33 vs 25%), while it has been proven that colloidal material is poorly removed due to its low physical retention in the sludge bed (Elmitwalli, 2000).

Some toxic effects were suspected, although there was no acidification in the reactor (pH ranged between 7 and 8 throughout the operation and VFA concentration ranged between 0–100 mg/L). The injection of acetate (1 g/L) was conducted to investigate whether there was methanogenic activity in the sludge. No gas production was registered and the acetate consumption in the UASB was practically none. Therefore, it could be concluded that no methanogenic activity was taking place and that the sludge had to be replaced. From day 150 the UASB was fed with diluted influent, with an average concentration of 670 mg COD/L. During this time the average COD removal was 60% with a methane production of 0.25 NL/d, which is 42 NL/m^3 of influent.

Dilution had a positive effect on the performance of the UASB reactor, which indicates the possible toxic effect of undiluted greywater. Another aspect to investigate is the possible lack of trace elements.

Aerobic treatment of greywater

Figure 6 shows the COD values of influent and effluent of the aerobic reactor, as well as the COD removal and the organic loading rate. In this reactor, the COD removal reached values above 90% for most of the cycles. It can be noticed that until day 60 the removal was very high (around 90%), an reason for increasing the loading rate. After some days the system adapted to higher loads and the removal reached again 90% COD removal. Even so, the organic loading rate has still to be optimised.

One interesting aspect was the low sludge yield observed, which was calculated to be 0.05 g VSS/g COD$_{removed}$, while the normal values for activated sludge systems range between 0.3–0.5 g VSS/g COD (Metcalf and Eddy, 2003). The sludge produced showed good settleability measured with a sludge volume index of 51 mL/g.

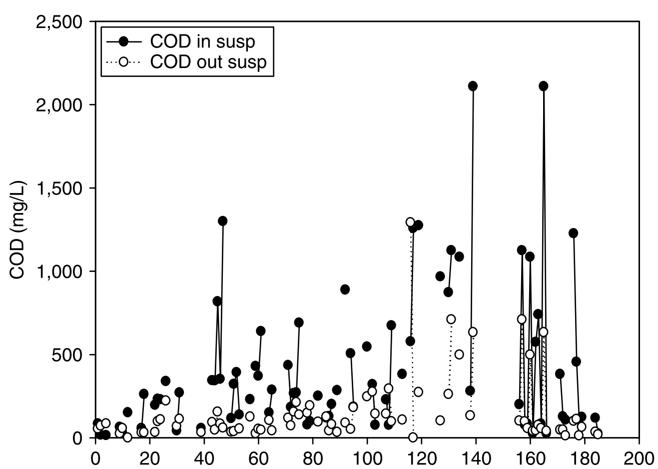

Figure 5 Suspended COD concentrations in the influent and effluent of the UASB reactor

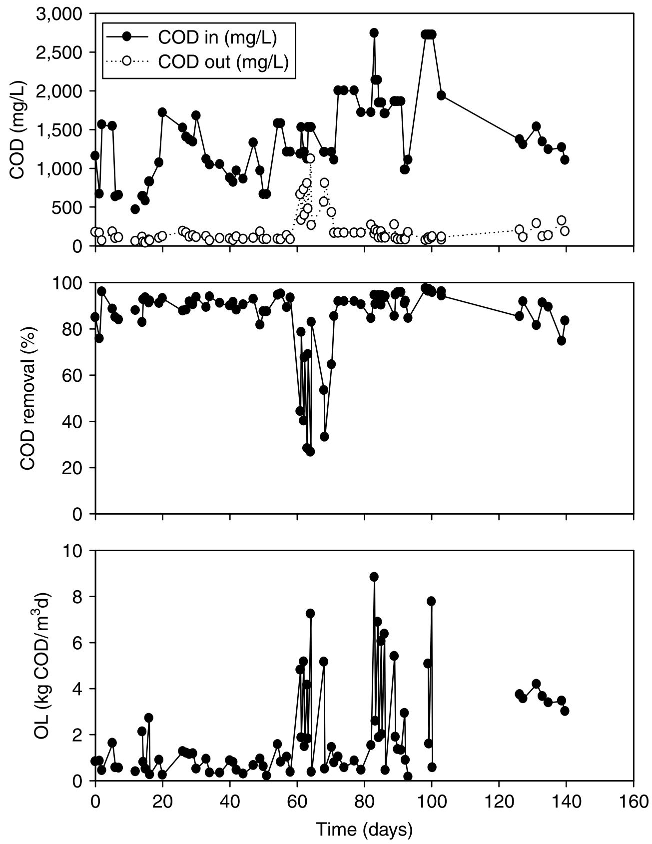

Figure 6 Performance data for fed-batch aerobic reactor

Outlook

From the characterisation of greywater from two different sources, it can be confirmed that the composition of greywater can significantly change with the source. With regard to heavy metals, Groningen's greywater complied with irrigation standards. On the other hand, extra attention should be paid to boron and aluminium in the greywater coming from Sneek. Further investigation is necessary before this can be fully explained, namely a better sampling procedure for greywater from Sneek must be established.

At the applied loading rates, anaerobic treatment does not work properly, reaching only a 40% COD removal. The aerobic treatment of greywater is more efficient in the COD removal than the anaerobic treatment, reaching 90% at loading rates ranging from 0.15 to 8 Kg COD/m^{3}d.

Inhibitory effects of the influent in the anaerobic bacteria are an interesting aspect to investigate as well as the effect of trace elements addition. It also remains to be seen if a combined anaerobic/aerobic process is worthwhile for the treatment of greywater. Further research will also include the physical–chemical removal of selected micro-pollutants which are also persistent after biological treatment.

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