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Sewage water treatment using conventional and packed up-flow anaerobic sludge blanket (UASB) reactor

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ABSTRACT

Feasibility of using conventional and packed up-flow anaerobic sludge blanket (UASB) reactors for the treatment of sewage water was studied. Two similar UASB reactors were operated at two different hydraulic retention time (HRT) of 6 and 8 hrs. The reactors were operated with activated sludge inoculation in March 2012. Sample collection was carried out after the steady state has been reached (about two months). The results showed that the efficiency of UASB reactors was comparable for the removal of chemical oxygen demand (COD), biological oxygen demand (BOD) and total suspended solids (TSS). On the other hand, the removal of faecal coliform (FC) did not exceed two log units in most cases. The results revealed that the quality of the effluent was not complying with WHO regulatory standards for reuse for irrigation. Consequently, post treatment step is of vital importance to protect the environment.

Key words: UASB, conventional, packed, anaerobic treatment, Skaka, domestic wastewater

INTRODUCTION

Rapid population in Arab countries increases scarcity of water in urban areas which raises a great concern and the need for appropriate wastewater reuse practices, especially for irrigation. The major challenge facing the Arab region in the first decade of the third millennium, and beyond, is that while water resources are limited, the demand will continue to increase steadily in the near future. Accordingly, the core problem is how to balance supply and demand under extremely difficult conditions: increasing scarcity and unpredictability (El Kharraz *et al*., 2012).

Mechanical treatment systems are maintenance and energy intensive (Tchobanoglous *et al*., 2003); consequently, their performance is affected when these requirements cannot be properly provided. Thus, it should be clear that in regions where mechanical treatment technologies cannot be effectively maintained, promoting less energy-intensive wastewater (WW) technologies could result in improving water quality, benefiting the health, economy and aesthetics of the region (Arias and Brown, 2009).

Anaerobic wastewater treatment is considered sustainable (Hammes *et al*., 2000) and suitable for on-site treatment (Zeeman and Lettinga, 1999) due to its low energy consumption, small space requirement and relatively simple reactor design. From the foregoing, anaerobic digestion presents a high potential in most developing countries for domestic wastewater treatment and thus is a suitable and economical solution (Foresti 2001). The anaerobic process can serve as a viable alternative, compared to conventional aerobic processes (Lettinga 1995; Schink 2002), for a variety of reasons. The fact that the process can be carried out in decentralized mode means also that this application can lead to significant savings in investment costs of sewerage systems (Lettinga *et al*., 2001; Verstraete *et al*., 2002 ; Aiyuk *et al.*, 2010).

An up-flow anaerobic sludge blanket (UASB) method has been represented as the core technology for an anaerobic wastewater treatment method, widely used for the treatment of medium and high organic strength wastewater (Yoochatchaval *et al.*, 2008; Syutsubo *et al*., 2008).

In the UASB reactor system, the up-flow mode of operation improves the physical removal of suspended solids by the gravity settling and by entrapment mechanism. During the process, the anaerobic microorganisms agglomerate to form a biogranules by a process of impulsive aggregation of bacteria to dense compact granules with good settling characteristics. Following the passage of liquid through this system, part of both soluble and accumulated suspended solids will undergo a biological oxidation converting the organics to biogas. The biological conversion of the organic matter in the UASB reactor is passed through three steps which are: hydrolysis, acidogenesis and methanogenesis (Sabry 2008)

The aim of the present work is to study the feasibility of using UASB reactor for the treatment of domestic wastewater in Skaka city, Saudi Arabia. Skaka city is the capital of Al Jauf region, which is located in the central part of the north of the Kingdom. Al Jauf climate is continental desert, cold in winter, hot and dry summer, and the average temperature in summer is 30°C and the maximum temperature is up to 42°C, the average temperature in winter is 8.5 °C.

MATERIALS AND METHODS

UASB Reactor

Two identical pilot-scale UASB reactors were designed and manufactured to treat domestic wastewater throughout this study. The UASB reactor consists of a cylindrical column (height: 2 m & internal diameter of 0.2 m) with a cone shaped bottom and gas/solid separator (GSS) at the top (Figure 1). The reactor was provided with 5 ports along its length for sludge sampling. The packed UASB reactor was equipped with 1.5 l of sponge (polyurethane foam-CF-type) situated in the sedimentation part of the reactor with a total effective surface area of 0.4 m^2. The sponge was arranged as a curtain shape to: (1) avoid clogging (2) facilitate the flocculation of the wastewater and (3) overcome washout of the sludge. The characteristics of the used sponge were: pore size = 0.63 mm and void ratio = 0.9 (El-Gohary *et al.*, 2009). Both UASB reactors were inoculated with sedimented activated sludge from the wastewater treatment facility in Skaka city. The characteristics of the used sludge were: TSS = 22 g/l; VSS = 15 g/l and VSS/TSS ratio = 0.68. The total amount of digested sludge added to the reactor was approximately 12 l, which represents 60% of the total reactor volume.

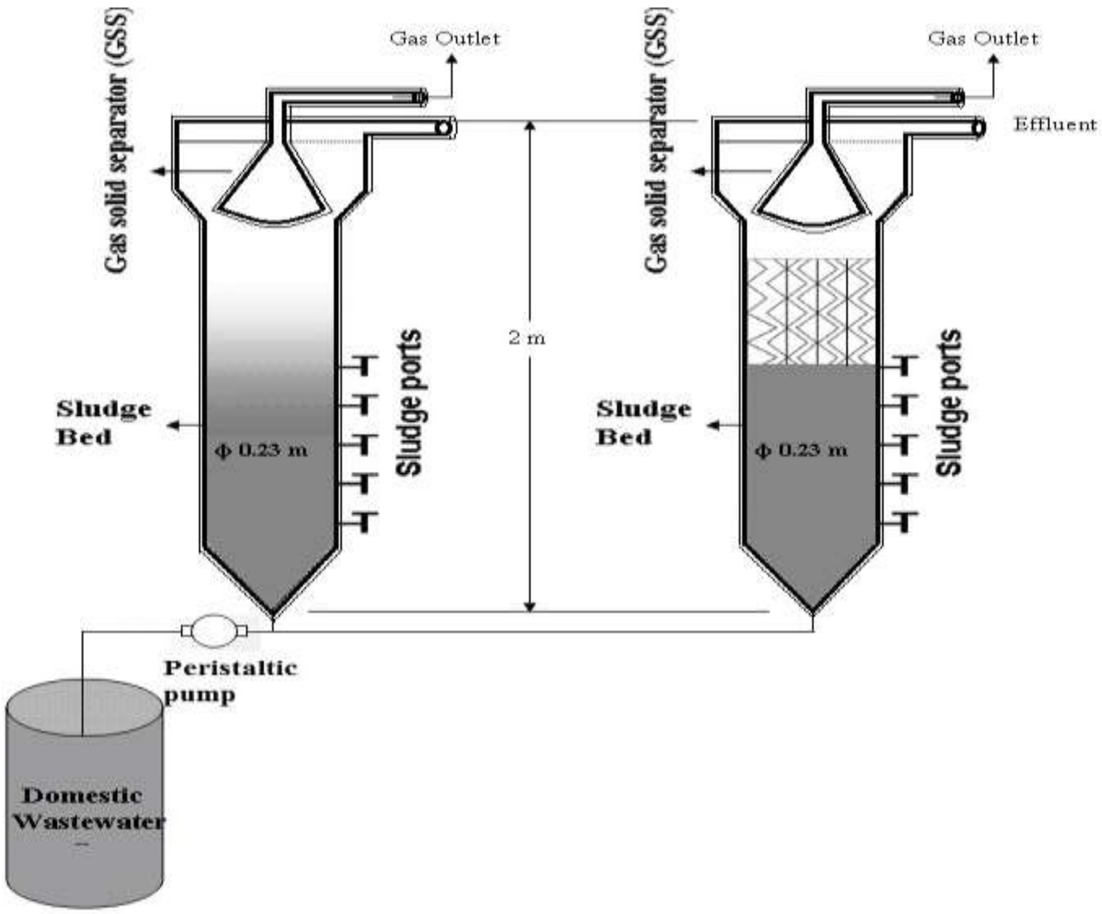

Figure 1: The dimensions of both packed and conventional UASB reactors used in the study

This work was carried out at two different hydraulic residence time (HRT), 6 and 8 hours. The following Table shows the HRT, hydraulic loading rate (HLR) as well as organic loading rate (OLR) throughout the study.

Table 1: Operating conditions of both packed and conventional UASB reactor throughout the study

Item	**Run 1**	**Run 2**
HRT (hr)	6	8
HLR (l/day)	332	249
OLR (kg/m^3/day)	3.4	2.55

Sampling and analytical methods

Composite samples of raw sewage and UASB effluent were collected and analyzed for total chemical oxygen demand (COD_{tot}), particulate chemical oxygen demand (COD_{par}), dissolved chemical oxygen demand (COD_{dis}), colloidal chemical oxygen demand (COD_{col}), biological oxygen demand (BOD), total suspended solids (TSS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), ammonia, total coliform (TC), fecal coliform (FC). Physicochemical analyses were carried out according to Standard Methods for Examination of Water and Wastewater (APHA 2005).

Microbiological examination

Three-fold dilutions were prepared from each sample and used to determine the bacterial indicators TC, FC (APHA 2005).

Statistical analysis

The arithmetic averages of percent removal and descriptive statistics were applied to the collected data using Microsoft Excel XP version 2003.

RESULTS AND DISCUSSION

Raw sewage

The COD values were in the range of 650-967 mg/l with an overall average of 837 mg/l while, the concentration of BOD and TSS were in the range of 415-660 mg/l and 145-341 mg/l, respectively. The ratio of BOD/COD is about 0.72. The average concentration of TKN, ammonia and TP were 65, 48 and 6 mg/l, respectively.

Table 2: Characteristics of raw sewage

Parameter	N*	Unit	Min	Max	Raw sewage
COD_{tot}	25	mg/l	650	967	837
COD_{par}	9	mg/l	370	590	480
COD_{sol}	9	mg/l	110	170	185
COD_{col}	9	mg/l	170	207	172
BOD	25	mg/l	415	660	605
TSS	25	mg/l	145	341	278
TKN	19	mg/l	57	74	65
Ammonia	19	mg/l	35	55	48
TP	19	mg/l	4	7.2	6
Organic nitrogen	19	mg/l	22	19	17
TC	17	MPN/100 ml	4×10^7	2×10^9	9×10^8
FC	17	MPN/100 ml	6×10^6	4×10^8	8×10^7

** Number of samples*

Performance of conventional and packed UASB reactors at HRT of 6 hr

The results presented in Table 3 show that the packed UASB reactor is quite effective for removal of the different COD fractions (COD_{tot}, COD_{dis} COD_{par} and COD_{col}). Residual COD_{tot}, COD_{sol} COD_{par} and COD_{col} were 253, 115, 64 and 74 mg/l, respectively. Corresponding percentage removal values were 70 for COD_{tot}; 38 for COD_{dis}; 87% for COD_{par} and 57 for COD_{col}. Residual BOD and TSS were 200 and 78 mg/l, respectively. This quite good performance towards the removal of COD fractions and BOD can be attributed to the relatively high sludge residence time (SRT = 29 days); which improves the hydrolysis and biodegradation of organic matter content of the wastewater. The TKN and organic nitrogen was reduced by 19% and 23% due to particulate N removal, and/or conversion to ammonia (Mahmoud 2002). Similarly, the level of TP was reduced in the conventional and the packed UASB reactor by 18 and 23%, respectively. The UASB reactor removed only the particulate nutrients by sedimentation and filtration and, therefore, it had relatively low removal of nutrients (Elmitwalli and Otterpohl 2007; Aiyuk *et al.,* 2010).

Table 3: Performance of the conventional and packed UASB reactors at 6 hours detention time

Parameter	N*	Unit	Conventional UASB effluent	%R	Packed UASB effluent	%R
COD_{tot}	25	mg/l	301	64	253	70
COD_{par}	9	mg/l	125	74	64	87
COD_{dis}	9	mg/l	112	39	115	38
COD_{col}	9	mg/l	64	63	74	57
BOD	25	mg/l	218	64	200	67
TSS	25	mg/l	117	58	78	72
TKN	19	mg/l	54	17	53	19
Ammonia	19	mg/l	43	10	47	2
TP	19	mg/l	5	18	4.6	23
Organic nitrogen	19	mg/l	11	35	6	65
TC	17	MPN/100 ml	$5x10^6$	99.44	$3.1x10^6$	99.66
FC	17	MPN/100 ml	$3x10^5$	99.63	$1.9x10^5$	99.76

** Number of samples*

Performance of packed and conventional UASB reactor at HRT of 8 hr

The HRT was fixed at 8 hours and the performance of the UASB reactors was evaluated. A substantial reduction of COD_{tot}, BOD and TSS in the packed UASB effluent was occurred at loading rate of 2.55 kgCOD/m^3/d resulting in an average percentage removal of 74%, 74% and 80%, respectively (Table 4). While, the removal rates that recorded in the effluent of the conventional UASB were 67%, 68% and 67% for COD, BOD and TSS, respectively.

Furthermore, TP were reduced by 25% and 45%, respectively. Corresponding residual concentrations were 4.5 and 3.3 mg/l. The TKN was reduced by 20% and 35% in the final effluent of classical and packed UASB reactor.

Table 4: Performance of the packed and conventional UASB reactor at 8 hours detention time

Parameter	N*	Unit	Conventional UASB effluent	%R	Packed UASB effluent	%R
COD_{tot}	25	mg/l	276.0	67	219.0	74
COD_{par}	9	mg/l	110.0	77	34.0	93
COD_{dis}	9	mg/l	110.0	41	115.0	38
COD_{col}	9	mg/l	56.0	67	70.0	59
BOD	25	mg/l	195.0	68	156.0	74
TSS	25	mg/l	92.0	67	56.0	80
TKN	19	mg/l	52.0	20	42.0	35
Ammonia	19	mg/l	45.0	6	39.0	19
TP	19	mg/l	4.5	25	3.3	45
Organic nitrogen	19	mg/l	7.0	59	3.0	82
TC	17	MPN/100 ml	$4.1x10^6$	99.5	$3.0x10^6$	99.7
FC	17	MPN/100 ml	$2.3x10^5$	99.7	$1.6x10^5$	99.8

** Number of samples*

Comparison between the treatment runs

Figure (2) shows the efficiency of the conventional as well as packed UASB reactor for the removal COD, BOD and TSS at different HRT and OLR. It was noted that the efficiency increased gradually by increasing the HRT from 6 to 8 hr. Also, the packing material enhancing the removal efficiency.

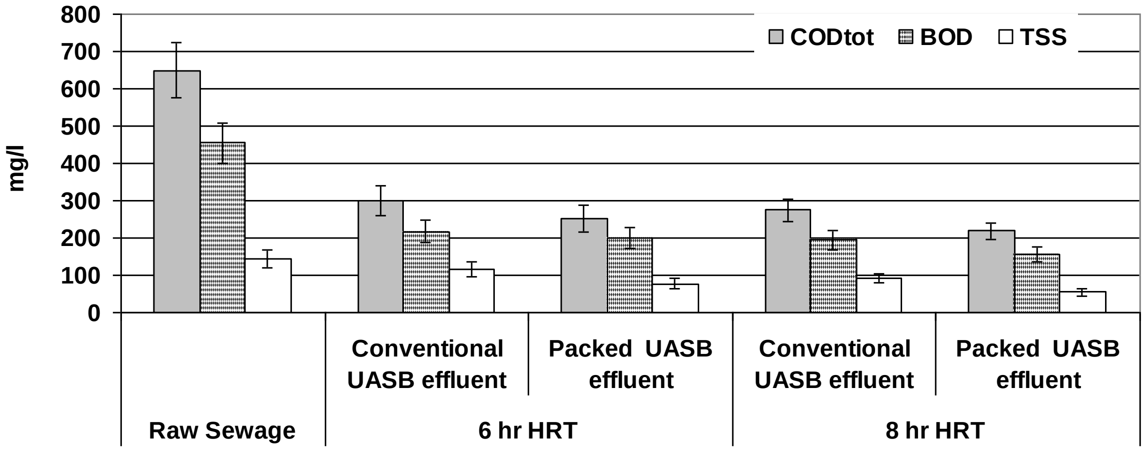

Figure 2: Concentration of COD, BOD and TSS in raw sewage as well as treated effluents at different HRT

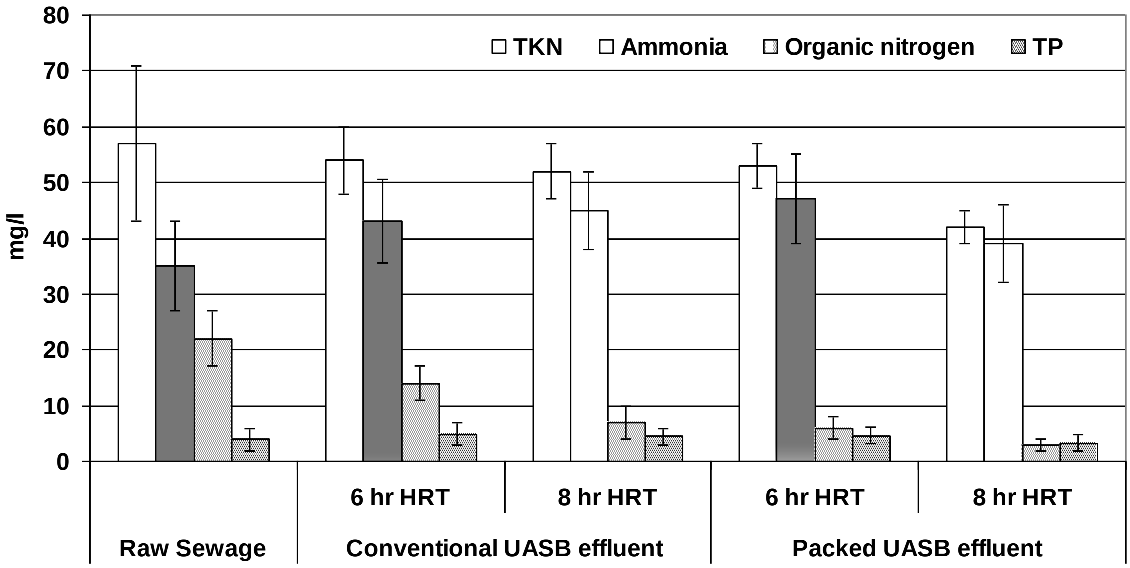

Figure 3: Concentration of TKN, Ammonia, Organic nitrogen and TP in raw sewage as well as treated effluents

The concentrations of TKN, Ammonia, organic nitrogen and TP are presented in Figure (3). It was clear that the organic nitrogen was reduced by increasing the RT from 6 to 8 hrs in the conventional UASB reactor. Organic nitrogen entrapped within the biological anaerobic system and conversion of some of TKN to ammonia took place by ammonification process. The organic nitrogen removal was found to be a function of HRT (El-Khateeb & El-Gohary 2003; Klimiuk and Kulikowska 2006). Comparing the effluent of conventional and packed UASB reactors, it is clear that the presence of packing material increase the reduction of organic nitrogen as well as TP. Reduction may be attributed to the retention of suspended matter containing nitrogenous compounds.

The effectiveness of wastewater treatment systems with respect to the elimination of microbiological pollution is often measured by determining the densities of TC and FC in effluent of wastewater treatment plants. WHO has recognized coliforms (TC and FC) as the key of fecal indicators (WHO 2002).

The counts of TC and FC were not greatly affected by the increasing of HRT. The major part of bacteria (TC as well as FC) are associated with the suspended solids and removed by entrapment in the UASB sludge bed (El-Khateeb *et al.*, 2006; Mungray and Patel 2011). The enhancement of removal of bacteria (especially colifroms) can be achieved by integration of bacteros to the biofilm created in the reactor (Tawfik *et al.*, 2004). The removal of TC and FC depends on the efficiency of sedimentation in such type of treatment (Mungray and Patel 2011). But in all runs the FC count reduction did not exceed 10^2.

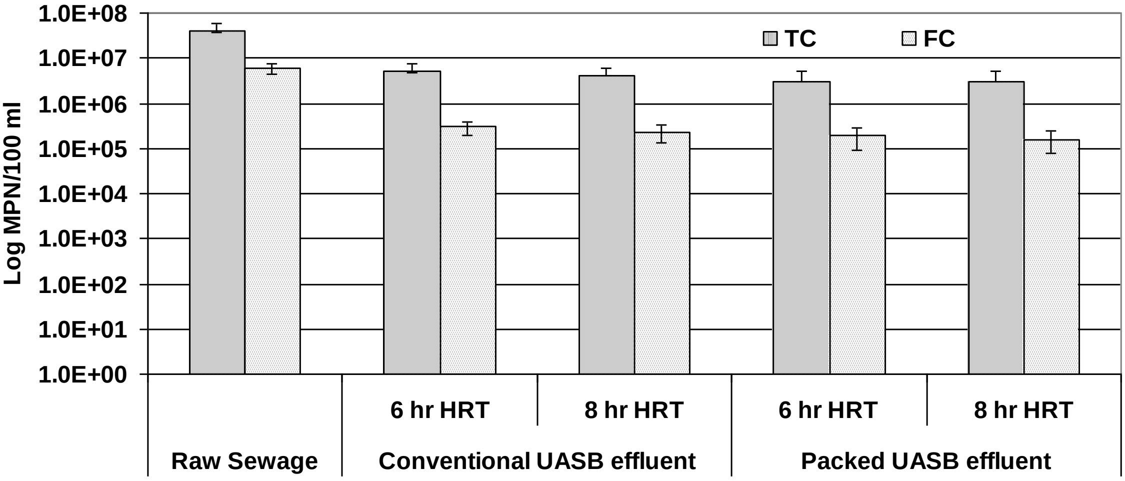

Figure 4: Efficiency of TC and FC removal

Conclusions

It was observed that the finally treated effluents still contained significant count of TC and FC (at different HRT). The TC and FC counts are greater than the permissible limit (log 3 or 1000 MPN/ml) specified by WHO for unrestricted irrigation (WHO 1989). The use of post treatment is of vital importance to meet the WHO standards for treated effluent reuse.

The packing material that was added in the settling zone in the UASB section prevents wash out of sludge and reduces the level of suspended solids and COD load in the effluent.

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