Performance of UASB septic tank for treatment of concentrated black water within DESAR concept

K. Kujawa-Roeleveld, T. Fernandes, Y. Wiryawan, A. Tawfik, M. Visser and G. Zeeman
Sub-department of Environmental Technology, Wageningen University, P.O. Box 8129, 6700 EV Wageningen, The Netherlands

Abstract Separation of wastewater streams produced in households according to their origin, degree of pollution and affinity to a specific treatment constitutes a starting point in the DESAR concept (decentralised sanitation and reuse). Concentrated black water and kitchen waste carry the highest load of organic matter and nutrients from all waste(water)streams generated from different human activities. Anaerobic digestion of concentrated black water is a core technology in the DESAR concept. The applicability of the UASB septic tank for treatment of concentrated black water was investigated under two different temperatures, 15 and 25°C. The removal of total COD was dependent on the operational temperature and attained 61 and 74% respectively. A high removal of the suspended COD of 88 and 94% respectively was measured. Effluent nutrients were mainly in the soluble form. Precipitation of phosphate was observed. Effective sludge/water separation, long HRT and higher operational temperature contributed to a reduction of E. coli. Based on standards there is little risk of contamination with heavy metals when treated effluent is to be applied in agriculture as fertiliser.

Keywords Anaerobic digestion; black water; decentralised sanitation and reuse; effluent reuse; UASB septic tank

Introduction
The most characteristic features of the decentralised sanitation and reuse (DESAR) concept comprise a separation of wastewater streams according to their characteristics and degree of pollution, their separate, affinitive treatment usually close to the place of origin and production of clean and/or potentially reusable effluent/product. Toilet wastewater and optionally solid kitchen refuse, carrying the highest organic and nutrient load, are digested in a, preferably, simple, robust anaerobic digester. Next to the accumulation system and CSTR, the UASB (upflow anaerobic sludge blanket) septic tank is one of the studied options within a long-term project carried out in Wageningen University, Sub-department of Environmental Technology. The UASB septic tank differs from the conventional septic tank in the up-flow mode of operation, due to which improved removal of suspended solids and biological conversion of soluble components are achieved. The UASB septic tank is designed for accumulation and stabilization of solids, making it a continuous system in relation to water and an accumulation system with respect to solids. The UASB septic tank might be an appropriate technology to be applied in the DESAR system because of the historical common use of septic tanks for on-site treatment and evidence that simple adjustments in their current construction may contribute to a higher performance. Feeding the UASB septic tank with a concentrated black water and optionally solid kitchen refuse constitutes a new approach.

Methodology
The pilot plant comprised two UASB septic tank reactors (UASBST1 and UASBST2) of 0.2 m³ each, operating at 15 and 25°C respectively. The anaerobic reactors were connected to 2 vacuum toilets (Roevac), using approximately 11 water to flush the waste.
each time to the 10 l equalization tank (ET). After filling, the content of the ET was pumped, using a shredder-pump, to the pressure release vessel located on top of the UASB<sub>ST</sub>. From there the wastewater was transported by gravity to the bottom of the UASB<sub>ST</sub> column and subsequently passed the sludge bed in up flow direction (Figure 1). Both UASB<sub>ST</sub>s were fed with faeces and urine in the amount as produced by one individual, which is 1 times faeces and 5 times urine per day (average Q<sub>in</sub> = 7.0 and 6.8 l<sup>-1</sup> d<sup>-1</sup> respectively). The average hydraulic retention time (HRT) was approximately 29 days and organic loading rate (OLR) respectively 0.33 and 0.42 gCOD l<sup>-1</sup> d<sup>-1</sup>. Because the feeding was not equally spread over the week, reactors faced peaks of lower HRTs (<8 days) and higher OLRs (> 1.4 g l<sup>-1</sup> d<sup>-1</sup>) especially at the beginning of the week. The UASB<sub>ST</sub> at 15°C was inoculated with 80 l sludge (TS = 10.4 g l<sup>-1</sup>) from another UASB septic tank treating diluted black water from conventional toilets at ambient temperatures. The UASB<sub>ST</sub> 2 at 25°C was started up without any inoculum. At the end of the operational period as described here (1 year from the start-up) kitchen refuse was added to the UASB<sub>ST</sub> 2 in the amount as produced by one individual ( = 0.2 kg p<sup>-1</sup> d<sup>-1</sup>) to evaluate its short term effect on the process performance.

Frequent and detailed characterization of influent was performed impaired with control of the effluent quality to assess the actual process efficiency. Influent sample was semi-composite consisting of the few grab samples collected in the subsequent, first days of the week. The development of the sludge bed was followed in terms of height, solids content and stability. The biogas production was monitored. The quality of sludge and effluent was evaluated for heavy metals and <i>E. coli</i> content.

**Results and discussion**

**Influent characterisation**

The influent wastewater to both reactors contained respectively 9.5 and 12.3 g l<sup>-1</sup> of total COD (COD<sub>tot</sub>) of which approximately 80% was in a suspended form (COD<sub>susp</sub>). Kjeldahl nitrogen (N<sub>Kj</sub>) was 1 and 1.4 g l<sup>-1</sup> (70% of ammonium, N<sub>NH<sub>4</sub></sub>) and total phosphorus (P<sub>tot</sub>), mainly in the form of organically bounded phosphate, 0.13 g l<sup>-1</sup> (of which 28% soluble ortho-phosphate, P<sub>PO<sub>4</sub></sub>). The pH of influent mixtures was relatively high – 8.7.

The detailed characterisation of the influent to both reactors is given in Table 1 and compared to the theoretical influent composition as found in the literature (Van der Wijs...
Organics removal efficiency

The effluent quality proved the ability of the UASB septic tank to efficiently remove the suspended material through its accumulation and partial biological conversion. The main contributor to the effluent COD$_{tot}$ of UASBST 1 (15°C) was soluble COD (COD$_{sol}$) that originated from the influent and from the hydrolysis process. The low operational temperature affected the methanogenic potential of the system. The average UASBST 1 effluent COD fractions measured in the last four months of operation were approximately 3.7, 1.0, 2.1 and 0.64 gCOD·l$^{-1}$ for respectively COD$_{tot}$, COD$_{susp}$, soluble and colloidal COD (COD$_{sol}$ and COD$_{col}$). The average VFA concentration was high, around 1.0 gCOD·l$^{-1}$.

The obtained effluent quality corresponded to a COD$_{tot}$ removal efficiency of 61% while the COD$_{susp}$ was removed in 88%. Obtained removal efficiencies were comparable to the results obtained in other studies using UASB septic tank. Bogte et al., (1993) and Luosarkin et al., (2005) using the UASB septic tank treating conventional black water (COD$_{tot}$ 1.7–2.7 gCOD·l$^{-1}$) at temperature of 14–17°C obtained respectively 60–69% and 71–77% COD$_{tot}$ and COD$_{susp}$ removal efficiency.

The average effluent COD from the UASBST 2 measured during the last four months of operation were 2.7, 0.6, 1.4 and 0.8 gCOD·l$^{-1}$ for COD$_{tot}$, COD$_{susp}$, COD$_{sol}$ and COD$_{col}$ respectively. The COD$_{tot}$ and COD$_{susp}$ removal efficiencies were 78 and 94% respectively. In the last period of operation kitchen waste was added to the influent. After, the effluent concentrations increased but the removal efficiencies remained high, 82% and 94% respectively. The UASBST 2 effluent characteristics clearly showed that the COD$_{sol}$ and COD$_{col}$ were the main contributors of the COD$_{tot}$, while COD$_{susp}$ was relatively low. The UASBST 2 showed a better performance compared to the UASBST 1 regarding COD removal efficiency. The hydrolysis rate of particulate matter and the methanogenic activity of sludge are higher in higher temperatures. This results in a higher solubilisation of particulate substrate (higher removal efficiency of COD$_{susp}$) and higher biological conversion of the soluble substrate into biogas (increasing the efficiency of COD$_{sol}$ removal).

Table 2 presents the average effluent quality and efficiency of both reactors for all COD...
fractions. In the last column of the table the effluent quality and removal efficiency for UASBST 2 after kitchen waste addition is shown. The efficiency obtained in this study was comparable with the results of Lettinga et al. (1993), where more than 90% COD$_{total}$ removal efficiency was obtained in UASB septic tank treating black water (5.5 gCOD l$^{-1}$) in tropical conditions.

The course of COD fractions in the effluent of both reactors throughout the whole operation period is shown in Figure 2. Low operational temperature and presence of inoculum in UASBST 1, means that no significant differences are evident during the start-up phase and the later period. Slightly higher COD$_{sol}$ and VFA level was measured in the later period, indicating intensification of solubilisation processes. Presence of inoculum enhanced a stable removal of particulate matter from the beginning of the operation. A distinction between start-up and stable operation is more clear for UASBST 2, the non-inoculated reactor but operating at higher temperature. The COD$_{sol}$ declines clearly around the 200th day of operation, from concentrations as high as 3.0 g l$^{-1}$ to around 1.4 g l$^{-1}$ indicating a higher rate of both solubilisation and methanisation.

**Biogas production**

The biogas production was probably underestimated since the average daily biogas production measured at the end of the experimental period was only 6.4 and 8.3 l d$^{-1}$ for UASBST 1 and 2 respectively. After addition of kitchen waste to UASBST 2, the biogas production increased instantaneously to 18 l d$^{-1}$.

**Nutrients**

Nutrients in the effluent of anaerobic reactors were mainly in the soluble form. The average effluent $N_{Kj}$ was slightly lower than of the influent while the average $N_{NH4}$ was slightly higher due to hydrolysis and ammonification of the organically bound nitrogen. The removal of $P_{tot}$ was partially due to precipitation and amounted to 40 and 50% for

### Table 2  Average effluent quality and removal efficiency of COD fractions (mg. l$^{-1}$) in UASBST 1 and 2

<table>
<thead>
<tr>
<th>COD fraction</th>
<th>UA SBST 1 (15°C)</th>
<th>Before kitchen waste addition</th>
<th>After kitchen waste addition</th>
<th>UASBST 2 (25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>effluent quality</td>
<td>% removal efficiency</td>
<td>effluent quality</td>
<td>% removal efficiency</td>
</tr>
<tr>
<td>COD$_{tot}$</td>
<td>3,699 ± 464</td>
<td>61</td>
<td>2,733 ± 491</td>
<td>78</td>
</tr>
<tr>
<td>COD$_{susp}$</td>
<td>976 ± 366</td>
<td>88</td>
<td>586 ± 346</td>
<td>94</td>
</tr>
<tr>
<td>COD$_{sol}$</td>
<td>2,086 ± 449</td>
<td>1,376 ± 186</td>
<td>1,718 ± 60</td>
<td>94</td>
</tr>
<tr>
<td>COD$_{col}$</td>
<td>636 ± 375</td>
<td>771 ± 247</td>
<td>1,463 ± 138</td>
<td>94</td>
</tr>
</tbody>
</table>

![Figure 2](https://iwaponline.com/wst/article-pdf/52/1-2/307/433738/307.pdf)

*Figure 2* Course of COD fractions in the effluent from UASBST 1 (15°C, left) and 2 (25°C, right) from the beginning of operation
UASBST 1 and 2 respectively. The $P_{\text{tot}}$ and $P_{\text{PO4}}$ were very similar in the effluents of both reactors, around 60 and 50 mgP l$^{-1}$ respectively. The average effluent $N_{\text{Kj}}$ and $N_{\text{NH4}}$ of UASBST 1 were 960 and 826 mgN l$^{-1}$ respectively. The average $N_{\text{Kj}}$ and $N_{\text{NH4}}$ in the effluent of UASBST 2 were 1,178 and 1,068 mgN l$^{-1}$ respectively, while after kitchen waste addition these concentration increased to 1,289 and 1,125 mgN l$^{-1}$. Then also the effluent $P_{\text{tot}}$ increased while $P_{\text{PO4}}$ decreased, confirming observed in the earlier research intensification of phosphate precipitation by the presence of kitchen waste (Kujawa-Roeleveld et al., 2003).

**Sludge bed**

The total solid concentration in UASB septic tanks was increasing in time (Figure 3) due to accumulation of particulate fraction from the influent and only its partial solubilization. At the end of the experimental period the sludge bed occupied less than half and one third of the height of UASBST 1 and 2 respectively. The TS on the bottom of the inoculated UASBST 1 (1/5th of the reactor height) was 35 g l$^{-1}$ (86% VS) and was gradually decreasing up to 3 g l$^{-1}$ in the top layer of the reactor while in UASBST 2 these values were respectively 22 g l$^{-1}$ (82% VS) and 4.3 g l$^{-1}$. The average TS of the reactors’ content at the end of the monitored period were 12 and 8 g l$^{-1}$ respectively. Higher conversion rate and lack of inoculation contributed to twice as slow a build up of the sludge bed in the reactor operated at higher T. This has the operational advantage since the withdrawal of the excessive sludge does not need to take place often. The sludge from both UASB septic tanks had similar maximum digestibility of 18% and 20% respectively after 70 days of incubation. Several factors influence the stability of the sludge. Regarding the operational temperature, the UASBST 2 had better conditions to convert the biodegradable substrate from the influent, thus the sludge from this point of view is more stable. The UASBST 1 due to a lower operational temperature was characterised by a lower conversion rate, thus more biodegradable substrate should be present in the sludge (= less stable). From the inoculation point of view, UASBST 1 contained a fraction of stabilised sludge (= more stable). The UASBST 2 was not inoculated and slowly developed its sludge bed.

**Heavy metals**

Having potential reuse of treated effluent and/or stabilised sludge in mind as an important DESAR issue the heavy metals in the effluent were determined. In Table 3 effluent from UASBST 2 is compared with irrigation water quality guidelines (Asano and Levine, 1998) and a commercial fertilizer (Palmquist and Jönsson, 2004). For all studied metals, the effluent concentrations are below the critical concentrations for irrigation, so from this...
point of view these effluents (and sludge) can be considered safe for use as agricultural fertilizer.

**Pathogens**

There was a reduction of *E. coli* in the UASB reactors, higher for higher operational temperature (Figure 4). The lowest obtained *E. coli* count in the effluent from UASBST 2 still does not comply with the standard for, e.g. unrestricted irrigation (WHO, 1989) and from this point of view an additional or more efficient treatment is needed.

**Conclusions**

Two UASB septic tanks fed with concentrated black water at 15 and 25 °C were monitored for a period of one year. The removal efficiencies of COD$_{tot}$ and COD$_{susp}$ in a UASBST at 25 °C were 70% and 92% respectively. The major fraction of effluent nitrogen and phosphate was in a soluble form of ammonium and phosphate, making the product of digestion attractive for nutrient recovery and reuse. Inoculation of the reactor ensures its faster start-up. The build-up of the sludge bed was slow implying that sludge withdrawal does not take place often. Heavy metals content was below the standard for irrigation while the *E. coli* count in the effluent of UASBST does not comply with the standards for agricultural reuse. Further investigation on the range of operational aspects and configurations as well as on the elimination of any health related risk by reuse are needed to set an integrated DESAR concept. The research is currently continued and evaluation of the long-term performance including the design guidelines for the UASB septic tank treating concentrated black water are under preparation.

**Acknowledgements**

The STOWA (Dutch Foundation for Applied Water Research) and Dutch Economy, Ecology, Technology (EET) programme are gratefully acknowledged for their financial support for this project.
References


