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Treating Ben-Waleed City Wastewater with Anaerobic Reactors Technology (UASB)

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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. 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 COD at HRT from 24 to 6 hours with the specific methane yield obtained was around 0.32 l CH_4/g COD removed. The 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.

معالجة مياه الصرف الصحي في مدينة بن وليد بتقنية المفاعلات اللاهوائية ((UASB

مسعود, ا, علي

تفتقر ليبيا إلى مرافق معالجة مياه الصرف الصحي ويتم تصريف مياه الصرف الصحي بالكامل تقريبًا دون معالجة في البحر أو الردم في المناطق المفتوحة يتطلب هذا الموقف معالجة مياه الصرف الصحي باستخدام تقنيات المفاعلات اللاهوائية البسيطة والفعالة من حيث التكلفة والمتوافقة مع الظروف المحلية حيث تتم في هذه الطريقة معالجة المياه وانتاج غاز الميثان كمصدر للطاقة. الهدف العام من هذا البحث هو تحديد خصائص مياه الصرف الصحي لمدينة بني وليد وتقييم أداء مفاعلات UASB لمعالجة هذه مياه.أظهرت النتائج المتحصل عليها أن مفاعلات UASB التي تعمل في درجات حرارة المحيطة كانت فعالة للغاية في معالجة المياه العادمة بتركيز COD المؤثر 629 مجم/ لتر في HRT من 24 إلى 6 ساعات مع إنتاج غازالميثان الذي تم الحصول عليه كان حوالي 0.32 لتر CH_4 /جم COD كانت كفاءة إزالة COD عالية عند 95٪ وكان إجمالي إزالة المواد الصلبة العالقة حوالي 95٪.

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 (Loutfy, 2011). Municipal wastewaters consist of a mixture of domestic sewage from households and a proportion of industrial and commercial effluents (Pescod, 1992). 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 (Metcalf & Eddy. 2003; Pescod 1992).

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 (Noykova, Muller et al., 2002).

Anaerobic digestion of wastewater biosolids, however, typically operates at mesophilic temperatures (~35-37 ºC), 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 (Lettinga and Pol 1991, Cronin and Lo 1998, Alvarez, Ruiz et al., 2006, Tiwari, Guha et al., 2006).

The Hydraulic Retention Time (HRT) is one of the most important parameters affecting the performance of a UASB reactor when used for the treatment of municipal wastewater (Vieira and Garcia, 1992). The hydraulic retention time (HRT) is defined as the average time for which the wastewater to be treated is present in the reactor, calculated by dividing the reactor working volume by the volume of influent per unit time.

The Hydraulic Retention Time varied between 4-20 hours but was mostly in the range of 4-8 hours (Cavalacanti et. al., 1999). 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 (Kalogo and Verstraete, 1999).

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 (24h, 12h, 8h and 6h).

MATERIALS AND METHODS

An experimental investigation was carried out using 4-litre continuously fed UASB reactors, maintained at ambient temperatures. The setup consisted of a four of UASB reactors, peristaltic pump, influent tank, effluent tank and gas was collected in a gas-impermeable sampling bags. Schematic diagram of the experimental set-up is shown in Figure1.

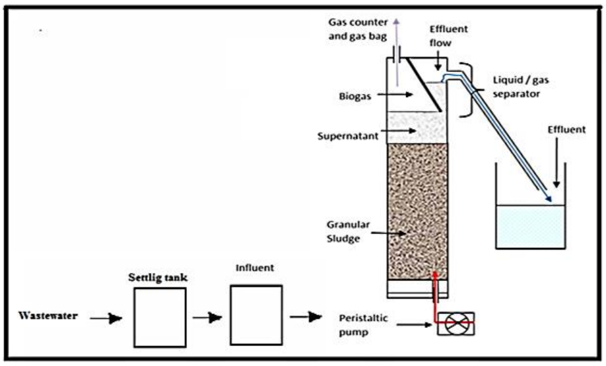


Figure 1 Diagram of the experimental set-up (Ali, 2020).

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 influent concentration of 629 mg/l COD (The average concentration of wastewater that was used as feed to the reactors), and the organic loading rate (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/l COD while full-scale plants rarely operate at HRT much below 8 hours. Operating conditions are summarised in Table 1.

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 respectively, with a specific methane yield of about 0.31 l CH_4/g 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.

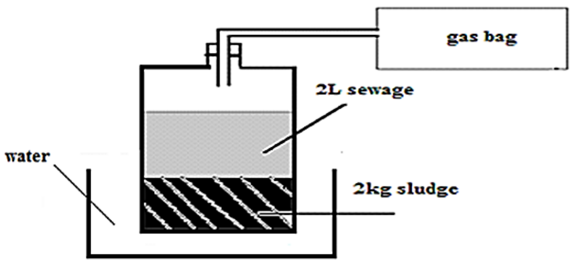


Figure 2 Set-up for granular sludge acclimatisation

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 4°C 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 filtering a sample of known volume through a 0.45 µm pore size glass fiber filter paper (GF/C, Whatman, UK) of known dry weight (~ 0.1 mg). After drying at 105 ºC for 24 hours, the paper was again weighed and the difference determined according to the following equation (Ali, 2014):

$$SS = \frac{(W_2 - W_1)\ x\ 1000}{V_s}$$

SS = suspended solids (mg/l)
W1 = weight of clean filter paper (mg)
W2 = weight of filter paper + sample (mg)
Vs = sample volume (ml)

COD measurement

COD was measured by the closed tube reflux method with the titrometric determination of the endpoint (Ali, 2014).

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 (Ali, 2020).

Gas Volume

Biogas was collected in a gas-impermeable sampling bags and volume was measured using a weight-type water displacement gasometer (Walker et al., 2009).

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.

$SO_4^{2-} + BaCl_2 \rightarrow BaSO_4$

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 SO_4^{2-} 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 (Sharma & Kaur,2016).

RESULTS

CHARACTERISTICS OF WASTEWATER

The characteristics of wastewater are shown in tables 1 and figure 3. The average pH value (7.1) was almost neutral. The COD and TSS contents on average were 629 and 527 mg/L, respectively. The sulphate concentration in domestic sewage is typically in the range of 20 to 50 mg/l (Metcalf & Eddy 2003); values reported for the Middle East include Egypt 35 mg/l and Palestine 138 mg/l (Pescod 1992). 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 (Hulshoff Pol, 1998). Higher sulphate contents of sewage, however, cause damage to infrastructure due to the production of sulphuric acid (Metcalf and Eddy, 2003). Alkalinity level (76 mg/L) and ammonia nitrogen contents (31 mg/L) are also similar to values for domestic wastewater (Henze and Ledin, 2001).The characteristics of sewage demarcate it a medium strength municipal wastewater (Mahmoud, 2002; Metcalf and Eddy, 2003).

Table 1 the characteristics of Baniwaleed city wastewater

Parameter	No. of samples	Max	Min	Average	STD
Temperature C°	90	22.9	18.5	20.1	± 1.1
pH	90	7.41	6.87	7.1	± 0.16
COD mg/l	13	698	577	629	± 36
TSS mg/l	13	616	464	527	± 32
Alkalinity as $CaCO_3$) mg/l	1	86	64	76	± 11
NH^{4+}-N mg/l	2	34	26	31	± 3
Sulphate ($SO4^{-1}$) mg/l	2	23	10	18	± 4

Figures 4 shows the monitoring parameters for all reactors during the experimental period (effluent pH, COD and TSS content) while Figures 5 shows COD removed, specific biogas added, specific biogas removed and actual/theoretical methane for all reactors. The main performance parameters are summarised in Table 2, 3 and table4.

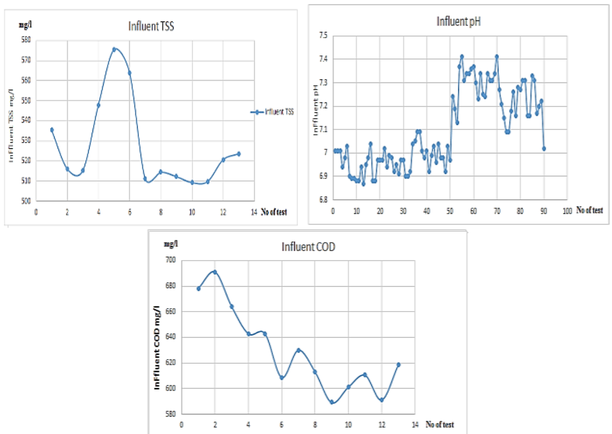
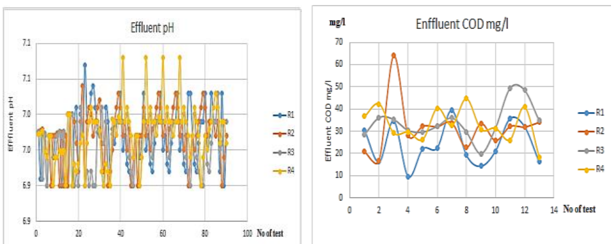


Figure 3 Influent pH, COD and TSS content



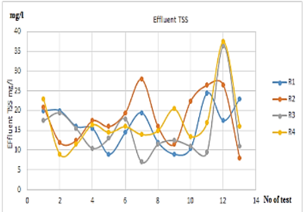


Figure 4 Effluent pH, COD and TSS content for all reactors

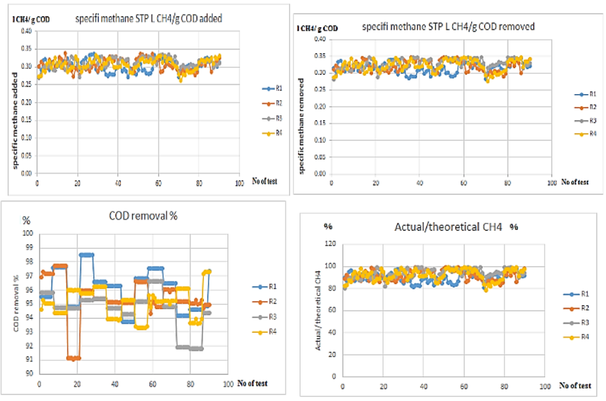


Figure 5 COD removed, specific biogas added, specific biogas removed and actual/theoretical methane for all reactors.

Table 2 All reactors performance on HRT reduction

Reactor	HRT h	Influent COD mg/l	Effluent COD mg/l	Effluent TSS mg/l
R1	24	678	26	19
	12	632	21	15
	8	607	22	11
	6	604	31	22
AVERAGE		630	25	17
R2	24	678	32	15
	12	632	33	20
	8	607	29	17
	6	604	32	20
AVERAGE		630	31	18
R3	24	678	33	18
	12	632	31	12
	8	607	28	12
	6	604	44	19
AVERAGE		630	34	15
R4	24	678	36	15
	12	632	32	15
	8	607	35	16
	6	604	30	24
AVERAGE		630	34	17.5

Table 3 All reactors performance on HRT reduction

Reactor	HRT h	COD removal %	Specific methane l/g COD added	Specific methane l/g COD removed	Actual/theoretical CH4
R1	24	96%	0.31	0.32	92%
	12	97%	0.3	0.31	88%
	8	96%	0.3	0.31	90%
	6	95%	0.3	0.32	92%
AVERAGE		96%	0.3	0.32	91%
R2	24	96%	0.31	0.32	91%
	12	95%	0.31	0.32	93%
	8	96%	0.31	0.33	93%
	6	95%	0.3	0.31	90%
AVERAGE		96%	0.31	0.32	92%
R3	24	95%	0.3	0.32	91%
	12	95%	0.31	0.33	94%
	8	95%	0.32	0.34	96%
	6	93%	0.31	0.33	94%
AVERAGE		95%	0.31	0.33	94%
R4	24	95%	0.3	0.32	91%
	12	95%	0.31	0.32	93%
	8	95%	0.31	0.33	94%
	6	95%	0.3	0.32	91%
AVERAGE		95%	0.31	0.32	92%

Table 4 UASB performance on HRT reduction from 24h to 6h

HRT	Parameter	samples	Max	Min	Average	STD
24	COD removal %	20	97%	94%	95%	± 2%
	Specific methane l /g COD removed	20	0.34	0.29	0.32	± 0.01
	Specific methane l /g COD added	20	0.33	0.28	0.30	± 0.01
	Actual/theoretical CH4 %	20	98%	84%	91%	± 4%
12	COD removal %	25	98%	91%	96%	± 1%
	Specific methane l /g COD removed	25	0.35	0.28	0.32	±0.02
	Specific methane l /g 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 COD removed	24	0.35	0.29	0.33	± 0.02
	Specific methane l /g COD 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%
6	Specific methane l /g COD removed	21	0.35	0.27	0.32	± 0.02
6	Specific methane l /g COD added	21	0.33	0.26	0.30	± 0.01
6	Actual/theoretical CH4 %	21	98%	91%	96%	± 1%

DISCUSSION

Effluent COD concentrations showed little or no change with average 31 mg/l (see fig4 and table 2). 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 (see fig4) 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 CH_4/g COD added and 0.32 l CH_4/g COD removed. Figure 5 showed COD removed, specific biogas added, specific biogas removed and actual/theoretical methane for all reactors at different HRT.The theoretical methane equivalence of COD is 0.35 litres CH_4 /g COD at STP 0 ºC and 101.325 kPa (Angenent and Sung 2001), and the actual specific methane production per g of COD removed therefore represents between 91 % to 96 % of this theoretical value

CONCLUSION

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 COD at HRT from 24 to 6 hours with the specific methane yield obtained was around 0.32 l CH_4/g 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.

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