Reclaimed Domestic Wastewater as a Sustainable Unconventional Water Resource

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Abstract

A promising technology, recently developed, is the combined Up-flow Anaerobic Sludge Blanket (UASB)-Down-flow Hanging Sponge (DHS) system for domestic wastewater treatment for developing countries. A combined system was operated for 325 days at a temperature of 25 ºC to examine the effect of transient and step hydraulic changes on the performance of a combined system in terms of COD, BOD5, TSS, and ammonia.

The results obtained indicated that, both transient and step changes in HRT (four fold decrease in the reference HRT of 32h), and the concomitant increase in organic loading rate (OLR), doesn't have any impact on the performance of the combined system. The final effluent concentrations of COD, BOD5, TSS and faecal coliform were always extremely low, in compliance with the standards of the most of developing countries for reuse in agricultural purposes. Removal efficiencies up to 85±7% in total COD, 92±8 % in total BOD5, and 99.65 % in F.coliform have been obtained in the combined system at an HRT of 6.0 h in the UASB reactor and 2.0 h in the DHS system. The calculated nitrification rate of the DHS system according to the nitrate production amounted to 0.11kgNO3-N/m3.d at an OLR of 3.1 kgCOD/m3.d. The sludge yield coefficient in the combined UASB and DHS system amounted to 0.28 and 0.068 gTSS/gCOD removed/day respectively. In view of these results, we recommend to use a combined system consisting of an UASB reactor and DHS system for COD, BOD5, ammonia and F.coliform removal at a total HRT of 8h (6h for UASB-2h for DHS) for sewage treatment.

Keywords: Sewage; UASB; DHS; Hydraulic load; BOD; F.coliform

Introduction

Various countries in arid and semi-arid regions are confronting water shortage issues. This gap between supply and demand is closely linked with agricultural production, environmental conditions, and climate changes. It is also probably due to reduced amounts of precipitation, decrease in natural groundwater recharge and low availability of natural water sources. Special ventures have to be undertaken in order to supply water at adequate quality for all utilization purposes. These can be accomplished by development of additional water sources that currently are considered marginal. The additional sources include domestic wastewater, runoff water and sea water for desalination. Domestic wastewater represents a sustainable unconventional water resource. Wastewater reuse provides both an additional supply of water for irrigation and a low cost source of nutrients and organic material which can act as crop fertilizer and soil conditioner. However, the deleterious impacts caused by the reuse of raw sewage or poorly treated effluents on public health are well known. The world health organization has stated that the removal of pathogenic bacteria is the principle objective for treatment of wastewater that is destined for reuse in agriculture (WHO,1989). The degree of treatment required various according to the specific reuse application and associated water quality requirements. Therefore, it becomes more and more important to develop appropriate wastewater treatment processes, which combine high treatment efficiency with low capital investment and maintenance costs, as well as simple operation requirements.

An affordable and sustainable technology namely Down- flow Hanging Sponge (DHS) in combination with Up-flow Anaerobic Sludge Blanket (UASB) as a pre-treatment has been originally developed by us for sewage treatment for developing countries. The DHS system constitutes a simple in design and operation, economic treatment option and is able to produce in combination with UASB reactor consistently a final effluent quality equal or better than that of a conventional activated sludge plant (Uemera *et al.,* 2000). Moreover, it represents a quite compact reactor system with a sufficiently long biomass retention time, allowing the application of higher volumetric loading rates at low energy cost and easy to operate at high process stability.

The 1st (cube type) and 2nd (curtain type) generation of DHS system in combination with UASB reactor for treatment of domestic sewage at temperature of 25 °C has been performed by (Agrawal *et al.,* 1997, Machdar *et al.,* 1997,2000). For corrections of some drawbacks of the 1st and 2nd generation of DHS system, the 3rd generation (random type) in combination with UASB reactor for sewage treatment will be investigated in detail here. Our proposed system (DHS-Random type) has several advantages compared to conventional trickling filter (TF). The TF of which micro-organisms attach themselves only to a media surface creating a biological filter or slime layer, but in 3rd generation DHS system the micro-organisms retained outside and inside the sponge which create a long sludge residence time (>100 days) (Tawfik *et al.,* 2006) and consequently, achieve a complete nitrification and produce a very low amount of excess sludge. Once again, DHS system brings the following advantages compared to conventional TF, the amount of active biomass brought in contact with the wastewater is very high and the biological process is very fast, thus very short retention time is needed which gives small plants with no investment cost. The process is in contrast to conventional TF which needs a very low loading rate to achieve a nitrification process (Chernicharo and Nascimento, 2001). Moreover, it is easy to enlarge the capacity of DHS system in case the flow and/or the organic load would increase in the future. In earlier research (Tawfik *et al.,* 2006), we found that, a 3rd generation of DHS system in combination with UASB reactor can also be used successfully for sewage treatment at low temperature of 15 °C and total HRT of 10.66 h (8.0 h for UASB and 2.66 h for DHS system.

The aim of this work is to (1) investigate the stability of the UASB- DHS system to step changes in organic and hydraulic changes over a period of time for COD, BOD_5, TSS and faecal coliform removal. Moreover, the sequence of in the elimination of organic matter, ammonia and F. coliform along the height of the DHS system was assessed and (2) produce an effluent quality complying for reuse in agricultural purposes.

Material and Methods

1 Experimental set-up of the pilot plant

A combined UASB-DHS system was situated and operated at Nagaoka sewage treatment plant, Japan (Fig.1). The sewage used in the experiment originated from the city Nagaoka. The sewage collected in a combined sewer system and is continuously pumped to the UASB reactor. The operational temperature of the total system was controlled at 25 °C to simulate the annual average ambient temperature in the most of developing countries. Table 1 shows the characteristics of the used sewage.

Table 1 average sewage characteristics used for the experiments

COD (mg/l)			BOD_5 (mg/l)			Nitrogen (mg/l)		F. coliform/100ml
Total	Sol.	Part.	Total	Sol.	Part.	NH4	TKN	
480±122	187±36	293±101	194±55	81±31	113±49	24±4	52±8	$4.6x10^6±2.1x10^6$

1.1 UASB reactor

A schematic diagram of the UASB reactor is shown in Fig. 1. The UASB reactor had a working volume of 155 l, height of 4.0 m, and an internal diameter of 0.224 m. Eighteen ports for obtaining sludge samples are arranged along the length of the reactor, the first one at 0.2 m above the base of the reactor and the others at the same level. The reactor contains a three identical conical Gas Solids Separator (GSS) at the top of the tank with a height of 0.4 m. The gas produced was directly measured by gas meter (LW-1). The UASB reactor was seeded with primary digested sludge from the wastewater treatment plant of Nagaoka city, Japan. The seed sludge had a concentration of 16.0 g/l for TSS and 9.0 g/l for VSS. The total amount of digested sludge added to the reactor was approximately 91l sludge which represents 59 % of the total reactor volume.

1.2 DHS system

Fig. 1 shows a schematic diagram of the DHS system. The DHS system was made of plexi-glass, with a capacity of 136 l and had an internal diameter of 0.22 m. The height of the reactor is 3.5 m. The DHS module occupied with a sponge volume of 51.6l which represents 38% of the reactor volume. The dimensions of the used sponge (cylindrical shape) amounted to 27 mm height*22mm diameter. The polyurethane material (CF type) used is supported by perforated polypropylene plastic material with fins to avoid clogging of the reactor. The sponge criteria are surface area (256m^2/m^3), density (30kg/m^3), void ratio (0.9), and pore size of 0.63 mm). The UASB reactor effluent flows by gravity to the distributor which located on the top of the DHS system and rotating at 19 rpm.

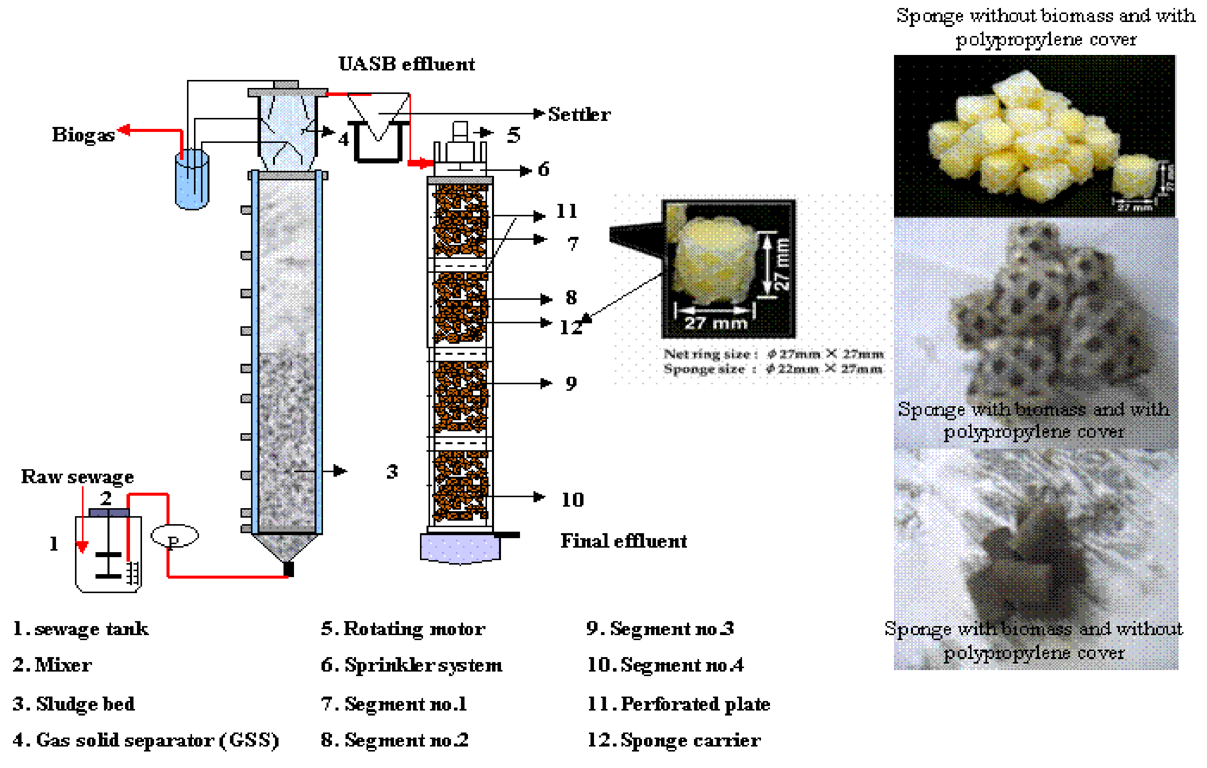

Fig.1 schematic diagram for a combined UASB-DHS system treating domestic wastewater.

1.3. Sampling and analysis.

Grab samples at certain time of the buffer tank (influent), the UASB reactor effluent and final effluent of DHS system were collected and immediately analyzed. The COD $_{total}$, BOD$_5$ $_{total}$, TSS, VSS and Faecal coliform (membrane filtration technique) were determined according to APHA (2005)**.** Raw samples were used for COD $_{total}$, BOD$_5$ $_{total}$ and 0.45 um membrane filtered samples for dissolved COD and BOD$_5$. The particulate COD and BOD$_5$ were calculated by the difference between COD $_{total}$, BOD$_5$ $_{total}$ and COD $_{filtered}$, and BOD$_5$ $_{filtered}$ respectively. Ammonia, nitrite and nitrate were determined by HPLC. Total Kjeldahl nitrogen (TKN), was measured according HACH method. Parameters like pH, DO, oxidation reduction potential (ORP) and temperature were daily measured.

DHS profile samples were collected at different locations of 80, 160, 240 and 320 cm of the water phase from DHS system by gently inserting a plastic container of 30 cm length, 20 cm, width and 5 cm depth (3l volume). Moreover, during the operation of the DHS system, biomass retained in the sponge was monthly harvested at various DHS –heights. The sludge was squeezed by distilled water and then total and volatile solids were determined in duplicate samples. Total and volatile solids were calculated according to sponge volume.

Results and Discussion

1 Impact of transient hydraulic changes on the performance of UASB/DHS system treating domestic sewage at a temperature of 25 ºC

Initially the Up-flow Anaerobic Sludge Blanket (UASB) was operated at low hydraulic loading rate (HLR) of 0.056 m^3/m^2.d, and long Hydraulic Retention Time (HRT) of 24 h after the sludge had been added to the reactor (Fig.2a). After six weeks of UASB operation at a temperature of 25 °C, 57±26% removal for total COD was achieved. Thereafter, the Down-flow Hanging Sponge (DHS) for post-treatment of UASB reactor effluent was started up. The initial imposed HLR and HRT for the DHS system were 0.011 m^3/m^2.d and 8.0 h respectively.

The results presented in Figs. 2b, c, d, e 3a, and b. show that, after 16 days, DHS system in combination with UASB reactor provided an average removal efficiency of 83±8% for COD $_{total}$, 68±5% for COD $_{soluble}$, 82±21% for BOD$_5$ $_{total}$, 77±35% for BOD$_5$ $_{soluble}$, 91±6% for TSS and 72±12% for ammonia

Afterwards, the HLR was doubled (0.112 m^3/m^2.d for UASB reactor and 0.023 m^3/m^2.d for DHS system) and maintained for 22 days. This corresponds to HRT of 12.0 h for UASB and 4.0 h for DHS system. During all these operational days the behavior of the total process was efficient, with COD $_{total}$, COD $_{soluble}$, BOD$_5$ $_{total}$, BOD$_5$ $_{soluble}$, and TSS removal efficiency higher than 86±7, 79±8, 95±5, 96±5, and 86±12 % respectively. Despite the increase of HLR imposed to DHS system by 0.011 m^3/m^2.d , a nitrification rate of 0.13 kgNO_3-N/m^3.d (82±6 %) was achieved in DHS system, when operated at organic loading rate (OLR) of 1.7 kgCOD/m^3.d (Fig. 3b). The concentrations of ammonia and nitrate in the final effluent amounted to 5± 1.6 and 21± 5 mg/l respectively.

The final experimental stage was 28 days of operation (day 43 to 71). During this period, the HLR was doubled again (0.224 m^3/m^2.d for UASB reactor and 0.047 m^3/m^2.d for DHS system), which corresponds to 8.0 h of HRT for UASB and 2.7 h for DHS system. Likewise, during this period, the combined system performance was indeed excellent, with COD_{total}, $COD_{soluble}$, $BOD_{5\ total}$, $BOD_{5\ soluble}$, and TSS removal efficiency up to 93±3, 88±5, 96±1.5, 95±3 and 96±4% respectively and no signs of instability (Figs. 2b, c, d, e and 3a). Lower removal efficiencies has been achieved (COD= 78.6–83.0%, BOD5= 92.5–94.0% and SS = 80.9–92.7%) in an anaerobic baffled filter reactor followed by aerobic post-treatment at longer HRT of 15 and 4 h, respectively (Bodık *et al.,* 2003).

Once again, although the HLR imposed to DHS system was almost doubled (0.047 m^3/m^2.d). The DHS system achieved an average removal efficiency of ammonia up to 77±11%, resulting only 7.0 ±3 mg NH_4-N/l and produced 20±7 mg NO_3-N/l in the final effluent. This indicates that, the system not only has been operated under organic substrate limiting conditions but also ammonia substrate limiting conditions. Therefore, in that case the combined system certainly can accommodate HLR's twice as high (0.224 m^3/m^2.d for UASB and 0.047 m^3/m^2.d for DHS system), without any risk of deterioration in the final effluent quality, at least as far as organic matter and partially ammonia removal concerned.

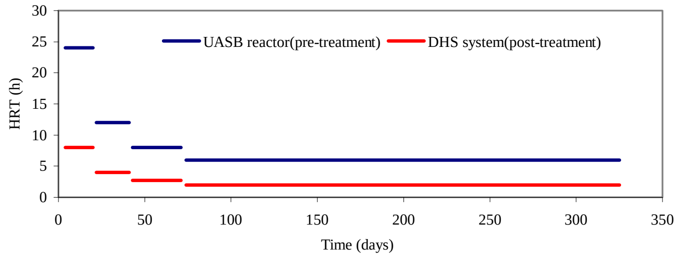

Fig. 2a transient hydraulic steps conditions during start-up period and steady state operating conditions of the combined UASB-DHS system treating domestic sewage.

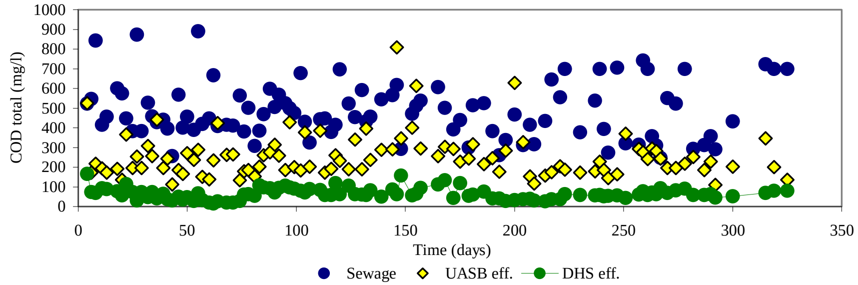

Fig.2b time course of COD total along treatment system.

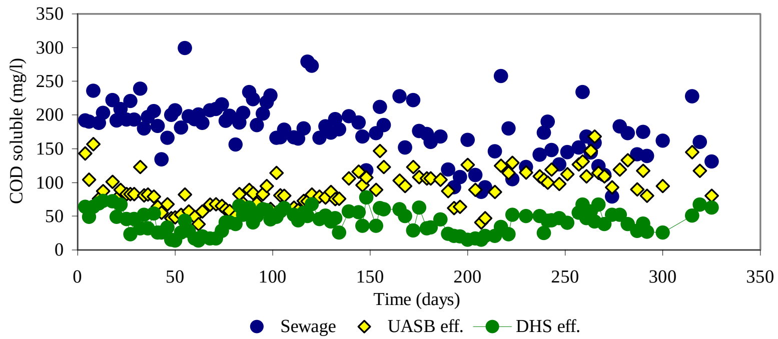

Fig.2c time course of COD soluble along treatment system.

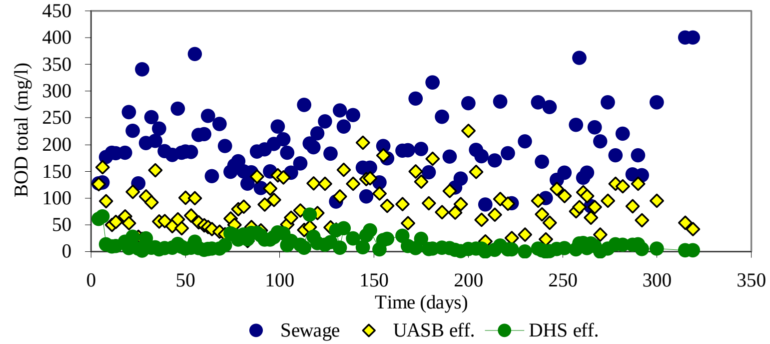

Fig.2d time course of BOD total along treatment system.

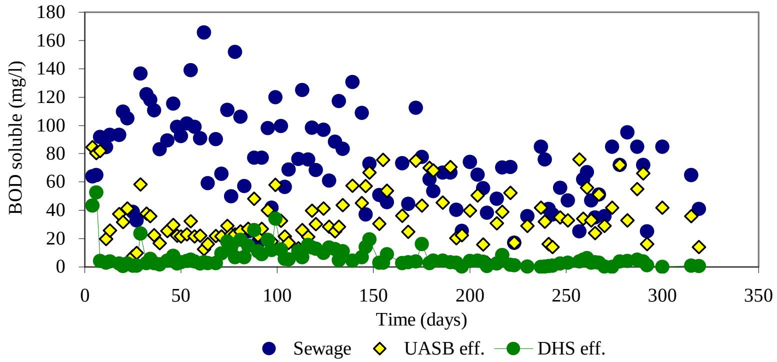

Fig.2e time course of BOD soluble along treatment system.

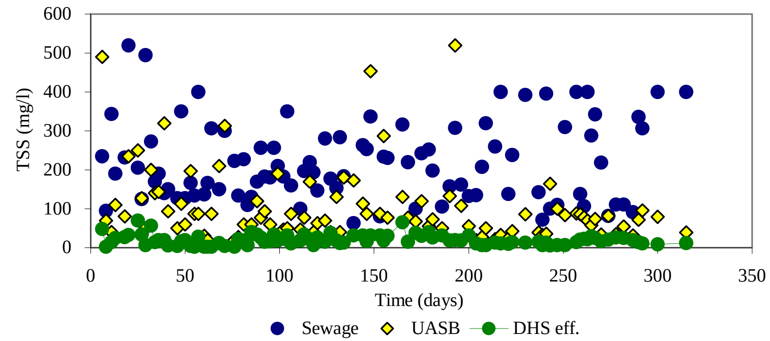

Fig.3a time course of TSS along treatment system.

In these experiments (day 73 to 325), the total HRT was decreased to 8.0 h (6.0 h for UASB and 2.0 h for DHS system) and operated at a temperature of 25 °C. The applied HLR to the UASB reactor and DHS system amounted to 0.448 and 0.095 m^3/m^2.d respectively. The course values for total COD and total BOD_5 are presented in Figs. 2b and d. The results clearly reveal that, the combined system achieved a substantial reduction of COD_{total}, $COD_{soluble}$, $BOD_{5\ total}$, and $BOD_{5\ soluble}$ resulting in an average effluent concentrations of only 68±25, 45±15, 15±13 and 7±6 mg/l. This indicates the high efficiency of the combined system for the removal of organic matter at a relatively short HRT and high HLR. Certainly, the high removal efficiency of the UASB reactor for organic matter at high temperature conditions of 25 °C, affects positively the performance of the DHS system. The experimental results with UASB-DHS system indicate that removal efficiencies of COD and BOD_5 are similar to those obtained by Machdar, *et al.,* (1997, 2000), who used the UASB in combination with the 1st generation (cube type) and 2nd generation (curtain type) of DHS system at the same operating conditions. Higher COD values (60-120 mg/l), BOD_5 values (>60mg/l) and TSS (>30 mg/l) have been reported by Chernicharo and Nascimento (2001) who used UASB/trickling filter for treatment of domestic sewage. Torres and Foresti, (2001), evaluated the sewage treatment system consisting of an UASB reactor followed by an aerobic sequencing batch reactor (SBR). COD and TSS overall efficiency up to 91% and 84% respectively were obtained at longer HRT of 30h (6h for UASB and 24 h for SBR).

The results presented in Fig. 3a shows that, the total process achieved an almost complete removal of suspended solids. Residual values in the final effluent were around 20±10 mg/l. This excellent performance towards the removal of suspended solids can be attributed to entrapment or / and adsorption followed by hydrolysis and degradation. The DHS in combination with UASB reactor not only performed very satisfactory for the removal of organic matter but also a considerable ammonia reduction was accomplished. The results in Fig 3b reveal that about 48% of the ammonia reduction was due to nitrification. The calculated nitrification rate according to nitrate production amounted to 0.11 $kgNO_3$-N/m^3.d.

Fig. 3c show that the residual value of F.coliform in the final effluent of the combined system amounted to $1.4x10^4 \pm 1.2x10^4$/100ml i.e. corresponding to a removal value of 2.07 log_{10} (99.65%). Further reduction of F.coliform was obtained by storage the treated effluent in a storage tank for 24 days. The decay rate of F.coliform increased with time as shown in Fig.3d. Average residual counts after a storage period of 13 and 20 days were $1.2x10^3 \pm 2.8x10^2$ and $0.5x10^3 \pm 1.4x10^2$/100ml, respectively. These values are in combination with those given by WHO (1989) for unrestricted irrigation purposes and as well as for discharge to surface water, where the F.coliform concentration amounts to less than 1000 F.coliform /100ml. Similar results have been obtained by Roeleveld *et al.,* (2003). They found that increasing the storage period from 84 to 120 leads to a decrease in the *E. coli* concentration in the accumulation system (AC) treating black wastewater.

2. DHS profile for wastewater and retained biomass

Profile of dissolved oxygen (DO) concentration and oxidation reduction potential (ORP) along the height of DHS system shows a gradual increase in the concentration of DO as the wastewater flows down (Fig. 4a). DO and ORP in the final effluent was in the range of 4-5.6 mg/l and 120-200 Mv respectively.

Figs. 4b, c, d, and e present the COD, BOD_5, ammonia and F. coliform concentrations along the DHS system at an HRT of 2.0 h and HLR of 0.095 m^3/m^2.d. The profile results show that in the upper part of the DHS system, mainly COD_{total}, and $BOD_{5\ total}$ was removed. White material, possibly sulfur was observed on the sponge in the upper part of the system. Nitrification occurred in the lower part of DHS system, where nitrifiers are available.

The results for DHS biomass profile presented in Fig. 5 shows a reduction in TSS and VSS concentrations from top to the bottom. No significant difference in water content (98%) and solid content (2%) has been detected in the biomass along DHS system height (Fig.5).

3. Excess sludge production in a combined system

Table 2 summarizes the average characteristics of the excess sludge from UASB and DHS system. The results show a substantially lower excess sludge of the combined system in comparison with that from activated sludge process treating domestic sewage (Wang, 1994). The excess sludge in the UASB and DHS system has the same VSS/TSS ratio of 0.7 which indicates the need for further sludge stabilization for example by using anaerobic digestion. The relatively low sludge volume index (SVI) of the UASB and DHS system reveals high settleability. Moreover, the sludge yield coefficient in the combined UASB and DHS system amounted to 0.28 and 0.068 gTSS/gCOD removed respectively.

Table 2 average characteristics of the excess sludge from the UASB and DHS system treating domestic wastewater

parameters	TSS (g/l)	VSS (g/l)	TSS/VSS	SVI (ml/g)	Sludge production (g/d)	Sludge yield coefficient (gTSS/gCOD removed).
UASB reac or	6.6±6	5±4.6	.74±0.05	117±87	42±42	0.28
DHS system	5.8±2	4. ±2	0.73±0.06	56 20	5±3	0.068

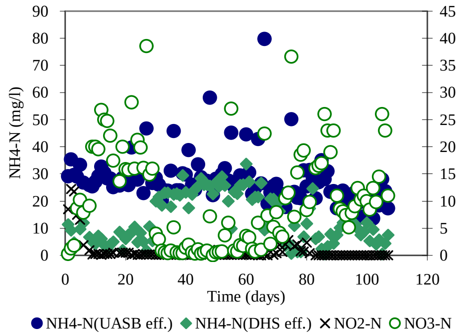

Fig.3b time course of NH4-N, NO3-N and NO2-N in the effluent of DHS system treating UASB effluent.

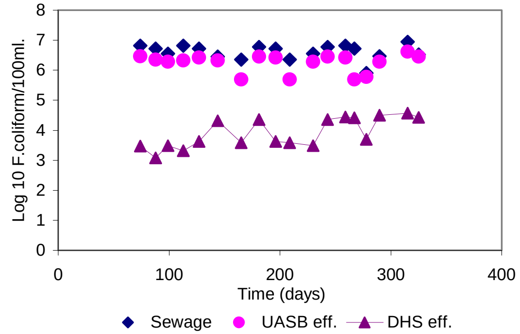

Fig.3c time course of F.coliform along treatment system.

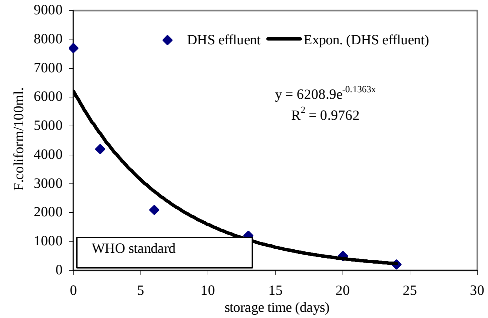

Fig.3d time course of F.coliform removal (decay) during storage period of DHS effluent.

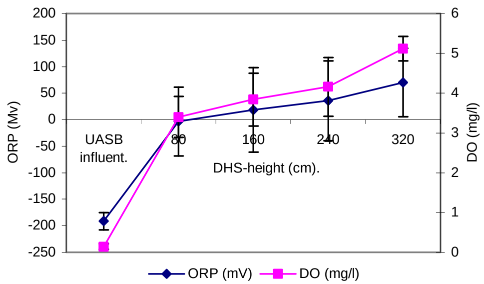

Fig. 4a ORP and DO along DHS system height.

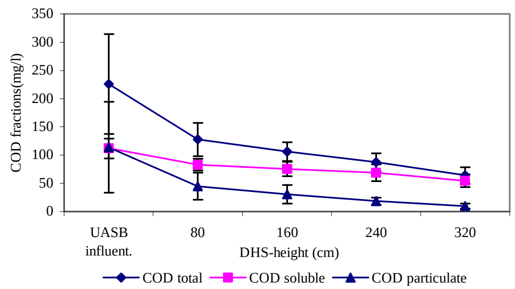

Fig. 4b COD total, soluble and particulate along DHS system height.

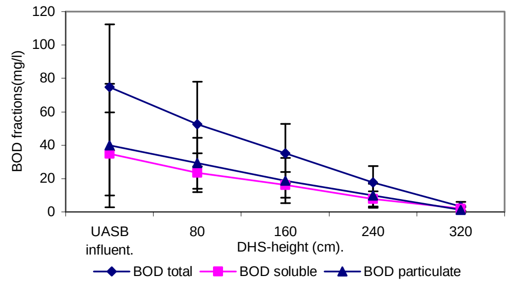

Fig. 4c BOD total, soluble and particulate along DHS system height.

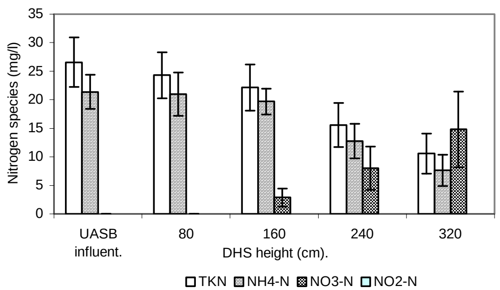

Fig. 4d nitrogen species along DHS system height.

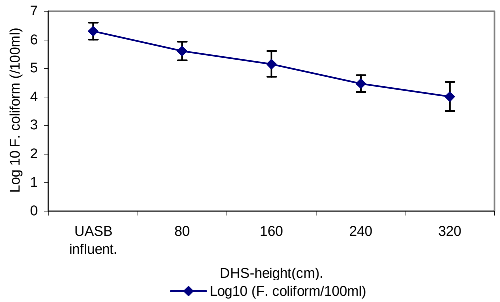

Fig. 4e F.coliform removal along DHS system height.

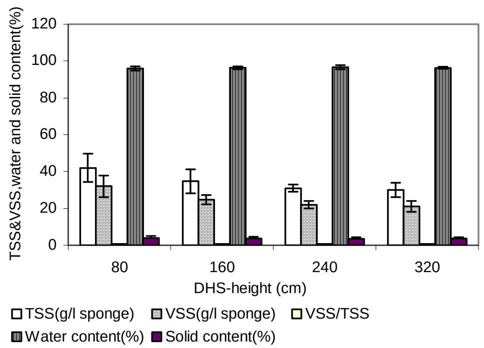

Fig.5 DHS biomass profile.

Conclusions

- A treatment scheme consisting of an UASB reactor followed by DHS system and operated at a temperature of 25 °C can produce an excellent effluent quality. Moreover, it has been found that, both transient and step changes in HRT (four fold decr ase in the refe ence HRT of 32h , and the conco itant increase n HLR, doesn't ave any negativ impact on the erformance of the combined system. The final effluent concentrations of COD, BOD_5 and TSS were always extremely low, and in compliance with standards of most of developing countries for reuse in agricultural purposes. The recycling, reuse or disposal of the side streams generated should be explored further and evaluated in future research.
- Removal efficiencies up to 85±7% in total COD, 92±8 % in total BOD_5, and 99.65 % in F.coliform have been obtained at an HRT of 6.0 h in the UASB reactor and 2.0 h in the DHS system.
- The sludge yield coefficient in the combined UASB and DHS system amounted to 0.28 and 0.068 gTSS/gCOD removed/day respectively.
- The F.coliform in the effluent of DHS system was ultimately removed after storage period of 20 days.

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