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Grey water treatment by using UASB reactor

Sachin Madhavrao Kanawade

Abstract
In this paper, the feasibility of grey water treatment in a UASB reactor was investigated. The batch recirculation experiments showed that a maximum total-COD removal of 79% can be obtained in grey-water treatment in the UASB reactor. The continuous operational results of a UASB reactor treating grey water at different hydraulic retention time (HRT) of 20, 12 and 8 hours at ambient temperature (14-24 8C) showed that 31-41% of total COD was removed. These results were significantly higher than that achieved by a septic tank (11-14%), the most common system for grey water pre-treatment, at HRT of 2-3 days. The relatively lower removal of total COD in the UASB reactor was mainly due to a higher amount of colloidal COD in the grey water, as compared to that reported in domestic wastewater. The grey water had a limited amount of nitrogen, which was mainly in particulate form (80-90%). The UASB reactor removed 24-36% and 10-24% of total nitrogen and total phosphorus, respectively, in the grey water, due to particulate nutrients removal by physical entrapment and sedimentation. The sludge characteristics of the UASB reactor showed that the system had stable performance and the recommended HRT for the reactor is 12 hours.

Keywords: Anaerobic digestion; domestic wastewater; ecological sanitation; grey water; UASB reactor

1. Introduction

In ecological sanitation, the wastewater is considered not only as a pollutant, but also as a resource for fertiliser, water and energy and for closing water and nutrients cycles (Otterpohl *et al*., 1999 [16]; Otterpohl *et al*., 2003 [17]; Elmitwalli *et al*., 2006) [4]. The ecological sanitation based on separation between grey and black water (and even between faeces and urine), is considered a visible future solution for wastewater collection and treatment. Grey water, which symbolises the wastewater generated in the household excluding toilet wastewater (black water), represents the major volume of the domestic wastewater (60-75%) with low content of nutrients and pathogens (Jefferson *et al*., 1999 [9]; Otterpohl *et al*., 1999 [16]; Eriksson *et al*., 2002) [5]. Most grey-water treatment plants include a one or two-step septic-tank for pre-treatment (Otterpohl *et al*., 2003) [17]. The grey-water treatment needs both physical and biological processes for removal of particles, dissolved organic-matter and pathogens (Jefferson *et al*., 1999) [9]. Recently, many researchers have studied the grey-water treatment either by application of high-rate aerobic systems, such as the rotating biological contactor (Nolde, 1999) [15], fluidised bed (Nolde, 1999) [15], aerobic filter (Jefferson *et al*., 2000) [10], membrane bioreactor (Jefferson *et al*., 2000) [10], or by application of low-rate systems, like slow sand filter (Jefferson *et al*., 1999) [9], vertical flow wetlands (Otterpohl *et al*., 2003) [17]. Although high-rate anaerobic systems, which are low-cost systems, have both physical and biological removal, no research has been done until now on grey water in these systems. The grey water contains a significant amount (41%) of chemical oxygen demand (COD) in the domestic wastewater (Otterpohl *et al*., 2003) [17] and this amount can be removed by the high-rate anaerobic systems. Although high-rate anaerobic systems have been successfully operated in tropical regions for domestic wastewater treatment, the process up till now has not been applied in low-temperature regions. The COD removal is limited for domestic wastewater treatment in high-rate anaerobic systems at low temperatures and, therefore, a long HRT is needed for providing sufficient hydrolysis of particulate organics (Zeeman and Lettinga, 1999 [19]; Elmitwalli *et al*., 2002) [3]. The grey water has a relatively higher temperature (18-38 ºC), as compared to the domestic wastewater (Eriksson *et al*., 2002) [3], because the grey water originates from hot water sources, like shower (29 ºC), Kitchen (27-38 °C) and laundry (28-32 °C). Therefore, high-rate anaerobic systems might run efficiently for on-site grey water treatment, even in low-temperature regions. The upflow anaerobic sludge blanket (UASB) reactor is the most applied system for anaerobic domestic wastewater treatment. Accordingly, the aim of this research is to study the feasibility of a UASB reactor for grey water treatment at ambient temperature.

2. Materials and Methods

Experimental set-up

A UASB reactor was installed in the Institute of Wastewater Management and Water Protection, Hamburg University of Technology, Germany. Figure 1 shows a schematic diagram of the system. The grey water was collected from ‘Flintenbreite’ settlement in Luebeck city, Germany. A 1m^3 container was installed in the settlement to collect the grey water, which was transported to the Institute. The collected grey water represented a wastewater of one day and was collected from the inlet sewer-pipe in the first septic-tank in the settlement. The UASB reactor started operation after adding a seed-sludge from an anaerobic digester treating primary and secondary sludge. The UASB reactor was operated

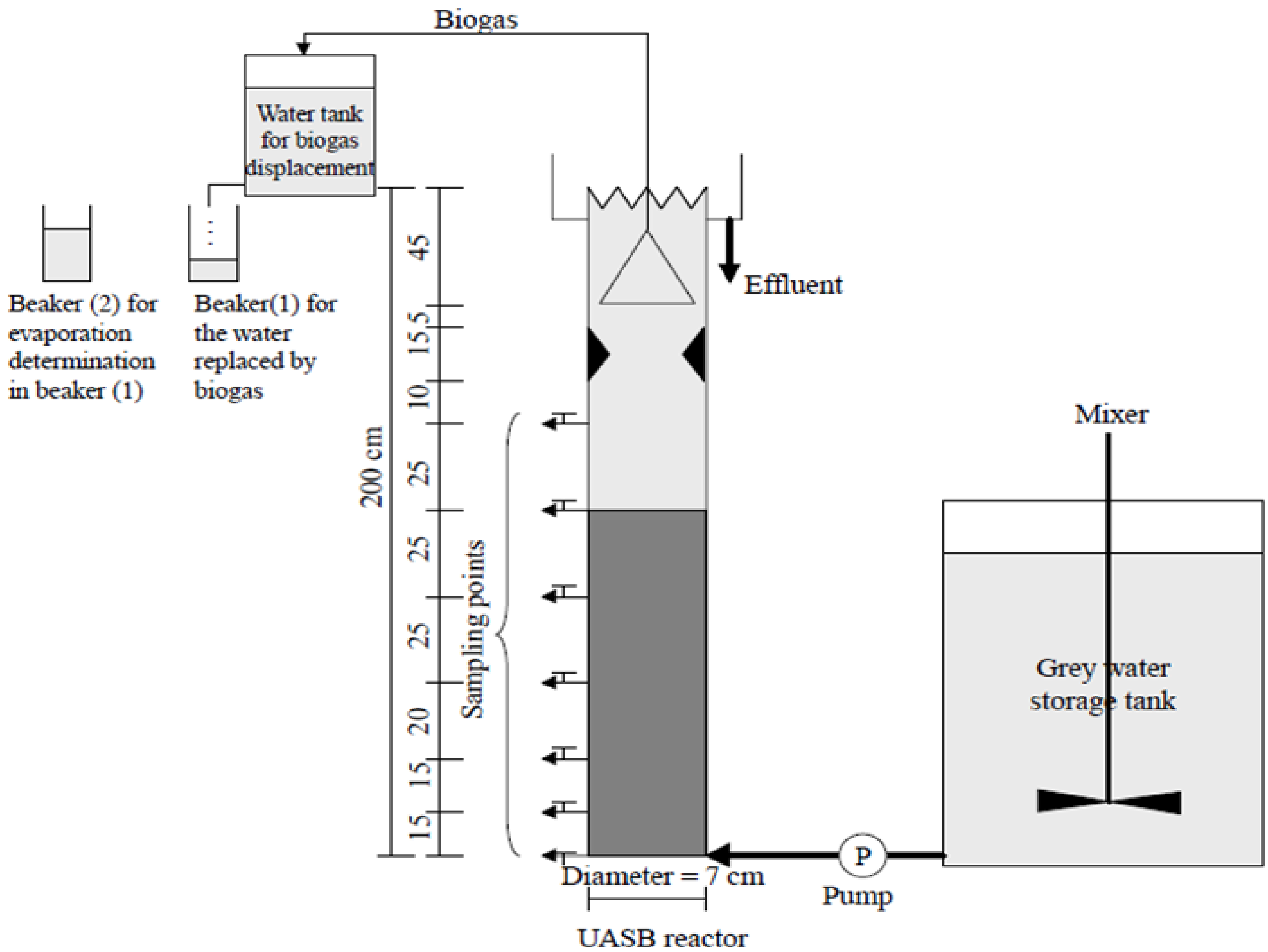

Figure 1 Schematic diagram of the UASB reactor treating grey-water at ambient temperature

At an HRT of 20, 12 and 8 hours for 140, 105 and 93 days, respectively. The septic tank at an HRT of 2–3 days is the most applied system for the pre-treatment of grey water and the main aim of this research is to replace the septic tank by a UASB reactor. Therefore, a column of 7 cm diameter and 2.0 metres height was used for measuring the settling of the grey water. The settling of the grey-water suspended solids (SS) in the septic tank can be represented by the settling of the SS in the column. At the end of continuous operation of the UASB reactor, batch recirculation experiments were carried out two times to determine the maximum removal of COD fractions (suspended, colloidal and dissolved) in grey water. In each batch recirculation experiment, the storage tank was filled with 28 litres of grey water (4 times of the UASB reactor volume) and after 3 HRT of the UASB reactor, the remaining grey water in the storage tank was recirculated in the UASB reactor for a period of 5 days. The COD fractions of the recirculated wastewater in the storage tank were measured in time for determination of the COD-removal course.

Analysis

COD, total Kjeldahl nitrogen (TKj-N), NH4-N, ortho and total P, total solids (TS) and volatile solids (VS) were determined as described by Standard Methods (APHA, 1998). Raw samples were used for total COD, 4.4mm folded paper-filtered samples for CODf and 0.45 mm membrane-filtered samples for dissolved COD. The suspended COD and colloidal COD were calculated by the differences between total COD and CODf, CODf and dissolved COD, respectively. Anaerobic digestibility and maximum specific methanogenic acitivity (SMAmax) tests at a temperature of 30 8C were performed for determination of, respectively, the remaining biodegradable fraction and maximum methanogenic activity of the sludge in the UASB reactor at the end of the each operational phase. The digestibility and the SMAmax were carried out for a mixture of the sludge from each tap in the reactor. The digestibility tests were carried out for a digestion period of 105 and 96 days for phase 1 and 2 respectively. The SMAmax was measured according to Elmitwalli *et al*. (2002), but by measuring COD depletion (instead of acetate depletion) to simplify the test. COD depletion was measured in the second feed with an initial acetate concentration of 1.5 gCOD/l for each feed and a sludge concentration of 2 gVS/l. The SMAmax test was done in duplicate for each sample.

3. Results and Discussion

Batch experiments

1) Settling experiments Figure 2 presents the course of COD fractions in the supernatant (40-50 cm from the top) of the column, which represent the septic-tank. The results showed that after settling of the grey water for a long period of 2-3 days (similar to the HRT of the septic tank), a limited removal of total COD was obtained (11-14%). Moreover, a release of colloidal COD (negative removal) was achieved. This might be due to the presence of lipids and surfactants in the wastewater, which are mainly coming from kitchen and laundry. Therefore, the septic tank is not an effective system for the pre-treatment of the grey water. The septic tank is mainly suitable for domestic wastewater pre-treatment (not grey water), where it can remove 30-40% of total COD (Metcalf and Eddy, 1999) [14].

2) Batch recirculation experiments. Figure 3 shows the results of the batch recirculation experiments. The results demonstrated that the UASB reactor is an efficient system for Grey-water treatment, as the maximum removal efficiencies for Total, suspended, colloidal and dissolved COD were

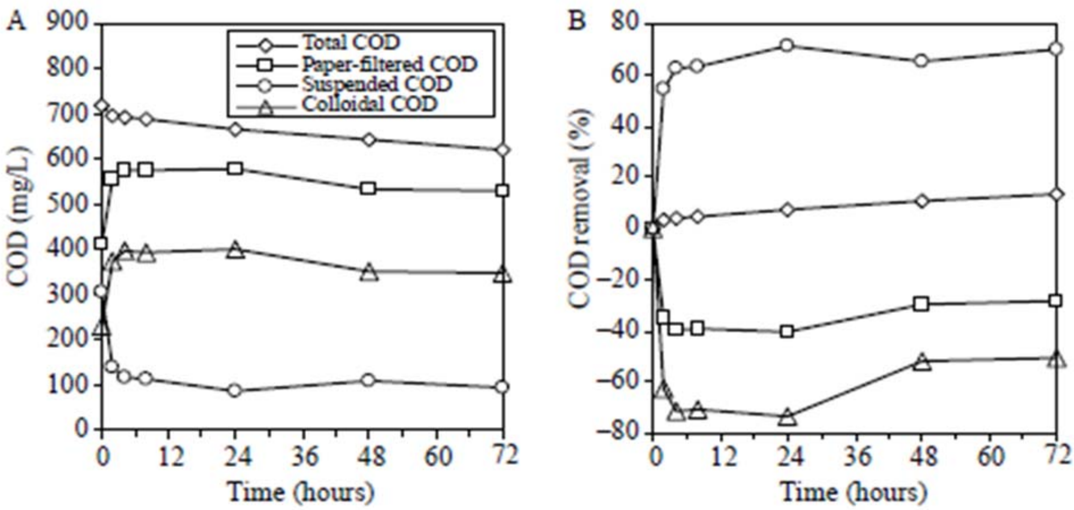

Figure 2 Course of COD-fractions concentration and removal efficiency in the supernatant (40 – 50 cm from the top) of a column representing a septic-tank (wastewater temperature = 17.5 °C)

79, 99, 72 and 66%, respectively. The maximum removal efficiency of grey-water COD fractions is relatively higher than those reported by Last and Lettinga (1992) [11], Wang (1994) [18] and Elmitwalli *et al*. (2000) for presettled, pretreated and raw domestic wastewater, respectively.

Performance of the UASB reactor

1) COD-fractions removal Table 1 shows the concentration and removal efficiency of COD fractions in grey water treatment in the UASB reactor. The results demonstrated that the suspended COD followed by colloidal COD represented the major part of the grey-water total-COD. In domestic wastewater and black water, the major part of total COD is suspended COD followed by dissolved COD (Levine *et al*., 1985 [12]; Elmitwalli *et al*., 2002 [3]; Gaillard, 2002). The particulate (suspended + colloidal) COD represented about 80% of grey-water total-COD, while it corresponded to 65–75% of domestic wastewater total-COD (Wang, 1994 and Elmitwalli *et al*., 2002) [3]. The higher content of particulate in grey water is due to the increase of the colloidal COD percentage (32–43% of total COD), while it is 25–30% of domestic wastewater total-COD (Elmitwalli *et al*., 2002) [3]. The relatively high percentage of the colloidal COD in the grey water might be due to the presence of surfactants and lipids in the wastewater. The percentage of suspended COD was almost similar in both grey water and domestic wastewater (40-48% of total COD), while the percentage of dissolved COD was higher in domestic wastewater (25-35%), as compared to grey water (18-20%).

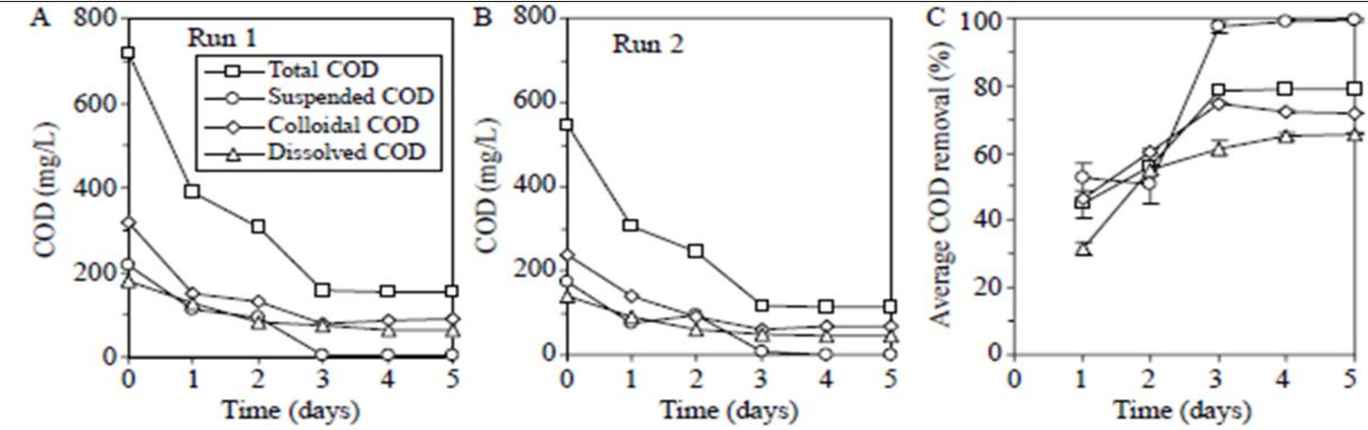

Figure 3 Course of COD-fractions concentration and removal efficiency in the batch recirculation experiments of grey water in the UASB reactor (wastewater upflow velocity and temperature were 0.25 m/h and 20 °C, respectively)

Table 1 Average concentration and removal efficiency of COD fractions and nutrients in grey-water treatment in the UASB reactor at different HRTs. Standard deviations are in brackets

Parameter	Phase 1: HRT = 20 h, temp. = 18 (14–21) °C		Phase 2: HRT = 12 h, temp. = 23 (21–24.5) °C		Phase 3: HRT = 8 h, temp. = 20 (19–21) °C	
	Influent	% Removal	Influent	% Removal	Influent	% Removal
Total COD	681 (124)	31 (5)	647 (137)	41 (13)	682 (106)	33 (7)
Suspended COD	268 (115)	61 (12)	298 (101)	61 (20)	327 (64)	42 (6)
Colloidal COD	291 (122)	18 (13)	231 (86)	28 (22)	219 (71)	28 (27)
Dissolved COD	134 (27)	23 (12)	117 (40)	16 (16)	136 (33)	14 (33)

Although the UASB reactor had the highest HRT (20 hours) in the first phase of operation, the reactor had the lowest total COD removal, mainly because the UASB reactor in phase 1 was operated at a low temperature (average =18 ^{O}C, ranged between 14 and 21 ^{O}C). However, the UASB reactor had a better performance than the septic tank at HRT of 2-3 days (11-14% total-COD removal). In phase 2, although the HRT of the UASB reactor was reduced to 12 hours, the UASB reactor had the highest total-COD removal of 41%, because the reactor was operated in the summer period at an average wastewater temperature of 23 ^{O}C. In phase 3, the total COD removal decreased to 31%, because the HRT of the UASB reactor was decreased to 8 hours at 20 ^{O}C. Accordingly, the UASB reactor treating grey water had a better total-COD removal, as compared to the septic tank, even at a short HRT of 8 hours. From the obtained results, it seemed that the removal of colloidal COD depended on the wastewater temperature, while the removal of suspended and dissolved COD depended on the wastewater temperature and the HRT of the UASB reactor. The results demonstrate that decreasing the HRT of the UASB reactor mainly reduced the total COD removal.

2) Nutrients removal Table 2 illustrates the average concentration and removal efficiency of nutrients (N and P) in grey-water treatment in the UASB reactor. The results indicated that the grey water had a limited amount of nitrogen, which was mainly in particulate form (80-90%), while in the black water and domestic wastewater, most of the nitrogen is soluble as NH_4. The concentration of phosphorus in grey water was almost similar to that in domestic wastewater (6.8-8.6 mg total-PO4-P/L for Dutch municipal wastewater, Elmitwalli *et al*., 2002) [3]. The UASB reactor removed only the particulate nutrients by physical entrapment and sedimentation and, therefore, it had relatively low removal of nutrients. Although the UASB reactor was efficient in the removal of the suspended COD, the reactor had a limited removal of particulate nutrients, especially particulate nitrogen. Therefore, it seemed that most of the particulate nutrients in the grey water were in colloidal form, as the UASB reactor had a limited removal of colloidal COD.

Table 2 Average concentration and removal efficiency of nutrients (N and P) in grey-water treatment in the UASB reactor. Standard deviations are in brackets

Parameter	Phase 1: HRT = 20 h temp. = 18 (14–21) °C		Phase 2: HRT = 12 h temp. = 23 (21–24.5) °C		Phase 3: HRT = 8 h temp. = 20 (19–21) °C	
	Influent	% Removal	Influent	% Removal	Influent	% Removal
Total PO_4-P	9.9 (0.3)	24 (8)	9.7 (0.7)	21.6 (9.1)	9.9 (0.8)	10.1 (2.9)
Ortho PO_4-P	6.6 (1)	16 (5)	8.7 (1.2)	20.1 (9.9)	8.4 (0.1)	15.6 (2.8)
Particulate PO_4-P	3.3 (0.7)	39 (8)	1 (0.5)	53 (32.2)	4.3 (4.3)	33.3 (62.8)
TKj-N	27.1 (3.5)	24 (4)	27.3 (4.5)	35.6 (2.3)	–	–
NH_4-N	5.5 (0.8)	4 (28)	3.9 (1.0)	2.3 (26.1)	3.5 (1.6)	8.6 (72.6)
Particulate N-N	21.6 (3.3)	29 (10)	24.4 (12)	40.2 (6.2)	–	–

3) Sludge characteristics and biogas production. Figure 4 explains the sludge profile in the UASB reactor at the end of each phase and Table 3 presents the characteristics of the sludge. The results indicate that the sludge concentration in the reactor increased on increasing the HRT and decreasing wastewater temperatures. The average sludge concentration in the UASB reactor (7-11 g VS/L) is lower than that reported in the treatment of municipal wastewater. The relatively low sludge concentration in the UASB reactor treating grey water is mainly due to the lower VS/TS ratio, as compared to that in the treatment of municipal wastewater (60-85%, Elmitwalli *et al*., 2002 [3]; Mahmoud, 2002) [13]. The UASB reactor treating grey water had a relatively low VS/TS ratio, because the reactor was treating raw grey water, without grits removal. Therefore, the grits in the raw grey water, like fine sand and inorganic material, precipitate in the reactor, resulting in low VS/TS ratio. The sludge profile, visual observations and COD/VS ratio confirm the previous assumption. The COD/VS ratio is similar to that reported for the treatment of municipal wastewater in the UASB reactor (Mahmoud, 2002) [13]. The sludge digestibility results demonstrate that the operation of the reactor in summer (phase 2) stabilised the accumulated sludge in the reactor. Moreover, the SMAmax was higher in phase 2, as compared to that of phase 1 and 3, due to relatively higher temperature in phase 2. The long sludge residence time (SRT) and low sludge-digestibility illustrated that the sludge in the reactor had a sufficient stability.

The results of biogas production showed that about 48, 63 and 56% of the removed total COD were converted to methane in, respectively, phase 1, 2 and 3. The previous values were calculated based on the measured biogas production and assumption of 75% methane in the biogas (based on the biogas composition in previous studies in the treatment of municipal wastewater in the UASB reactor, Elmitwalli *et al*., 2002 [3]; Halalshah, 2002 [7]; Mahmoud, 2002) [13]. The highest conversion of the wastewater to biogas was in phase 2, due to relatively higher temperature. This led to improvement of particulate hydrolysis and methanogenesis in the reactor, as shown by higher SMAmax in phase 2.

Final discussion

The batch recirculation experiments showed the application potential of the UASB reactor in grey water treatment, as a high value (79%) of maximum total COD removal was achieved. However, the results of continuous treatment of the grey water in the UASB reactor showed that a relatively low removal of total-COD (31-41%) was obtained at HRT between 8 and 20 hours and wastewater temperature between 14-24 8C. However, this value is higher by 2-3 times than that can be achieved by septic tank (the common system for grey water pre-treatment). Moreover, the real temperature of grey water ranges

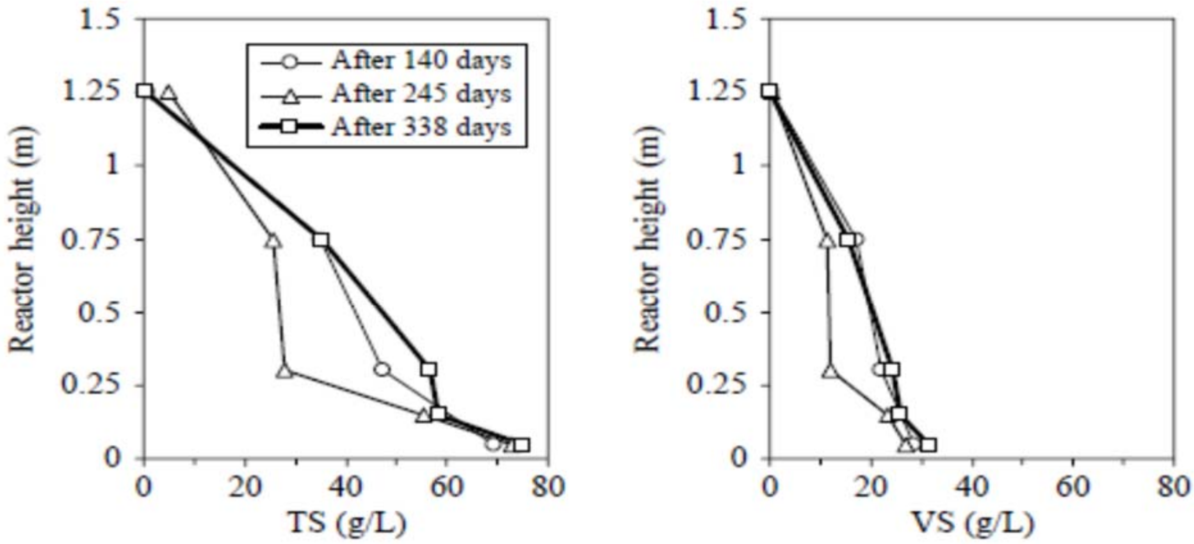

Figure 4 Sludge profile in the UASB reactor at the end of each operational phase

Table 3 Characteristics of the sludge taken from the UASB reactor at the end of each phase. Standard deviations are in brackets

Parameter	Influent	Influent	Influent
	Phase 1: HRT = 20 h, temp. = 18 (14–21) °C	Phase 2: HRT = 12 h, temp. = 23 (21–24.5) °C	Phase 3: HRT = 8 h, temp. = 20 (19–21) °C
Average VS (g/L)	11	7	8.7
Average VS/TS (%)	59	41	43
COD/VS (mg/mg)	2.1	1.90	1.86
SRT* (days)	432	312	330
Digestibility (% kg COD/kg COD)	25 (3)	16 (2)	–
SMA_{max} (kg COD/(kg VS.day))	0.05 (0.01)	0.08 (0.015)	0.07 (0.01)

*Calculated based on the excess sludge at the end of each phase

Between 18 and 38 ^{O}C (Eriksson *et al*., 2002), which is higher than that applied in this research. Therefore, the on-site treatment of grey water in a UASB reactor can result in a higher total COD removal, as compared to that achieved in this research. The UASB reactor treating grey water should have a longer HRT, as compared to that treating domestic wastewater, because the grey water has a high peak flow factor of 6.2 (Imura *et al*., 1995). Grey water is produced over short periods, whereas toilet flushing takes place more consistently through the day. Therefore, a HRT of 12 hours can be considered the suitable HRT for grey water treatment in a UASB reactor at ambient temperature. The UASB reactor can be applied for on-site grey water treatment in urban and rural areas. In urban areas, the effluent of the UASB reactor, which is almost free of SS, can be transported by a small bore sewer system (low cost system) to the nearby available areas, where it can be post treated and reused in urban agriculture. The application of the UASB reactor for grey water treatment will increase the application potential of ecological sanitation based on separation between grey and black water. It is assumed within the ecological sanitation that the produced biogas will be utilized for electricity production and/or heating.

For example, in the settlement of 'Flintenbreite' in Luebeck city, Germany, the produced biogas from anaerobic digester of black water and kitchen organic-wastes is used for heating and electricity production. In the settlement, the grey water is pre-treated in a two-step septic-tank followed by vertical wetlands. Such a system needs a long HRT, while at application of a UASB reactor for the pre-treatment of the grey water, a short HRT can be applied. Moreover, the produced biogas can be utilised for heating and production of electricity, if it is combined with the produced biogas from the anaerobic digester of the black water and kitchen organicwastes. Also, due to higher removal efficiency of total COD and partial removal of nutrients in the UASB reactor, the hydraulic loading of the post-treatment system (like vertical wetlands in the settlement) can be increased and, accordingly, a small land area will be required.

4. Conclusions

The grey water contained a higher amount of colloidal COD, as compared to that reported in domestic wastewater. The grey water had a limited amount of nitrogen, which was mainly in particulate form, while the concentration of phosphorus in grey water was almost similar to that in domestic wastewater. The batch recirculation experiments showed that a maximum total COD removal of 79% can be obtained in treatment of the grey water in a UASB reactor. The continuous operational results of a UASB reactor treating grey water at different HRTs of 20, 12 and 8 hours at ambient temperature (14–24 ^{O}C), showed that 31–41% of the total COD can be removed. These results are significantly higher than that achieved by a septic tank (11–14%), at HRT of 2–3 days. Moreover, the UASB reactor removed 24–36% and 10–24% of, respectively, total nitrogen and total phosphorus in the grey water.

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