UASB treatment of a highly alkaline fruit-cannery lye-peeling wastewater

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Abstract

Anaerobic treatment of a highly alkaline fruit-cannery lye-peeling wastewater was investigated, using an upflow anaerobic sludge blanket (UASB) reactor. Only a short initialisation period was required before COD reduction and OLR had stabilised at 85 to 90% and 2.40 kgCOD·m⁻³·d⁻¹, respectively. With subsequent increases in OLR to 8.1 kgCOD·m⁻³·d⁻¹, the COD reduction remained between 85 and 93% and biogas production peaked at 4.1 ℓ·d⁻¹ (63% methane). COD and reactor pH started to decrease after 111 d. Decreases in gas production were observed by Day 102, decreasing to 2.48 ℓ·d⁻¹ by Day 111 and 0.93 ℓ·d⁻¹ after 129 d. Subsequent reductions in the OLR, by reducing influent COD, had no effect on reactor stability. Loss of reactor performance was ascribed to the accumulation of sodium (potentially > 20 000 mg·ℓ⁻¹) within the reactor biomass, leading to inhibition of methanogenesis.

Keywords: UASB, anaerobic digestion, fruit cannery, treatment, lye

Introduction

Food-processing industries in South Africa are under increasing pressure to reduce the impact of their wastewater streams on the environment. With the promulgation of the National Environmental Management Act, Act 107 of 1998 (Republic of South Africa, 1998a) and the National Water Act, Act 36 of 1998 (Republic of South Africa, 1998b) the polluter-pays-principle has been adopted, i.e. the polluter pays for the treatment and disposal of the effluent produced. The production of large volumes of untreated wastewater can thus become a very serious financial burden. It is the basic requirement of the legislation on pollution control that wastewater purification be an integral part of industrial processes and that the producer of the wastewater should provide staff, capital and plant to purify the produced wastewater to prescribed standards (Republic of South Africa, 1998a & b; Gray, 1999). Industrialists should also be aware of the environmental impact of their processes and take steps to minimise these effects (Ikhu-Omoregbe and Masiiwa, 2002).

Due to the nature of the fruit-canning process, large volumes of water are used in the transportation of the product, washing and rinsing, blanching, retorting and cooling operations (Wayman, 1996). Disposal of cannery wastewaters is often complicated by the seasonal nature of the industry, the presence of suspended solids and particulate organics (Harada et al., 1994), cleaning solutions (most commonly sodium hydroxide), often in formulations with various chelating, softening or surface-active additives, nitric and phosphoric acids (Mawson, 1997) and sodium hydroxide (used during peeling of certain fruits and vegetables) in the wastewater. In the past these wastewaters had been treated and disposed of by irrigation, lagooning or by means of an activated sludge process (Monson, 1959; Hanks et al., 1968; Gambrell and Peele, 1973; Stalzer, 1976) and irrigation

of lye wastewaters was still practised in South Africa as recently as 2000. Currently, most South African fruit canneries recycle their lye solutions as far as possible and dilute the rest by mixing with other cannery wastewaters.

Anaerobic digestion of food processing wastewaters has been successfully implemented (Austermann-Haun et al., 1999; Frankin, 2001). The use of UASB technology to treat seasonal fruit-cannery wastewaters has recently been shown to be a feasible option, with COD reductions of up to 93% at organic loading rates (OLR) of 10.95 kgCOD·m⁻³·d⁻¹ and hydraulic retention times (HRT) of <12 h (Trnovec and Britz, 1998). The wastewater originating from the lye-peeling operation, however, requires special attention. This highly alkaline wastewater has COD levels of between 45 000 and 50 000 mg·ℓ⁻¹ and a pH of between 12.5 and 13.8, impacting significantly on the overall treatability of the cannery wastewater.

The aim of this study was to assess the applicability and effectiveness of the UASB process to treat a fruit-cannery wastewater. The wastewater used in this study was a highly alkaline lye-peeling fruit wastewater obtained from a local fruit cannery.

Material and methods

Digester design

A laboratory-scale upflow anaerobic sludge blanket (UASB) reactor was used. The digester had an operational volume of 2.3 ℓ (total height of 830 mm and internal diameter of 50 mm) and combined a UASB design with an open gas/solids separator at the top of the reactor (McLachlan, 2004). The biogas exited through the top, while the substrate was introduced into the reactor at the base. The overflow of the reactor emptied through a U-shaped tube to prevent any atmospheric oxygen from entering the system. The re-circulation upflow velocity for the reactor was set at 2 m·h⁻¹. The temperature of the insulated reactor was maintained at 35°C using heating tape and an electronic control unit (Meyer et al., 1985). The volume of the biogas was determined using a manometric unit equipped with an electronically control-

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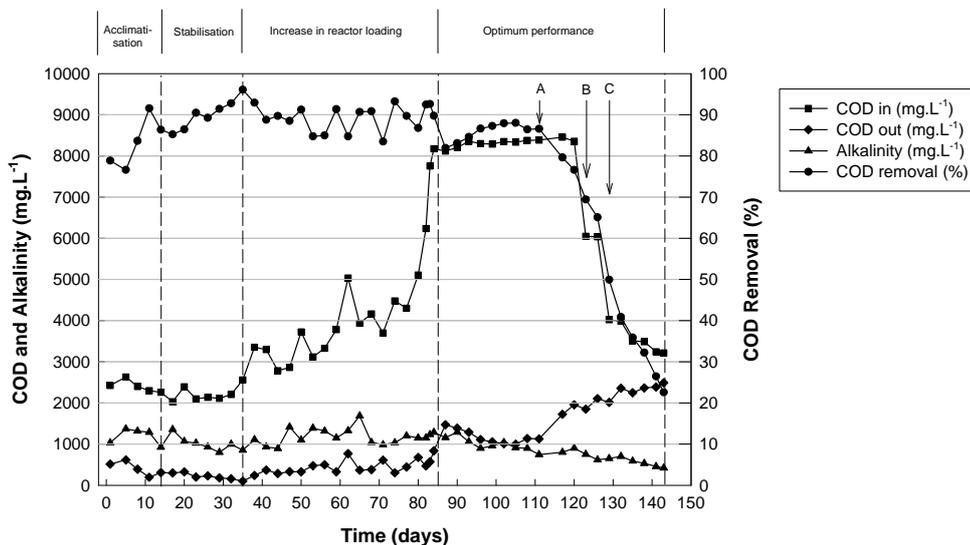
led counter and a gas-tight valve and the volumes corrected to standard temperature and pressure (STP). The substrate was fed semi-continuously to the reactor by means of a peristaltic pump (Watson-Marlow 101) controlled by an electronic timer.

Reactor start-up

The reactor was seeded with 500 g of water-drained anaerobic granules from another anaerobic digester giving a settled sludge-bed height of approximately 300 mm. The reactor was then allowed to stabilise for 48 h in order to allow the bacterial community to acclimatise and fed with a diluted synthetic substrate, and the HRT was set at 24 h. After three weeks this was replaced with a highly alkaline lye-peeling wastewater from a fruit-canning factory with an average COD of 2 500 mg·ℓ⁻¹ (2 030 to 2 630 mg·ℓ⁻¹). Once the system had achieved 85 to 90% COD reduction efficiency the influent COD concentration was increased as well as subsequent increases in the OLR. This was considered to be a 'stable state', during which the variation in reactor performance parameters was less than 10%.

Wastewater and substrate

The full-strength highly alkaline wastewater had an initial COD of 45 000 to 50 000 mg·ℓ⁻¹ and a pH of between 12.5 and 13.5. The sodium concentration of the wastewater was *ca*. 40 000 mg·ℓ⁻¹. The full-strength wastewater was allowed to undergo natural fermentation until the pH was approximately 7.5. The wastewater was then diluted to a COD concentration of 2 500 mg·ℓ⁻¹ and the pH pegged at 8.5 and used as substrate. The sodium concentration of this diluted substrate was approximately 2 000 mg·ℓ⁻¹.

The composition of the synthetic substrate (in mg·ℓ⁻¹) was: glucose 1 250; sodium lactate 5 000; urea 500; and KH_2PO_4 500. The substrate was also supplemented with 1.0 mℓ trace element solution (Nel et al., 1985) and the pH pegged at 8.5 with calcium hydroxide for maximum granule growth. The substrate was then diluted to the required COD concentration of 2 500 mg·ℓ⁻¹.

Analytical methods

The following parameters were monitored, in duplicate, according to *Standard Methods* (1998): pH; alkalinity; and total solids (TS). COD and orthophosphate phosphorus were determined colorimetrically using a DR2000 spectrophotometer (Hach Co.,

Loveland, CO) and standardised procedures (*Standard Methods*, 1998). Sodium ion concentration was determined, in duplicate, using a Varian MPX Inductively Coupled Plasma (ICP) Spectrometer at a wavelength of 589 to 592 nm. The emissions were compared to those of standardised sodium solutions.

The biogas composition was determined on a Varian 3300 GC equipped with a thermal conductivity detector and 2.0 m x 3.0 mm i.d. column packed with Hayesep Q (Supelco, Bellefonte, PA), 80/100 mesh. The oven temperature was set at 55°C and helium was used as carrier gas at a flow rate of 30 mℓ·min⁻¹.

Results and discussion

The UASB reactor efficiency parameters are shown graphically in Figs. 1 and 2. The operation of the UASB reactor has been divided into time periods of reactor start-up (not shown), substrate acclimatisation, reactor stabilisation, increase in reactor loading and optimum performance:

Reactor start-up

During the start-up period (data not shown) the influent COD of the synthetic substrate was kept at 2 500 mg·ℓ⁻¹ (± 150 mg·ℓ⁻¹) and the COD reduction increased to 93%, averaging 90% during the third week. The reactor effluent pH varied between 6.84 and 7.48, the average OLR during the three-week start-up period was 2.45 kg COD·m⁻³·d⁻¹. The reactor effluent alkalinity remained constant at 1 000 mg·ℓ⁻¹ (± 110 mg·ℓ⁻¹). After three weeks the synthetic substrate was replaced with a highly alkaline lye-peeling wastewater.

Substrate acclimatisation

The average COD load of the highly alkaline lye-peeling wastewater was 2 200 mg·ℓ⁻¹. Initially the COD reduction decreased to 77% on Day 5 before stabilising and increasing to between 85 and 90% after 14 d. The reactor effluent alkalinity averaged 1 186 mg·ℓ⁻¹ (± 447 mg·ℓ⁻¹ as CaCO₃) (Fig. 1). The reactor pH varied between 7.18 and 7.27, the average OLR during this period was 2.40 kg COD·m⁻³·d⁻¹ (Fig. 2).

Reactor stabilisation

During the period Day 14 to 35, the influent COD load was kept constant at 2 200 mg·ℓ⁻¹ (± 360 mg·ℓ⁻¹) and the COD reduction
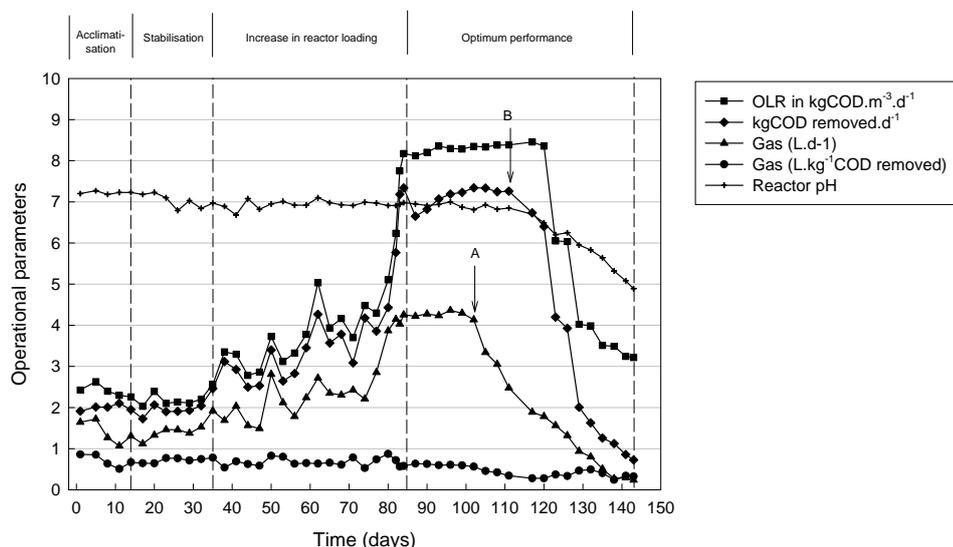
was found to vary between 85 and 96% (Fig. 1). The reactor effluent pH varied between 6.80 and 7.23, the average OLR for this period was 2.20 kgCOD·m⁻³·d⁻¹ and biogas production remained relatively constant at 1.4 ℓ·d⁻¹ (Fig. 2).

Increase in reactor loading

The influent COD was gradually increased, during Days 36 to 85, to a maximum of 8 200 mg·ℓ⁻¹, with the OLR reaching 8.10 kgCOD·m⁻³·d⁻¹ on Day 85. The COD reduction remained at an average of 90% (83.5 to 93.2%) (Fig. 1) The biogas production was also found to increase from 1.4 to 4.0 ℓ·d⁻¹ by Day 85. During this period the reactor effluent pH varied between 6.70 and 7.10 (Fig. 2).

Optimum performance

From Day 85 to 120 the influent COD was kept constant at 8 300 mg·ℓ⁻¹ (8 120 to 8 456 mg·ℓ⁻¹). A COD reduction of between 82 and 90% was achieved (Fig. 1) and the effluent pH was found to vary from 6.78 to 6.98 (Fig. 2) until Day 111. After Day 111 it was found that the COD and pH had decreased to 76% and 6.49, respectively. Methanogens are known to be inhibited at pH levels of below 6.5 (Lin and Yang, 1991; Droste, 1997; Bitton, 1999). On Day 121 the influent COD concentration was lowered to 6 000 mg·ℓ⁻¹ in an attempt to stabilise the reactor system pH and COD reduction by lowering the fermentable carbon source. The COD reduction, however, continued to decrease and two subsequent decreases in influent COD to 4 000 mg·ℓ⁻¹ on Day 129 and to 3 500 mg·ℓ⁻¹ on Day 135, were also unsuccessful in stabilising the COD reduction efficiency or pH, which continued to drop after Day 120 to Day 143 indicating that acidification of the reactor had taken place. The COD reduction decreased from 76% on Day 120 to below 50% on Day 129 and to 22% after 143d. During this same period the reactor effluent pH decreased from 6.49 on Day 120 to 5.95 on Day 129 and 4.89 after 143 d.

The gas production after Day 85 remained relatively constant at *ca.* 4.1 ℓ·d⁻¹ (63% methane), until Day 102, whereafter the gas production decreased to 2.48 ℓ·d⁻¹ (48% methane) by Day 111 and to 0.93 ℓ·d⁻¹ (22% methane) by Day 129. The data show that the gas production started to decrease (Day 102) before any other negative tendencies were observed in either COD reduction or reactor effluent pH. This dramatic decrease in the methanisation rate could possibly be as a result of the high levels of sodium

(influent Na⁺ concentration of *ca.* 7 300 mg·ℓ⁻¹) accumulating in the reactor. It has been reported that sodium, at low concentrations, is essential for methanogens, probably because of its role in the formation of adenosine triphosphate (ATP), the oxidation of NADH (Feijoo et al., 1995) or in the chemi-osmotic coupling mechanism (Rinzema et al., 1988). It has also been shown that the presence of high sodium concentrations (10 000 to 25 000 mg·ℓ⁻¹) is inhibitory to anaerobic wastewater treatment in that methanogenesis is inhibited to varying degrees (Feijoo et al., 1995).

In this study the sodium concentration of the initial diluted lye-peeling substrate was *ca.* 2 000 mg·ℓ⁻¹ (± 200 mg·ℓ⁻¹). When the influent COD concentration was at a maximum of 8 300 mg·ℓ⁻¹ (Days 85 to 120), the sodium concentration of the substrate was *ca.* 7 300 mg·ℓ⁻¹. During this period the sodium concentration of the reactor effluent varied between 6 800 and 7 200 mg·ℓ⁻¹. The difference in reactor influent and effluent Na⁺ concentrations would suggest an accumulation of sodium within the reactor's biomass. Based on the rapid decrease in CH_4 production, it is possible that accumulation of sodium within the system led to the inhibition of the methanogenic population, with subsequent acidification of the entire system and accumulation of volatile fatty acids.

The above data are in agreement with reports by De Baere et al. (1984) who investigated the effect of NaCl shock treatments on a flow-through anaerobic digester. They reported that initial inhibition and a 50% inhibition were observed at 30 000 and 35 000 mg·ℓ⁻¹ sodium, respectively. According to these authors adaptation to increasing amounts of NaCl significantly affected the tolerance of the methanogenic association when compared to the shock treatment. With adaptation, an initial inhibition was observed at 65 000 mg·ℓ⁻¹ and 50% inhibition at 95 000 mg·ℓ⁻¹ of NaCl. Feijoo et al. (1995) reported that sodium concentrations ranging from 3 000 to 16 000 mg·ℓ⁻¹ (in the absence of nutrients or other salts) caused a 50% inhibition in the methanisation of volatile fatty acids. Rinzema et al. (1988) found that the maximum specific acetoclastic activity of granular sludge was hardly affected at sodium concentrations of below 5 000 mg·ℓ⁻¹ (10% inhibition), whereas the activity was practically reduced to zero at 14 000 mg·ℓ⁻¹ Na⁺. In UASB systems, the results were slightly more favourable, with 10% and 100% inhibition at 5 500 and 15 000 mg·ℓ⁻¹ Na⁺, respectively (Rinzema et al., 1988). Kim et al. (2000) also found that methane production decreased with increases in sodium concentrations above 5 000 mg·ℓ⁻¹ and

that at 20 000 mg·ℓ^{-1} a 50% reduction in theoretical gas volume was observed. In this study, it was clear from the concentration of sodium in the reactor effluent that the level of accumulated sodium in the reactor could readily have reached levels of > 20 000 mg·ℓ^{-1}.

Conclusions

In this study, digestion of the organic fraction present in fruit-cannery lye-peeling wastewaters was again shown to be a feasible treatment option, with COD reductions of up to 95% being obtained. Furthermore, it would appear that the microbial consortium involved in the anaerobic digestion process can acclimatise to higher sodium-ion levels present in the wastewater. This is in agreement with observations in the literature. However, accumulation of sodium ions within the reactor biomass to levels of above 15 000 mg·ℓ^{-1} can also become detrimental to the overall stability of the reactor, inhibiting the anaerobic digestion process, leading to decreased COD reduction (decreased from 90% to 22%), gas production (decreased from 4.1 to 0.93 ℓ·d^{-1}) and reactor acidification (pH dropped from 6.98 to 4.89). It appears that the methanogens are more sensitive to higher sodium levels, as the biogas and methane percentages were the first parameters to change. Decreases in methane production could thus be an early warning system of sodium accumulation or toxicity and should thus be closely monitored in systems treating wastewaters containing high sodium concentrations. In the case of fruit-cannery wastewaters, it would also be advisable to integrate the highly alkaline lye-peeling wastewater with other wastewaters generated in the canning process, in order to dilute the sodium-ion concentration, so as to lower the risks of negatively affecting the efficiency of anaerobic digestion processes. From the data obtained in this study it was also considered important to examine the use of additional chemical processes to facilitate the decrease of the organic load of the fruit-cannery wastewater following the UASB treatment, in order to meet the 75 mg·ℓ^{-1} 'general' legal limit for discharge to a natural water system.

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