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Study of the Efficiency UASB Reactors in the Treatment of Wastewater at 35°C

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Abstract

The research assessed the potential of up flow anaerobic sludge blanket (UASB) reactors to provide full-flow anaerobic treatment of wastewater 35°C. The work was carried out using laboratory-scale UASB reactors fed on a wastewater. The reactors were operated under a range of condition to test their performance and stability based on four main indicators: chemical oxygen demand (COD) removal, total suspended solids (TSS) removal, gas production and gas composition. The results from this investigation showed that UASB reactors operated at a temperature of 35°C were highly effective in the treatment of synthetic sewage at influent COD concentrations from 450 to 2250 mg l^{-1} COD at a constant HRT of 1 day, and at HRT from 24 to 8 hours with an influent COD concentration of 450 mg l^{-1}. The specific methane yield obtained was around 0.32 l CH_4 g^{-1} COD removed. COD removal efficiencies were high at ≥ 93% and total suspended solid removal was around 95%. The results confirmed that full flow treatment under mesophilic conditions, was feasible at wastewater temperatures of 35°C. The warm temperate areas that are suited to this application, e.g. Libya also often have relatively low water use and/or high rates of re-use due to water scarcity.

Keywords

(UASB) Reactors, COD Removal, TSS Removal, Methane, Mesophilic Conditions

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1. Introduction

The Mediterranean region is considered as one of the world's most water-stressed regions. Wastewater production is the only potential water source, which will increase as a result of the increase in population and the need for fresh water [11]. Municipal wastewaters consist of a mixture of domestic sewage from households and a proportion of industrial and commercial effluents [15]. The wastewater itself normally consists of ~99% water; and is usually further characterised with respect to its rate of flow or volume, chemical constituents, physical condition and in some cases microbiological quality [15, 16]. Contaminants are removed from wastewater through the process known as sewage treatment, which may involve a combination of biological, chemical and physical processes designed to remove biological, chemical and physical contaminants. All these processes are directed towards the production of an environmentally safe effluent [6]. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without peril to human health or unacceptable damage to the natural environment. In conventional sewage treatment, the biological processes employed are generally aerobic, with activated sludge and biological filtration systems being the most common examples of suspended growth and fixed film processes, respectively. Anaerobic biological treatment is an alternative approach that offers several advantages: in addition to removing the energy-intensive requirement for the supply of oxygen, anaerobic systems usually have low sludge yields and produce methane that can be captured for use as a renewable energy source. Anaerobic systems are already in widespread use in the water and wastewater industry for

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treatment of primary, secondary and co-settled sludges (municipal wastewater bio solids) and other high-strength effluents [2]. Decentralized wastewater treatment systems must be studied and implemented in small and rural areas that are not served by public sewage networks in order to achieve sustainable water management practices. Among the existing technologies, the UASB process is widely recognized as having major advantages over aerobic treatment, such as lower capital investment, lower energy consumption, reduced sludge formation, and biogas exploitation [12]. Anaerobic digestion of wastewater bio solids, however, typically operates at mesophilic temperatures (~35-37°C), and in dilute wastewaters there is insufficient energy potential per unit of volume to raise the temperature to this range.

The up flow anaerobic sludge blanket (UASB) reactor is now a common type of high-rate reactor for treatment of industrial and domestic wastewaters. It has a simple design, can be easily built and maintained, is relatively low cost, and can cope with a range of pH, temperature, and influent substrate concentrations [1, 5, 8, 18]. The majority of UASB treatment studies report mesophilic operations, which have proven to be particularly effective in combining a high biogas production with strong process stability [10]. A number of laboratory-scale studies have investigated the potential of this design and of modified versions of it for the treatment of various wastewater types [3, 4, 9, 14, 17].

2. Methodology

An experimental investigation was carried out using eight 4-litres continuously fed UASB reactors figure 1, maintained at 35±1°C. Four of the reactors were operated at a constant HRT of 24 hours. The OLR in these reactors was increased by increasing the influent concentration during the experimental period, starting at 450 mg COD l^{-1} on day 0 then rising to 900, 1350, 1800 and 2250 mg COD l^{-1}. The other four reactors were operated at a constant influent concentration of 450 mg COD l^{-1}, and OLR was increased by increasing the daily feed and reducing the HRT from 24 to 12 and then 8 hours. Operating conditions are summarised in Table 1.

Table 1. Reactor operating conditions for baseline studies at 35°C.

Reactor			Target OLR	Target HRT
Constant HRT	From	To	g COD l^{-1} day^{-1}	Hours
	0	43	0.45	24
	44	103	0.9	24
R1-2	104	145	1.35	24
	146	162	1.8	24
	163	318	2.25	24
	0	43	0.45	24
R3-4	44	116	0.9	24
	117	145	1.35	24
	146	318	2.25	24
Constant influent COD concentration				
	0	61	0.45	24
R5-8	62	91	0.9	12
	92	197	1.35	8

3. Results and Discussion

Reactor performance at constant HRT with increasing OLR.

The main performance parameters for each set of operating conditions are summarised in Table 2.

Table 2. UASB performance at different OLR and constant HRT.

Reactor	Average OLR	COD removal	Methane	SMP added	SMP removed
	g COD l^{-1} day^{-1}	%	%	l CH4 g^{-1} COD added	l CH4 g-1 COD removed
Nominal OLR 0.5 (last 30 days of start-up)					
1	0.44	0.9	0.78	0.256	0.284
2	0.46	0.94	0.78	0.259	0.276
3	0.44	0.94	0.78	0.261	0.278
4	0.44	0.9	0.78	0.202	0.224
Average	0.45	0.92	0.78	0.245	0.266
Nominal OLR 1 (last 30 days)					
1	0.9	0.96	0.78	0.328	0.343
2	0.96	0.96	0.79	0.307	0.32
3	0.93	0.95	0.79	0.32	0.336

Reactor	Average OLR	COD removal	Methane	SMP added	SMP removed
	g COD l^{-1} day^{-1}	%	%	l CH4 g^{-1} COD added	l CH4 g-1 COD removed
4	0.93	0.95	0.79	0.307	0.323
Average	0.93	0.95	0.79	0.315	0.33
Nominal OLR 1.3 (last 20 days)					
1	1.34	0.98	0.78	0.326	0.334
2	1.39	0.97	0.78	0.308	0.318
3	1.38	0.96	0.79	0.31	0.322
4	1.34	0.97	0.79	0.311	0.321
Average	1.36	0.97	0.78	0.314	0.324
Nominal OLR 1.8 (last 10 days)					
1	1.81	0.97	0.76	0.318	0.326
2	1.84	0.97	0.76	0.289	0.297
Average	1.82	0.97	0.76	0.303	0.311
Nominal OLR 2.3 (last 50 days)					
1	2.28	0.96	0.76	0.31	0.324
2	2.3	0.96	0.77	0.314	0.327
3	2.3	0.96	0.78	0.314	0.328
4	2.24	0.96	0.75	0.316	0.329
Average	2.28	0.96	0.76	0.313	0.327

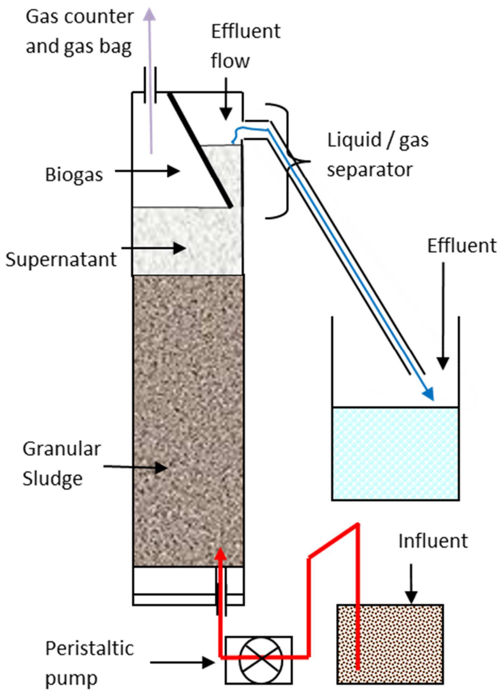

Figure 1. 4-litres continuously fed UASB reactors [7, 13].

Treatment performance

Effluent COD concentrations rose approximately in step with influent COD. COD removal efficiency was over 90% in all reactors from day 2 onwards and remained consistently high at all OLR tested, with an average value of 95% for R1-4. Effluent TSS concentrations were generally below 20 mg l^{-1} apart from occasional disturbances. TSS removal efficiency was also high, stabilising at around 93% at the maximum OLR of 2.3 g COD l^{-1} day^{-1}.

Biogas production

Volumetric gas production in all reactors responded quickly to increases in OLR reaching around 0.74 l CH_4 l^{-1} day at the maximum OLR applied. Specific biogas and methane production showed some fluctuation up to day ~75, indicating that the reactors were still acclimating to the substrate and the OLR. These values then stabilised at around 0.40 l biogas g^{-1} COD added, 0.311 l CH_4 g^{-1} COD added and 0.32 l CH_4 g^{-1} COD removed. The average biogas methane content in all reactors was around 77%. The theoretical methane equivalence of COD is 0.350 litres CH_4 g^{-1} COD at STP (Angenent and Sung 2001), and the actual specific methane production per g of COD removed therefore represents around 92% of this theoretical value.

Overall performance

Table 3 summarises the results at each OLR. It can be seen that, apart from at the lowest OLR, COD removal and SMP are unchanged tested while the volumetric methane production (VMP) increases linearly with OLR, at a rate of 0.33 l CH_4 g^{-1} COD added. This is as expected, as the range of OLR tested is well within the reported capacity of mesophilic UASB. The values in table 3 are closely similar to those found by Idrus (2013) using the same sewage substrate.

Table 3. Overall performance parameters with increasing OLR.

Average OLR	COD removal	Methane	SMP added	SMP removed
g COD l^{-1} day^{-1}	%	%	l CH4 g^{-1} COD added	l CH4 g^{-1} COD removed
0.45	0.92	0.78	0.245	0.266
0.93	0.95	0.79	0.315	0.33
1.36	0.97	0.78	0.314	0.324
1.82	0.97	0.76	0.318	0.326
2.28	0.96	0.76	0.313	0.327

Reactor performance at constant influent COD with increasing OLR.

The second set of reactors (R5-8) was started up and used to investigate the performance of the system with a constant influent COD concentration and with increases in OLR achieved by reducing the HRT. The main performance parameters for each set of operating conditions are summarised in Table 4.

Table 4. UASB performance at different OLR and constant influent COD.

Reactor	Average OLR	Average HRT	COD removal	Methane	SMP added	SMP removed
	g COD l^{-1} day^{-1}	Hours	%	%	l CH4 g^{-1} COD added	l CH4 g^{-1} COD removed
Nominal HRT 24 hours (last 30 days)						
5	0.48	23.3	0.93	0.75	0.31	0.332
6	0.48	23.3	0.94	0.76	0.32	0.341
7	0.47	23.7	0.94	0.75	0.319	0.34
8	0.46	24	0.93	0.75	0.322	0.345
Average	0.47	23.6	0.94	0.75	0.318	0.34
Nominal HRT 12 hours						
5	0.97	11.4	0.9	0.76	0.309	0.345
6	0.97	11.4	0.9	0.77	0.301	0.334
7	0.97	11.4	0.91	0.77	0.29	0.319
8	0.97	11.4	0.91	0.75	0.294	0.322
Average	0.97	11.4	0.9	0.76	0.298	0.33
Nominal HRT 8 hours						
5	1.41	7.9	0.89	0.78	0.305	0.342
6	1.42	7.9	0.89	0.78	0.306	0.343
7	1.42	7.8	0.91	0.78	0.299	0.328
8	1.42	7.9	0.91	0.77	0.317	0.348
Average	1.42	7.9	0.9	0.78	0.307	0.34

Treatment performance

Effluent COD concentrations rose slightly with the decrease in HRT from 24 to 12 hours, but remained ≤ 60 mg l^{-1} Average COD removal efficiency remained over 90%. Effluent TSS concentrations were consistently below 20 mg l^{-1} and TSS removal efficiency was high, averaging around 95% throughout the experimental period.

Biogas production. Volumetric gas production responded very quickly to increases in OLR in all reactors apart from R5, where there was a lag until day~35: this was probably due to floating on day 4 followed by setting up again. Specific biogas and methane production stabilised at around 0.40 l biogas g^{-1} COD added, 0.311 l CH_4 g^{-1} COD added and 0.33 l CH_4 g^{-1} COD removed (average for last 100 days). The average biogas methane content in all reactors was around 77%. The actual specific methane production per g of COD removed was around 96% of the theoretical value.

Overall performance

The results for each OLR tested are summarised in Table 5.

Table 5. Average performance parameters at each OLR during operation at 35°C.

Average OLR	Average HRT	COD removal	CH4	SMP added	SMP removed
g COD l-1 day-1	Hours	%	%	l CH4 g-1 COD added	l CH4 g-1 COD removed
0.47	23.6	0.94	0.75	0.318	0.34
0.97	11.4	0.9	0.76	0.298	0.33
1.42	7.9	0.9	0.78	0.307	0.34

It is clear that the UASB reactors are capable of providing highly effective treatment in terms of COD and TSS removal in the conditions tested, and of recovering a high proportion of the energy available in the substrate in the form of methane.

4. Conclusions

The results showed that UASB reactors operated at a temperature of 35°C were highly effective in the treatment of sewage at influent COD concentrations from 450 to 2250 mg l^{-1} COD at a constant HRT of 1 day, and at HRT from 24 to 8 hours with an influent COD concentration of 450 mg l^{-1}. The specific methane yield obtained was around 0.32 l CH_4 g^{-1} COD removed. COD removal efficiencies were high at ≥ 93% and total suspended solid removal was around 95%. Anaerobic wastewater treatment is a low cost process, and is finally ready to be considered simple and reliable. The main advantages over the conventional aerobic processes are reduced required area, lower energy consumption, lower nutrients requirements, and the possibility of energetic application of the biogas.

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