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Research Note

Performance Evaluation of UASB System for Treating Slaughterhouse Wastewater

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Direct discharge of high-strength industrial effluent often upsets municipal wastewater treatment plant processes. This pilot study was undertaken to evaluate the performance of a UASB system in pre-treating effluent from a medium-size traditional slaughterhouse. Experiments were conducted in a continuous flow 500-l pilot plant initially inoculated with 200 l municipal anaerobic digested sludge. With an influent COD concentration of 3000-5000 mg/l, the system was started with a loading of 1.8 kg COD/m^3.d (F/M of 0.24 kg COD/kg VSS.d) at 25°C. The granules formed after 4 months of operation were dark brownish with a diameter of 1-4 mm and a settling velocity of 20 m/hr. Once granules were formed, upflow velocity was gradually increased to 0.8-1 m/hr (HRT of 2.5 hr) and VSS concentration reached 25 g/l. It was possible to increase the loading up to 14 kg COD/m^3.d (F/M of 1.4 kg COD/VSS.d) at 29°C with total COD removal efficiencies of 85-90%. Under these conditions 250-350 l gas (75% methane) was generated for each kg COD removed.

INTRODUCTION

With the increasing cost of energy as well as stricter sludge disposal regulations, more attention has been paid to anaerobic treatment of medium to high-strength effluents. Technological developments as well as improved process knowledge has made high loading possible and has resulted in a more sustainable operation of these systems. Since its introduction in the early 80s [1], the upflow anaerobic sludge blanket (UASB) system has gone through a lot of improvement in both design and operational details and has been used to treat a variety of industrial effluents [2]. This system has been widely adopted for the treatment of medium- to high-strength industrial wastewater [2,3] and recent research studies indicate the feasibility of this process in the treatment of domestic effluents [4,5].

Sayed et al. [6,7] reported 76-87% COD removal at HRTs of 12-16 hrs for bench and pilot scale treatment of meat packing effluent. Using a 33.5 l continuous flow UASB reactor receiving slaughterhouse effluent, they reported removal efficiencies of 82% and 87% at 20 and 30°C with loading of 7 and 11 kg COD/ m^3.d, respectively. In another study with a high particulate COD influent (up to 50%), McComis and Litchfield [8] reported that normal loading of 3.5 (HRT of 8 hr) and occasional loading of 7.5 kg COD/ m^3.d (HRT of 5 hr) was possible, resulting in removal efficiencies of up to 70% total and 95% filtered COD.

Biogas production rates vary depending on the ecology, temperature and substrate used in UASB reactors. According to Singh et al. [5], typical biogas production and methane content were in the range of 167 to 199 ml CH_4/g-COD removed and 65 to 86%, respectively. Others report yields of 50-100 ml/g COD removed with a 75 to 80% methane content [9] to average biogas productivity of 290 ml CH_4/g COD fed, biogas composition of 70-75% methane and a COD removal percentage greater than 75% [10]. For reactors treating municipal sewage without any supplementary heating, similar specific gas yield of 0.340 ml methane/g COD removed has been obtained [4].

A range of organic and hydraulic loading can be successfully accommodated by UASB reactors depending on the substrate used and the quality and quantity of microbial community. Syutsubo et al. [11] reported a COD loading of 30 kg COD/m^3.d with a COD removal efficiency of 85%. According to Soto [12], excellent

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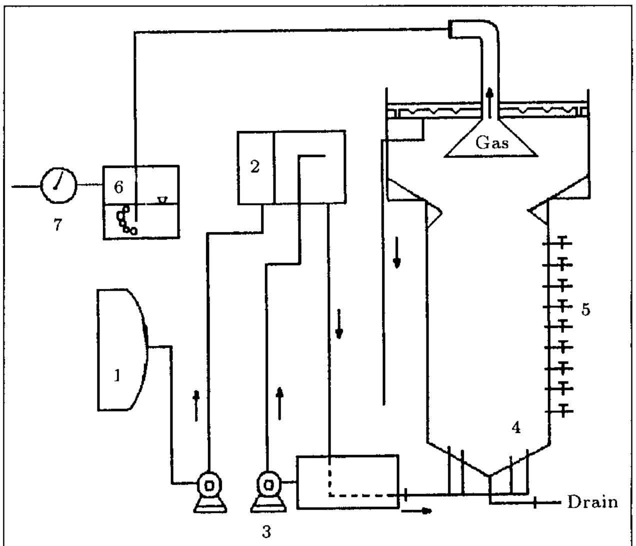
stability and high treatment efficiency were achieved with hydraulic residence times as low as 2 hours at an OLR of 6 kg COD/m^3.d, the COD removals being 95% (30°C) and 92% (20°C), while the percentage of COD converted to methane reached 67% (30°C) and 48% (20°C). The digester operated at 20°C maintained similar efficiencies when OLR was increased up to 9 kg COD/m^3.d, at an HRT of only 1.3 hr. When more easily degradable substrate such as glucose is used, removal efficiencies of up to 90% can be obtained [13].

In a treatability study, Martinez et al. [14] were able to achieve 82% of soluble COD at OLR of 1.8 kg COD/m^3.d. In another study, Ruiz et al. [15] reported better performance of UASB at OLRs of 1-6.5 kg COD/m^3.d, compared to anaerobic filters. Neither of these studies reported indications of granule formation and organic loadings were relatively low.

This study presents the results from using the UASB system for treating slaughterhouse wastewater containing blood and high protein content. The focus of the study was to determine reactor removal efficiencies at progressively increasing organic loading rates under favorable environmental conditions of mesophilic temperature and hydraulic retention times.



1-Feed tank, 2-Flow control weir, 3-Recycle pump, 4-Influent distribution, 5-Sampling taps, 6- Water seal, 7-Gas meter.

Figure 1. Schematic of UASB system receiving effluent from slaughterhouse.

MATERIALS AND METHODS

The experiments were carried out in a 500-l effective volume square (50 cm × 50 cm) Plexiglass pilot set up downstream of a medium size traditional slaughterhouse, without blood recovery. There was no differentiation of effluent from different operations in the slaughterhouse and blood and wash-waters from stomach and intestines along with wastewater from toilets and refrigerated chambers were all combined. As such, the addition of nutrients was not deemed necessary, since wastewater characteristics including lack of blood recovery indicated an adequate concentration of essential proteins and trace elements. The effective height of the reactor was 210 cm with sampling ports provided to quantify sludge characteristic at different elevations along the reactor (see Figure 1). To better capture sludge behavior at the bottom, sampling taps were more closely spaced at the bottom of the reactor compared to the upper elevations.

The reactor was inoculated with 200 l mesophilic sludge from a municipal anaerobic digester with a VSS content of 29 g/l and the system was started at low upflow velocities with an initial HRT value of 45 d. The temperature of influent was adjusted by an inline thermostat prior to reactor entry. Slaughterhouse effluent was pumped into a reservoir from the sewer. After separating inert particles in a cyclonic grit chamber, effluent was pumped into a container at the top and then fed by gravity into the influent distribution line of the reactor. A separate pump was used for flow recycle purposes.

Routine analyses including soluble (filtered sample with a 0.45 μm pore size glass microfiber filter) and total BOD_5 and COD, alkalinity, nitrogen and phosphorus were performed using procedures outlined in Standard Methods [16]. Samples were centrifuged, prior to volatile fatty acid analysis using distillation method. Concurrent with VFA analysis, VFA/alkalinity ratio was also being used for control purposes. Gas evolution was measured by a cumulative gas flow meter located downstream of a water trap and analyzed by Schimatzu (9A with molecular sieve and carbon active columns and FID and ECP detectors) gas chromatograph. To determine the settling velocity of granules, a graduated 1-m high and 5-cm diameter cylinder was used. Most of the parameters were monitored daily during the start-up phase and every other day during the normal operations. Nitrogen, phosphorus and gas analyses were performed every two weeks. A one- to two-week acclimation period was usually allowed after any change in loading and/or upflow velocity change prior to conducting any analysis.

RESULTS AND DISCUSSION

Performance of the reactor can be evaluated for three different phases of the study, namely start-up period (days 1-70), optimum conditions (days 71-166) and maximum capacity (days 167-227). In the start-up phase of the study, 40% of the reactor volume was filled with municipal anaerobic sludge seed (VSS of 29 g/l) to shorten this stage as much as possible. Batch feed was applied to allow efficient biomass growth followed with a continuous feed with upflow velocity of 0.02-0.06 m/h (HRT of 33-100 hr) at 15-20°C. COD removal efficiencies were in the 30% range. Gradual adaptation of microbial population as well as heating of the influent to 25-30°C enabled the reactor to perform progressively better with time. At the end of this period, it was possible to obtain removal efficiencies of up to 80% at an organic loading rate (OLR) of 6.9 kg COD/m^3.d. After this stage, the rate of OLR increase was higher but the system did not seem to suffer from any performance reduction. At maximum performance stage, it was possible to have OLRs of above 30 kg COD/m^3.d. However, the total COD removal efficiencies decreased to 44-67% range and the system seemed to become unstable. Wastewater characteristics are provided in Table 1 and a summary of operational parameters during different periods of study are reported in Table 2.

Effect of OLR on Removal Efficiencies

Variations in the performance of the reactor as a result of OLR increases are shown in Figure 2. Organic load and microbial activity (COD removed per unit mass of VSS) follow similar patterns indicating stable operational conditions. In the first three months, OLR increases were gradual to allow the microbial population to adapt. Increased OLR to 14.2 for days 109-130 and 25 kg COD/m^3.d for days 131-143 did not cause any reduction in performance and 83 and 87% COD removal efficiencies were observed at temperature ranges of 31-35°C. Emptying some of the biomass from the reactor (VSS reduction from 5.6 to 4.8 kg) and temperature reductions to 24-27°C, in late August

Table 1. Wastewater characteristics of UASB reactor at different periods of study.

Parameter	Range	Average
BOD_5	914 - 1921	1478 ± 341
TCOD	2205-5973	4001 ± 1110
SCOD	1939-4693	3186 ± 813
TSS influent	1390-12850	550 ± 360
TVSS reactor	6550-12200	9380 ± 1920
$P\text{-}PO_4^{3-}$	6.5-33	17 ± 12
$N\text{-}NH_3$	27-161	89 ± 50
T,°C	19-31	25.9 ± 3.7
pH	6.8-7.8	7.2 ± 0.3
Alkalinity as $CaCO_3$	1200-1865	1351 ± 181
Volatile fatty acid as acetic acid	292-650	440 ± 124

All values except pH and T in mg/l.

despite continued increase in OLR, caused removal reductions to 75-78% as shown in Figure 3. Gas production had a range of 50 l/d in the initial phases of operation at 15°C to 900 l/d at 25°C but was variable at high OLRs. Analysis of biogas, on the average, showed 75% methane, 7.1% carbon dioxide and 13.8% nitrogen.

Up to day 35, ambient and reactor temperatures were similar but with the installation of heater, in the period of 36-70 days temperature was gradually increased to 27°C. During the summer (days 71-173), temperature was above 25°C and a consistent increase of COD removed per unit VSS was observed. This period coincided with the warmest period of the study, where temperature of the reactor was 31°C and maximum expansion of the sludge bed had occurred.

Table 2. Operational conditions and performance of UASB reactor at different periods of study.

Period	HRT (hr)	Feed				Effluent, mg/l			Biogas		SCOD
		TCOD	SCOD	OLRt	OLRs						
		mg/l		kg COD/m^3.d		TCODe	SCODe	SSe	m^3/m^3.d	kg/kgVSS.d	Rem (%)
9-35	45 ± 5	3061 ± 851	2574 ± 516	1.7 ± 0.64	0.31 ± 0.27	2127 ± 646	2087 ± 251	67 ± 45	0	0	25 ± 11
36-56	9 ± 2	3114 ± 1168	2296 ± 801	3.0 ± 1.1	2.11 ± 0.84	1260 ± 535	734 ± 395	45 ± 37	0.57 ± 0.27	0.06 ± 0.04	62 ± 26
57-70	6.2 ± 0.5	5035 ± 1426	3769 ± 499	6.9 ± 2.1	5.12 ± 0.79	857 ± 346	596 ± 218	58 ± 33	1.3 ± 0.31	0.13 ± 0.03	84 ± 6
71-77	6 ± 1	4589 ± 766	3506 ± 1054	7.8 ± 1.67	6.05 ± 2.5	756 ± 245	431 ± 54	123 ± 60	1.59 ± 0.23	0.15 ± 0.02	86 ± 6
78-108	5.7 ± 1.5	3263 ± 1136	2562 ± 684	7.3 ± 2.7	5.7 ± 1.5	600 ± 290	444 ± 207	40 ± 53	1.83 ± 0.65	0.15 ± 0.05	82 ± 9
109-130	10.9 ± 2.8	5973 ± 1714	4693 ± 1534	14.2 ± 6.2	11.9 ± 5.1	1124 ± 1092	426 ± 130	158 ± 118	1.71 ± 0.62	0.10 ± 0.03	89 ± 5
131-143	5 ± 0.8	5069 ± 1968	3500 ± 747	25 ± 10	16.9 ± 3.6	486 ± 230	306 ± 73	74 ± 49	1.59 ± 0.76	0.09 ± 0.04	91 ± 2
144-166	4 ± 0.6	4899 ± 1782	4027 ± 1071	29.4 ± 10.7	24.2 ± 6.4	1575 ± 1025	835 ± 539	-	1.56 ± 0.58	0.11 ± 0.04	78 ± 16
167-173	3.3 ± 0.2	4796 ± 1610	3852 ± 573	34.5 ± 11.6	27.7 ± 4.1	1405 ± 903	834 ± 761	290 ± 113	1.99 ± 0.21	0.13 ± 0.01	75 ± 25
174-181	2.7 ± 0.1	2205 ± 985	1939 ± 846	19 ± 6.4	16.7 ± 3.2	1065 ± 340	1027 ± 230	272 ± 48	0.98 ± 0.35	0.06 ± 0.02	47 ± 4
182-192	2.5 ± 0.1	4293 ± 902	3182 ± 586	41.2 ± 8.7	30.5 ± 6.2	1610 ± 360	1070 ± 180	66 ± 12	1.24 ± 0.32	0.07 ± 0.03	72 ± 8
193-203	2.5 ± 0.2	2570 ± 958	2000 ± 700	24.6 ± 9.3	19.3 ± 6.7	1374 ± 303	1374 ± 303	290 ± 28	0.63 ± 0.35	0.04 ± 0.01	55 ± 6
204-227	2.3 ± 0.2	3246 ± 594	3520 ± 612	31.7 ± 8.7	38 ± 7.2	1226 ± 0	1152 ± 230	261 ± 88	1.27 ± 0.36	0.08 ± 0.03	65 ± 6

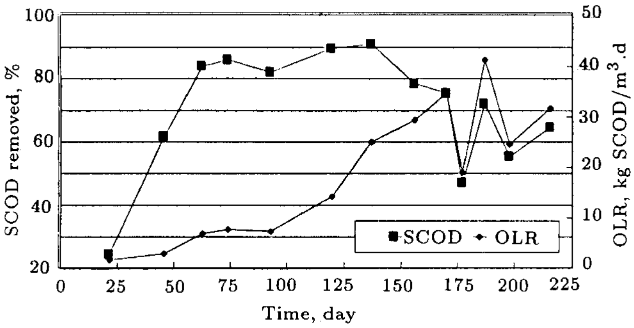


Figure 2. Removal efficiency variations as a result of changing organic loading rate.

With the onset of cooler weather (days 174-181), performance was decreased and as such, organic loading rate to the system was lowered. Fluctuations observed from day 174 onward are due to the inability of the auxiliary heater to compensate for excessive heat loss due to cold weather. Nonetheless, stability of pattern between OLR and SCOD removal per unit weight VSS is evident as shown in Figure 3.

Granule Formation

By day 110 of operation the sludge bed had expanded to fill the whole reactor and as a result, effluent SS reached a maximum of 1.6 g/l. This was the beginning of granule formation in the bottom portion of the reactor. Having observed granules in the lower part of the reactor, upflow velocity was further increased to eliminate flocculent sludge trapped in between. This caused granules to become suspended in the reactor and further granule growth conditions prevailed. In the initial and final phases of sludge bed expansion and granule formation, OLR of system was 14 and 25 kg COD/m^3.d, respectively.

Granules formed were brownish black in color and had diameter ranges of 1-4 mm and a specific gravity of 1.02 to 1.14. SS and VSS values were 63 ± 5 and 54.4 ± 5, respectively.

Sludge Washout

As shown in Figure 4, initially removal efficiencies were lower than 50% and gas production was in the 300 l/d range, signifying low microbial activity for the reactor. Low flow rate resulting in upflow velocities of less than 0.25 m/hr did not cause any expansion of the sludge bed and as such effluent SS concentrations remained as 70 mg/l. With increased ambient temperatures during the summer, reactor heat loss was reduced and the temperature of the reactor reached 31°C. At this point, microbial activities were increased, resulting in more biogas evolution and bed expansion. The end result was sludge washout as indicated by the sharp peak of Figure 5 around day 120 of the operation. There was no indication that the observed washout was due to any substrate accumulation and/or destabilization of the system because there were no decreases in the specific activity of the sludge.

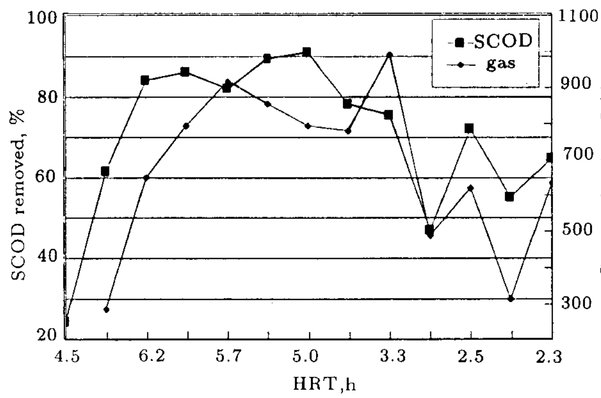


Figure 4. Effect of hydraulic retention time on the removal efficiency and biogas production.

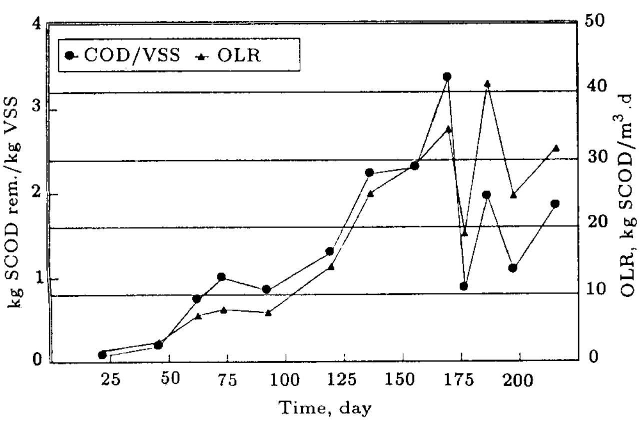


Figure 3. Microbial activity of the UASB reactor during different operational conditions.

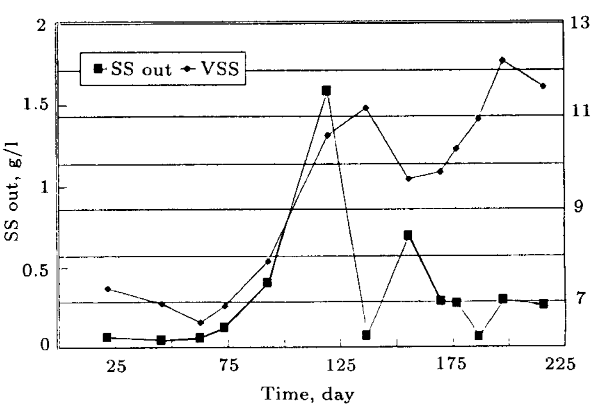


Figure 5. Effluent solids concentration resulting from transient behavior of microbial community within the reactor.

After removing 250 l sludge from the uppermost sampling port, effluent SS were again reduced. Upflow velocity and OLR were further increased from this stage to enhance development of sound sludge characteristics. A sludge settler was placed downstream of the effluent to prevent drastic washout and allow the return of sludge to the reactor. The second peak shown in Figure 4 around day 154 (effluent SS of 0.7 g/l) is the result. With time, upflow velocity and OLR were increased and with the escape of flocculent sludge, appropriate operational conditions rendered granule development feasible as indicated by low effluent solid concentrations. The provision of settler was a precautionary measure for sludge capture. Under shock-load situations in full-scale systems, the settler can also act as an anaerobic digester unit for conversion of absorbed but not degraded organic matter within the microbial cells. After the system is restabilized, sludge can be returned to the main reactor.

CONCLUSIONS

The results of this study show the feasibility of UASB in anaerobically degrading traditional slaughterhouse effluent. Based on the results, it can be concluded that while high organic loadings can be tolerated by the system for a short period of time, for stable operations, organic loading rates should be maintained below 20 kg COD/m^3.d. Excess loadings can result in operational problems including sludge washout and loss of microbial population. While upflow velocities close to 1 m/hr improve microbial activity, this rate should be selected such that sufficient contact time is available between wastewater and microbial population (HRT in the 6-8 hr range).

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