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Municipal Wastewater Treatment By Using Upflow Anaerobic Sludge Blanket Reactor (Uasb) At Ambient Temperatures

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Abstract

The overall aim of this investigation is to determine the characteristics of raw municipal wastewater and assess the performance of UASB reactors to treat municipal wastewater of Baniwaleed city.

Libya, like many other developing countries, lacks municipal wastewater treatment facilities and almost total domestic wastewater is indiscriminately discharged untreated in sea or open damping, which can cause soil contamination, surface and groundwater contamination and ultimately risk to human being through food chain. This situation demands to reclaim nutrient rich municipal wastewater by using simple efficient and cost effective sewage treatment techniques compatible with local conditions.

The results showed that UASB reactors operated at ambient temperatures were highly effective in the treatment of wastewater at influent COD concentration 629 mg l^{-1} COD at HRT from 24 to 6 hours with the specific methane yield obtained was around 0.32 l CH4 g^{-1} COD removed. COD removal efficiencies were high at 95% and total suspended solid removal was around 95 %.

The UASB technology provides a low-cost system for the direct treatment of municipal wastewater and can be applied in small communities where the wastewater flow variation is high due to rainy season or population load increases during the tourist season or due to seasonally operated food industries.

Keywords: Up flow anaerobic sludge blanket (UASB), Chemical oxygen demand (COD) and hydraulic ration time (HRT)

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 [1]. Municipal wastewaters consist of a mixture of domestic sewage from households and a proportion of industrial and commercial effluents [1]. 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 [1,2].

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 [3]. 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 treatment of primary, secondary and co-settled sludges (municipal wastewater biosolids) and other high-strength effluents [4].

Anaerobic treatment is a biological process carried out in the absence of oxygen for the stabilisation of organic materials by conversion to methane and other inorganic end products such as carbon dioxide and ammonia. An advantage of anaerobic technology is the production of a biofuel (methane) from organic wastes. The process does not require aeration, can deal with high organic loadings and produces relatively little waste biomass. About 70 - 90% of total biodegradable compounds present in wastewater are converted into biogas, whereas in aerobic processes the overall degradation to CO_2 is 40 - 50%. Anaerobic processes are therefore potentially more cost effective than aerobic and interest in them has increased in recent decades [5].

Anaerobic digestion of wastewater biosolids, however, typically operates at mesophilic temperatures (~35-37^{o}C), and in dilute wastewaters there is insufficient energy potential per unit of volume to raise the temperature to this range.

The upflow 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 [6-9].

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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 [10-14]. While progress has been made, the key challenges for these and other high-rate systems remain the following: issues in treating wastewaters; problems of performance; shock loading sensitivity; and toxic material sensitivity. In practice, more than one of these may occur simultaneously, leaving multiple variables that need to be assessed experimentally if the performance of these systems is to be evaluated and improved.

The HRT is one of the most important parameters affecting the performance of a UASB reactor when used for the treatment of municipal wastewater [15].

UASB treatment plants are reportedly working in various tropical cities [16-19]. The HRT varied between 4-20 hours but was mostly in the range of 4-8 hours [20]. The results demonstrated that COD removal efficiency of the reactor was a function of HRT and COD removal efficiency approached to 80% even though the sludge was not well granulated and was merely a suspended fluffy mass [21].

The overall aim of this investigation is to determine the characteristics of raw municipal wastewater and assess the performance of UASB reactors to treat municipal wastewater of Baniwaleed city. The main objectives of the study are:

1. To characterize wastewater in terms of parameters like BOD, COD, TSS, pH, temperature, alkalinity, sulphate and ammonia.

2- To study the performance of UASB reactors under deferent HRT (24 h, 12 h, 8 h and 6 h).

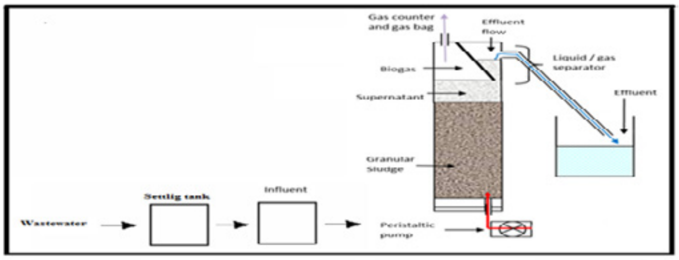

Figure 1: Diagram of the experimental set-up

The UASB reactor is made of Perspex material, and is comprised of a tubular section at the bottom and an expanded section termed as gas- liquid-solid separator (GLSS) at the top. The four reactors were operated at a constant influent concentration of 629 mg COD l-1, and OLR was increased by increasing the daily feed and reducing the HRT from 24 to 12 ,8 and then 6 hours. These upper and lower limits were selected as the aim was to simulate the treatment of domestic wastewater: in practice the strength of this is unlikely to exceed 2 g COD l-1 while full-scale plants rarely operate at HRT much below 8 hours. Operating conditions are summarised in Table 1.

Parameter	No. of samples	Maximum	Minimum	Average	STD
Temperature	90	22.9	18.5	20.1	± 1.1
pH	90	7.41	6.87	7.1	± 0.16
BOD	1	320	280	300	± 20
COD	13	698	577	629	± 36
TSS	13	616	464	527	± 32
Alkalinity	1	86	64	76	± 11
NH4+-N	2	34	26	31	± 3
Sulphate (SO4-)	2	23	10	18	± 4

Table 1: The characteristics of Baniwaleed city wastewater

Reactor start-up

Inoculum. 2 kg of granular sludge was added to a 4-litre container at ambient temperatures, as shown in Figure 2. Two litres of wastewater was adding for each container. The container was shaken and the granular sludge was allowed to settle, after which the supernatant was poured off and replaced with fresh sewage. The gas produced was collected in a gas-impermeable bag and the volume measured daily. After ~15 days the biogas and methane production were 0.8 and 0.61 l day-1 respectively, with a specific methane yield of about 0.31 l CH4 g^{-1} COD added, and the granular sludge was considered to have re-acclimated to the operating temperature. The granular sludge was removed from the containers, mixed thoroughly, and 2 kg wet weight was used as inoculum for each UASB reactor.

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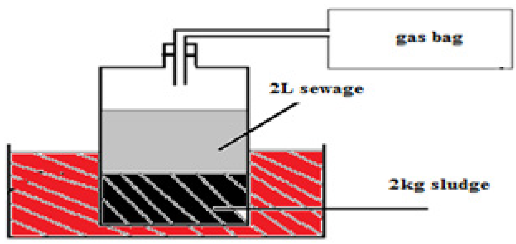

Figure 2: Set-up for granular sludge acclimatisation

Sampling

Composite samples of municipal wastewater were collected from Baniwaleed municipal wastewater. Wastewater was collected in 20-liter plastic can, which was duly labelled, sealed, transported to laboratory and stored at 4oC for further analysis. Wastewater was then characterized in terms of various parameters.

Analytical methods

Total suspended solids: Total suspended solids (TSS) content was measured by passing a sample of known volume through a 0.4 µm pore size glass fiber filter paper (GF/C, Whatman, UK) of known dry weight (~ 0.1 mg). After drying at 105°C for 24 hours, the paper was again weighed and the difference determined.

BOD measurement: Standard method (5210 B) was followed to determine BOD. Dilution water was prepared by adding 1 ml each of phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solutions per liter of water at 20°C. Dilution water was then aerated with filtered air and three dilutions were made for each sample. Wastewater sample and dilution water was filled in airtight 300 ml BOD bottles, which were, then water sealed and incubated at 20 ± 1°C for 5 days. Dissolved oxygen (DO) was measured immediately after filling BOD bottles with diluted sample and after five days of incubation and blanks.

COD measurement: COD was measured by the closed tube reflux method with the titrometric determination of the endpoint [22].

Gas Composition: Biogas composition was quantified using a Varian Star 3400 CX gas chromatograph. The GC was fitted with a Hayesep C column and used either argon or helium as the carrier gas at a flow of 50 ml min-1 with a thermal conductivity detector. The biogas composition was compared with a standard gas containing 65% CH4 and 35% CO2 (v/v) for calibration. A sample of 10 ml was taken from a Tedlar bag used for sample collection and was injected into a gas-sampling loop.

Gas Volume: Biogas was collected in a gas-impermeable sampling bags and volume was measured using a weight-type water displacement gasometer [23].

Sulphate measurement: The turbidimetric method of measuring sulphate is based on barium sulphate precipitating in a colloidal form of uniform size in the presence of a sodium chloride, hydrochloric acid and glycerol.

$SO4_{2-} + BaCl_2 \rightarrow BaSO_4$

The absorbance of the barium sulphate formed was measured using a spectrophotometer at 420 nm against standards. The conditioning reagent was prepared by mixing together in a beaker 25 ml glycerol, 15 ml of concentrated hydrochloric acid, 50 ml of 95% isopropyl alcohol and 37.5 g of sodium chloride and making up to a final volume to 250 ml using deionised water. Standards were prepared in 50 ml stoppered volumetric flasks by adding 10, 20, 30, and 40 ml of standard sulphate solution prepared by accurately weighing 1.419 g anhydrous sodium sulphate dissolved in 1 litre of deionised water (1.0 mg SO42–ml-1). 0.5 g of barium chloride was then added to each flask which was then made up to the final volume with deionised water. The sample was first filtered through a 0.45 µm GFC filter added to a 50 ml flask, barium chloride added and the volume made up to the mark. The adsorbance of the standards and sample were measured against a deionised water blank using a 1 cm path length in a spectrophotometer (CECIL 3000 Series scanning spectrophotometer) at 420 nm. The concentration of the sample was determined by reading the value from the standard calibration graph.

Results and Discussion

Characteristics of wastewater

The characteristics of wastewater are shown in Table 1 and figure 3. The average pH value (7.1) was almost neutral. The BOD5, COD and TSS contents on average were 300, 629 and 527 mg/L, respectively. Sulphate contents on average 18 mg/L also sufficiently meets the requirement of anaerobic digestion because anaerobic treatment is effective when the COD / Sulphate ratio exceeds 10 [24]. Higher sulphate contents of sewage, however, cause damage to infrastructure due to the production of sulphuric acid [2]. Alkalinity level (76 mg/L) and ammonia nitrogen contents (31 mg/L) are also similar to values for domestic wastewater [25].The characteristics of sewage demarcate it a medium strength municipal wastewater [2,26].

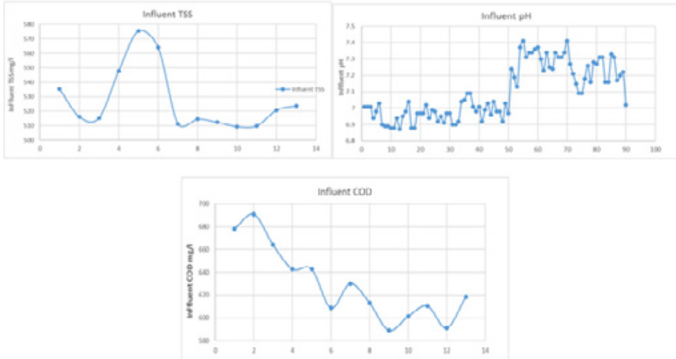

Figure 3: Influent pH, COD and TSS content

5.2 Reactor performance at reduced HRT

Figures 4 and 5 show the monitoring parameters for R1-4 during the experimental period. The main performance parameters are summarised in Table 2.

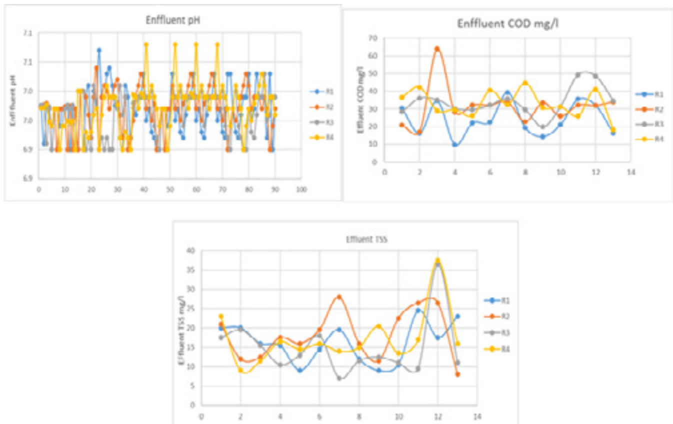

Figure 4: Enffluent pH, COD and TSS content for R1-4

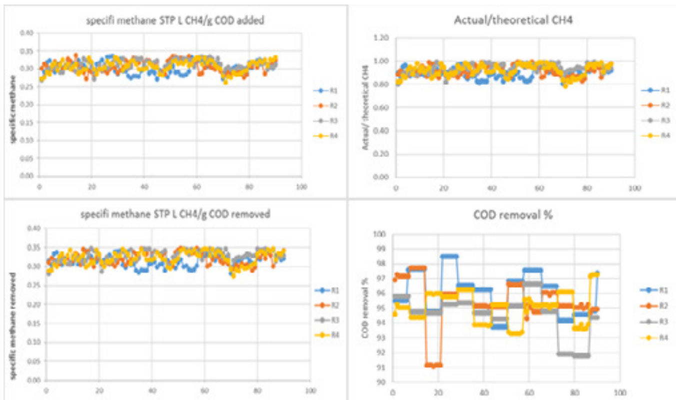

Figure 5: COD removed, specific biogas added, specific biogas removed and actual/theoretical methane for R1-4.

HRT	Parameter	No. of samples	Maximum	Minimum	Average	STD
24	COD removal %	20	97%	94%	95%	± 2%
	Specific methane l g-1COD removed	20	0.34	0.29	0.32	± 0.01
	Specific methane l g-1COD added	20	0.33	0.28	0.3	± 0.01
		20	98%	84%	91%	± 4%
12	COD removal %	25	98%	91%	96%	± 1%
	Specific methane l g^{-1} COD removed	25	0.35	0.28	0.32	±0.02
	Specific methane l g^{-1} COD added	25	0.34	0.27	0.31	±0.02
	Actual/ theoretical CH4	25	99%	81%	92%	± 5%
8	COD removal %	24	98%	93%	96%	± 1%
	Specific methane l g^{-1} COD removed	24	0.35	0.29	0.33	± 0.02
	Specific methane l g-1COD added	24	0.34	0.28	0.31	± 0.02
	Actual/ theoretical CH4	24	99%	83%	93%	± 1%
6	COD removal %	21	97%	92%	95%	± 1%
	Specific methane l g^{-1} COD removed	21	0.35	0.27	0.32	± 0.02
	Specific methane l g^{-1} COD added	21	0.33	0.26	0.3	± 0.01
	Actual/ theoretical CH4	21	98%	91%	0.96	± 1%

Table 2: UASB performance on HRT reduction from 24h to 6h

Treatment performance

Effluent COD concentrations showed little or no change with average 31 mg l^{-1}. COD removal efficiency fell slightly the maximum removal 98% and minimum removal 91% with average 95% in all reactors.

Effluent TSS concentrations remained below 38 mg l^{-1} and TSS removal efficiency ranged between 91-98% with average 97%.

Biogas production. Gas production showed a slight disturbance following the initial drop in HRT, but stabilised at around 0.31 l CH4 g^{-1} COD added and 0.32 l CH4 g^{-1} COD removed (Figure 5).

The average biogas methane content in all reactors was unchanged or marginally higher at 78-79 %.

Conclusion

Libya, like many other developing countries, lacks municipal wastewater treatment facilities and almost total domestic wastewater is indiscriminately discharged untreated in sea or open damping, which can cause soil contamination, surface and groundwater contamination and ultimately risk to human being through food chain. This situation demands to reclaim nutrient rich municipal wastewater by using simple efficient and cost effective sewage treatment techniques compatible with local conditions.

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