Evaluation of optimum mix ratio of abattoir and textile industry wastewater for anaerobic co-digestion

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Abstract

Textile industry effluents are carcinogenic and highly recalcitrant hence difficult to degrade especially through biological methods. On the contrary, abattoir effluents are characterized by high organic contents that pose problems during the substrates degradation process. Anaerobic degradation process is a preferred choice of wastewater treatment because of its ability to generate biogas during organic substrates' digestion process. Anaerobic co-digestion is the concept of degrading two effluent streams with complementary characteristics in order to improve the substrate removal rate. The feasibility of co-digesting abattoir and textile wastewater in a UASB reactor was evaluated at mesophilic and ambient temperature conditions in this study. Textile and abattoir industry wastewater were characterized and mixed to create the requisite synergy. Preliminary experiments were conducted in 500 ml batch reactors to evaluate the optimum abattoir to textile synthetic wastewater ratio. The abattoir to textile effluent ratio was found to be 60:40 respectively. COD and BOD_5 were the parameters used to measure biodegradability in the mixed wastewater samples. The co-digested mixture was found to be biodegradable based on the BOD:COD ratio of 0.53.

Keywords: Wastewater, Textile industry, Abattoir industry, Anaerobic co-digestion, Synergy.

1 Introduction

The global issue on environmental integrity in all industries is production of waste and particularly techniques of how to dispose of it safely. Environmental pollution is manifested in various ways some of which are; noise, air and water pollution among others. Water pollution is predominantly exhibited by wastewater generated from industries which eventually end up in critical sources of water like ground-water, springs, rivers and eventually dams as well as large water bodies. This poses a great risk to aquatic fauna and flora thereby extending to human beings and animals that depend on marine resources for nourishment (Muhammad et al., 2011).

Abattoir effluents are classified under high-strength wastewaters because of their characteristic high organic matter and remarkable environmental impact. Textile effluents on the other hand are classified under recalcitrant wastewaters because of the non-biodegradable nature of the constituent pollutants. Anaerobic wastewater treatment techniques are commonly utilized in degradation of abattoir wastewater due to its ability to degrade various types of organic pollutants and at the same time expend minimal energy while generating biogas which is a reliable source of green energy. Therefore, wastewater degradation in the absence of oxygen is regarded as one of the major sources of renewable energy. The breakdown of substrates in the absence of oxygen with the aid of acetogenic (hydrogen-producing) and methanogenic (methane-producing) bacteria converts complex organic compounds into methane, carbon dioxide and water. However, anaerobic treatment methods are most efficient when degrading nutrient rich wastewater but very inefficient when degrading nutrient deficient wastewaters.

Anaerobic wastewater treatment is more preferred in literature over aerobic treatment because of the generation of renewable biogas energy and minimal running cost. Studies have reported success in the application of UASB reactors in degrading high strength wastewaters. According to literature, anaerobic co-digestion improved biogas generation and substrate removal rate through stabilization of the reactant and optimization of the Carbon/Nitrogen ratio. The degradation of textile effluent has been found to be difficult and time consuming because of the recalcitrant nature of the constituent pollutants. Although anaerobic co-digestion has been successful in most high-strength wastewaters, limited information cited covered the co-digestion of textile and abattoir effluents. Therefore, the main aim of this study was to determine the optimum abattoir to textile wastewater ratio for efficient reactor biodegradation in terms of chemical oxygen demand (COD) removals and biogas yield.

2 Materials and Methods

The abattoir wastewater was sampled from an abattoir factory in Parys, South Africa. In an effort to achieve effluent reproducibility, the textile wastewater was synthesized to simulate industrial textile wastewater characteristics. Granular sludge from the secondary digester of a municipal sewage treatment plant was used to inoculate the UASB reactor.

Anaerobic batch reactors (500 ml) were used to investigate the optimum mixing ratio of abattoir to textile wastewater (see Fig. 1). Various proportions of AW: TW (v/v) (20:80; 40:60; 60:40; 80:20) were degraded in 0.5 L batch reactors and the biodegradability and toxicity of the wastes under mesophilic conditions evaluated (37±1 ºC). The wastewater was added batch-wise daily for 11 days and the prevailing parameters investigated (COD, BOD_5 pH and methane yield). In order to simulate a continuous process, 50 ml of the supernatant volume was sampled daily, from which the wastewater was analyzed then a fresh wastewater sample of equal volume was replaced throughout the whole operation period.

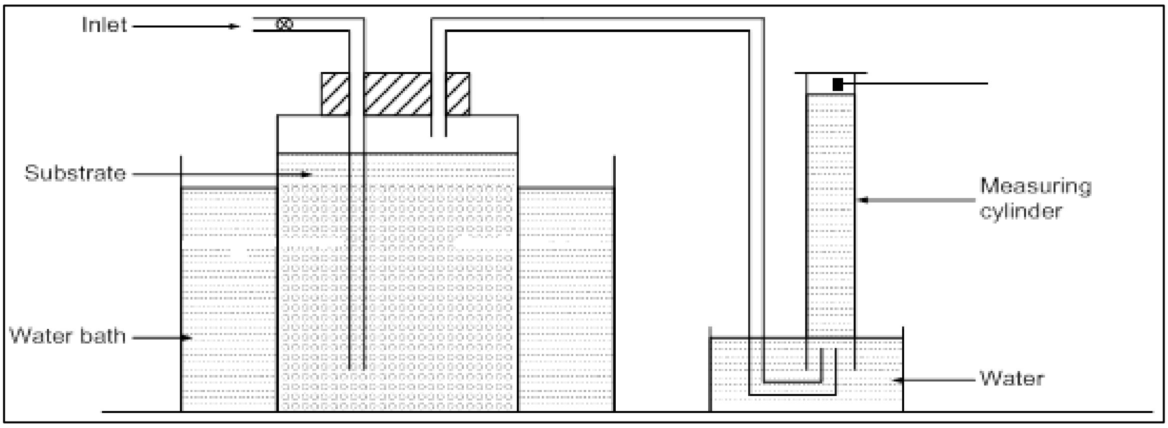

Fig. 1: Schematic diagram of the batch reactor

Kinetic Evaluation

A first-order model (Eqn. 1) postulated by Grau et al. (1975) was applied in kinetic characterization of the experimental runs in order to evaluate the influence of influent organic load and temperature variation on the anaerobic process kinetics.

$$S/S_o = \exp - (k_1 X_o t / S_o) \quad (1)$$

Where: S is the residual substrate concentration (g COD/L), S_o is the initial substrate concentration (g COD/L), k_1 is a kinetic constant linked with Grau's first-order kinetic model (g COD/L day), X_o biomass concentration (VSS)/L.

Analytical Methods

Analyses of COD, BOD_5, Total solids (TS), TSS, were done according to the procedure standards methods (APHA, 1998). Concentration of the gases in the biogas (CH_4 and CO_2) was also analyzed by gas chromatography, using the same chromatograph equipped with thermal conductivity detector. The analyses of the different parameters during the anaerobic process were done in triplicate at steady-state. Ms Excel was used to compute the data illustrated in this study.

3 Results

Raw abattoir wastewater sampled was characterized and the results obtained were used to ascertain the range of synthetic abattoir effluent parameters. Raw abattoir wastewater was characterized according to the Standard Methods of wastewater treatment (APHA-AWWA-WEF 2005). Due to the fluctuating characteristics exhibited by textile effluents, the wastewater used in this study was synthesized in order to achieve some degree of homogeneity.

Performance of the preliminary anaerobic batch Reactors.

The co-digestion of abattoir and textile wastewater was investigated at various percentage proportions of abattoir to textile wastewater. The AW:TW percentage proportions were 80:20; 60:40; 40:60; 20:80 as well the controls, 0:100 and 100:0 percent of the abattoir to textile wastewater, respectively. The respective COD values at various ratios are shown in Table 1.

The interaction mechanisms improved the quality of wastewater mixture at all abattoir to textile effluent proportions on account of the settlement of precipitated suspended solids. Anaerobic biodegradation results from the batch reactors suggested that percentage COD removal and biogas production increased with decreasing content of abattoir wastewater up to 60:40 and 40:60 abattoir:textile effluent percentage ratio respectively, after which both parameters decreased.

Table 1. Batch reactor performance at different effluent proportions after 11-day operation period.

PARAMETERS	ABATTOIR:TEXTILE WASTEWATER RATIO					
	100:0	80:20	60:40	40:60	20:80	0:100
pH	7.55±0.34	7.66±0.33	7.61±0.26	7.63±0.22	7.76±0.21	8.02±0.24
COD Before (mg/L)	6418±104	5276±97	3622±84	2963±72	2635±78	2464±53
BOD_5/COD Ratio	0.76±0.07	0.64±0.06	0.55±0.06	0.43±0.04	0.37±0.05	0.24±0.03
Biogas (L/$gCOD_{REM}$)	0.0747 ± 0.009	0.0579 ± 0.008	0.1268 ± 0.018	0.1126 ± 0.013	0.0436 ± 0.005	0.0338 ± 0.003
Turbidity	350.7±89	398.8±35	369.3±34	320.9±58	262.2±65	218.2±98

The abattoir and textile effluent mixture stabilized the anaerobic co-digestion process because of the synergy created from neutralization of the toxic and recalcitrant properties of TW. Therefore, in the subsequent co-digestion process, the mixture used was in the ratio of 60:40 of abattoir to textile wastewater. The better performance of the 60:40 reactor was further justified by the biodegradability of the effluent which was 0.55 as opposed to 0.43 BOD:COD ratio for the 40:60 mix ratio. A BOD:COD ratio higher than 0.5 conventionally depicts an effluent that can be degraded biologically and the higher the value, the more biodegradable it becomes (Sharma et al., 1996).

This experiment was executed in order to determine the optimum abattoir to textile wastewater mix ratio for the co-digestion anaerobic degradation. The optimum abattoir:textile wastewater percentage ratio was 60:40 for which the COD was 3622 mg/L.

Batch experiment kinetic evaluation

The experiments were characterized by Grau's first-order kinetic model. The gradient (p) values and first-order kinetic constant values (k'_1) are shown in Tables 2 and 3.

Table 2: Gradient (p) values evaluated using Grau's first-order kinetic model.

Run	So (g COD/L)	Slope values (p, in days^{-1})			
		A (35 °C)		B (ambient temperature)	
		P value	VC* (%)	*P value*	VC* (%)
1	3.622	0.0826	81.6	0.0345	76.8
2	2.766	0.0518	88.8	0.0264	66.4
3	1.725	0.0401	56.4	0.0253	76.0
4	1.109	0.0062	45.4	0.0046	58.3
5	0.674	0.0112	70.9	0.0095	70.8

*VC, variance coefficients.

Table 3: Kinetic constant (k'_1) values evaluated using Grau's first-order kinetic model.

Run	So (g COD/L)	Values of $k'1$ (g COD/L day)			
		A (35 °C)		B (ambient temperature)	
		$k'1$	VC* (%)	$k'1$	VC* (%)

1	3.622	0.2992	81.6	0.1250	76.8
2	2.766	0.1433	88.8	0.0730	66.4
3	1.725	0.0692	56.4	0.0436	76.0
4	1.109	0.0069	45.4	0.0051	58.3
5	0.674	0.0075	70.9	0.0064	70.8

*VC, variance coefficients.

The values of k'_1 were significantly lower for the degradation at ambient conditions compared to the degradation at mesophilic conditions. A decrease of k'_1 values was observed when the influent organic load decreased from 3.622 to 2.766 g COD/L for both reactor conditions (mesophilic and ambient). A similar observation was made by Sanchez et al. (2001) apart from the fact that lower differences of the k'_1 values were noted at higher influent organic load. The expression representing reaction rate, $-dS/dt = k'_1 S/S_o$ (Grau et al., 1975), was immensely affected by the influent organic load range. Consequently, a decrease in the influent organic load derailed the rate of substrate removal.

4 Discussion

Evaluation of the operating parameters for steady state co-digestion process in the UASB

The UASB reactor achieved steady state after 24 days as shown in Fig. 2 while being fed continuously at a flow rate of 0.375 L/d (8 day HRT). The flow rate of the reactor was then increased gradually up to 3 L/d (1 day HRT).

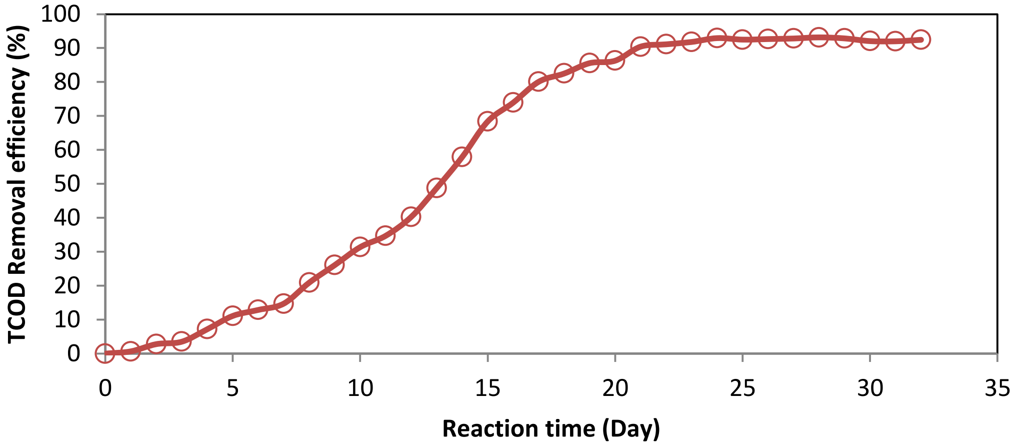

Fig. 2: Effect of reaction time on TCOD removal efficiency at 0.375 L/d flow rate.

Effect of OLR, HRT and flow rate on substrate removal

The percentage reduction of SCOD, VSS, TCOD and TSS was caused by the increase in volumetric organic loading rate (V_{OLR}) at constant initial TCOD. At a V_{OLR} of 1.81 g TCOD/L d, an abrupt drop in percentage reduction was observed.

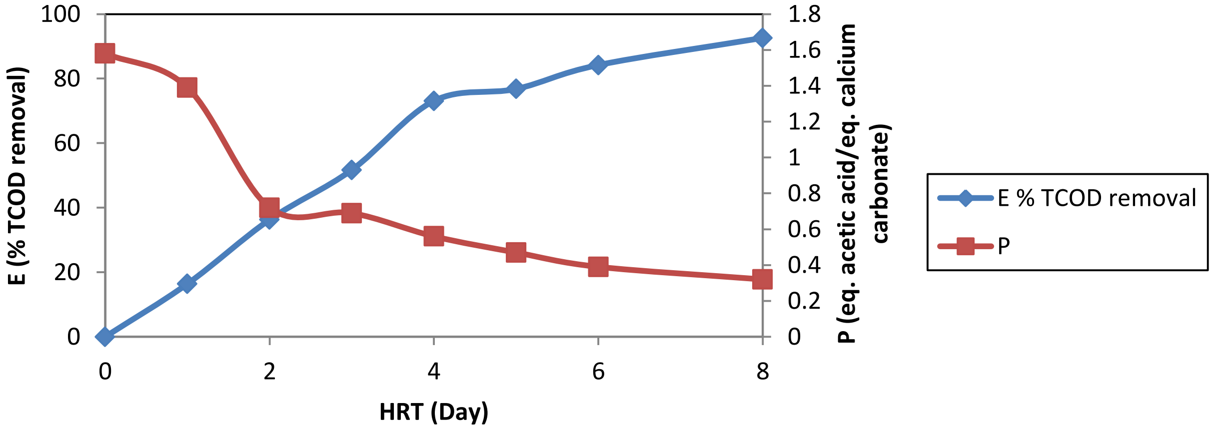

Figure 3: The effect of HRT variation on TCOD percentage reduction and TVFA/alkalinity ratio (*P*).
An increase in TVFA/Alkalinity ratio (*P*) was responsible for this drop in TCOD because the TVFA increased whereas alkalinity decreased which collectively resulted to a drop in the pH value. The biogas quality was highly influenced by the *P* ratio such that an increase in *P* resulted in an increase in CO_2 concentration on all the experimental runs examined. The effect of HRT on the *P* ratio is illustrated in Fig. 3.

As HRT increased, the value of P decreased. However, when the VOLR was more than or equal to 1.81 g TCOD/L d, the percentage reduction dropped abruptly thereby increasing the TVFA/Alkalinity ratio beyond 0.7 which consequently destabilized the anaerobic degradation conditions. The TVFA/Alkalinity ratio (P) increased from 0.3 to 0.7 when the concentration of Carbon dioxide increased as shown in Fig. 4.26. At high P values, Carbon dioxide concentration remained rather constant. A similar trend was observed by Sanchez et al. (2001) and Yu et al. (2002). However, the CO_2 concentration increased when the value of P went up from 0.3 to 0.7 and remained practically constant at higher P values.

5 Conclusions

Abattoir and textile effluent were synthesized for efficient reproducibility. The two effluent streams were then mixed in particular proportions in order to establish the optimum mix ratio for efficient reactor performance. The optimum abattoir to textile wastewater ratio obtained was 60:40, which had TCOD of 3622 mg/L. The mixture was found to be more biodegradable compared to individual synthetic textile effluent stream.

The results of this study showed that synthetic effluent mixture of abattoir and textile industries could be degraded effectively using UASB reactor at different HRTs varying between 1 and 8 days. The kinetics evaluated according to Grau's second order multicomponent substrate removal kinetic model yielded a correlation coefficient of 0.996 and a significant kinetic coefficient (k_s) of 0.389, which were found suitable for predicting the performance of a lab-scale UASB reactor.

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