

Anaerobic treatment of cassava starch extraction wastewater using a horizontal flow filter with bamboo as support

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Abstract

Small-scale sour starch agroindustry in Colombia suffer from absence of water treatment. Although starch processing plants produce diluted wastewater, it is a source of pollution and cause environmental problems to the nearby rural population. A laboratory scale anaerobic horizontal flow filter packed with bamboo pieces was evaluated for the treatment of cassava starch extraction wastewater. The wastewater used in the experimentation was the draining water of the starch sedimentation basin. The reactor was operated for 6 months. It was inoculated with a semi-granular sludge from an anaerobic UASB reactor of a slaughterhouse. Maximum organic loading rate (OLR) applied was 11.8 g COD/L d without dilution of the wastewater. At steady state and maximum OLR applied, 87% of the COD was removed and a gas productivity of 3.7 L/L d was achieved. The average biogas yield was 0.36 L/g COD removed. Methane content in the biogas was in the range of 69–81%. The total suspended solids (TSS) removed were 67%. The relative high lactic acid content did not negatively influence the performance of the reactor. No perturbation due to cyanide (3–5 mg/L) was observed during the reactor operation. The results obtained indicated that the anaerobic horizontal flow filter could be used efficiently for the treatment of wastewater from Colombian starch processing small-scale agroindustry.

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1. Introduction

Cassava sour starch is the product of traditional and rural low-technology agroindustry in Latin America. In the region of the Cauca Valley (Colombia), wastewaters generated from the starch extraction process by about 250 existing small-scale plants are directly discharged into rivers without any treatment (Rojas et al., 1996). Although starch processing plants produce diluted wastewater, it is a source of pollution and causes environmental problems to

the nearby rural population. Cassava processing plants generate two liquid residues. The first results from the washing and peeling of cassava roots in a rotary drum, and generally contains a large amount of inert material with low chemical oxygen demand (COD). The second results from draining the starch sedimentation tank, and has a higher contaminating load of COD and biochemical oxygen demand (BOD). Wastewater characteristics are highly dependent on the efficiency level of the machines used in the factory. A typical sour starch plant, often run by a family, daily processes 1–5 tons of cassava roots and consumes about 12 m³ of water per ton of fresh cassava roots. This generates a contaminating load of about 100 kg of COD per ton of roots that is discharged into Colombian rivers each day. Despite its cyanide content (average 3.5 mg/l) and acidity (pH 4.5–5.5), the resulting

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wastewater is susceptible to anaerobic degradation (Rojas et al., 1999; Gijzen et al., 2000).

Considering the socio-economic profile of such small-scale industrial farming operations, it was necessary to develop an appropriate low cost technology for the treatment of starch extraction wastewater. The anaerobic filter is a treatment system that meets these specifications for the treatment of sewage and industrial waste (Young and McCarty, 1969). Its operating principle is based on immobilizing microorganisms on a support that could be of lignocellulosic nature.

In this study we investigated the performance of an anaerobic horizontal flow filter filled with bamboo to treat wastewater originated from a typical small-scale cassava starch extraction factory. We used bamboo, which grows throughout the country, is inexpensive, and has a very low susceptibility to biological degradation, as filling (Camargo and Nour, 2001). The horizontal flow filter was meant to promote a predominant plug flow regime, thus favoring phase separation and solids immobilization (Cuzin et al., 1992).

2. Methods

2.1. Bamboo filter and operating conditions

The experimental reactor was a rectangular fiberglass tank packed with bamboo pieces as fixed bed (Fig. 1). The overall ($L \times W \times H$) dimensions of the reactor were $54 \times 12 \times 20$ cm. Bamboo pieces (20–30 cm long, 1 cm diameter) were longitudinally cut and laid out in the reactor, parallel to the horizontal water flow. The level of liquid in the reactor was maintained at approximately 1 cm above the top of the support media. The working volume was 9.46 L. The bed porosity measured by water volume difference was 69%; therefore the water volume of the reactor was 6.52 L.

The digester was equipped with inlet and outlet ports for feeding and for effluent discharge, respectively, and with a port for collecting gas. The feed was pumped into the feed-

ing compartment of the reactor and the effluent was withdrawn from the outlet port. Biogas exited at the top of the reactor through a wet gas meter. The reactor was operated in the south of Colombia at a room temperature of 30 °C and 19 °C for daily and nightly temperature, respectively.

2.2. Wastewater

The wastewater used in this experiment was collected every week from the sedimentation tank outlets of the starch factory “La Esmeralda” located in the Cauca department (Colombia) and stored at 5 °C until use. It was diluted with tap water when required before feeding. While feeding the reactor, in order to limit the development of microbial activity, the wastewater was kept, under continuous stirring in a refrigerator, at 5 °C.

2.3. Inoculum material

The inocula material required for the start-up of the reactor was procured from a full-scale UASB plant treating wastewater from a local slaughterhouse (Carnes y Derivados de Occidente Ltd., Cali, Colombia). The reactor was inoculated with 2.0 L of semi-granular sludge and operated under recycling conditions for 3 days before switching it over to continuous operation. The volatile suspended solids (VSS) content of the inoculum was 0.1 g/g wet sludge and the methanogenic activity was found to be 0.36 ± 0.02 g COD_{CH_4} /g VSS d.

2.4. Technical analysis

Influent and effluent samples were periodically taken for analysis. Total solids (TS), total suspended solids (TSS), volatile suspended solids (VSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), alkalinity, turbidity, total nitrogen (N-Kjeldahl) and phosphorus were analyzed in triplicate according to Standard Methods (APHA-AWWA-WPCF, 1985). Samples were filtered

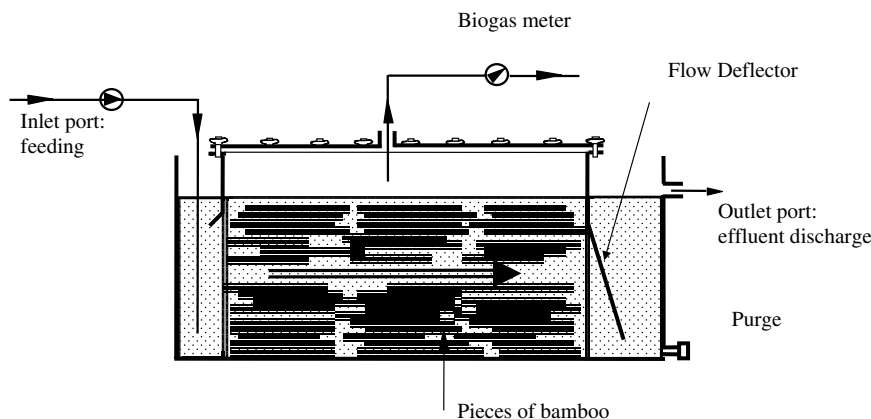


Fig. 1. Horizontal flow reactor with bamboo as support.

through 0.45 µm glass fiber filters for the determination of soluble COD.

Organic and volatile fatty acids (VFA) were determined in triplicate by HPLC by using an Aminex HPX87H column (Bio-Rad Richmond, CA.) and a refractometer. Samples were centrifuged at 10,000 rpm for 5 min and filtrated through 0.45 µm to remove suspended solids prior to being fed to the chromatographic columns. Sugar determination was made using the total sugar method with anthrone (Dubois et al., 1956). Cyanide was measured spectrophotometrically with the Merck Spectroquant 14800 Kit (E. Merck KGaA, Darmstadt, Germany).

Biogas production was measured volumetrically using a wet gas flow meter (Schulmberger). Methane content of biogas was determined by using a Shimadzu GC-8A gas chromatograph (Shimadzu Scientific Instruments North America, 7102 Riverwood Drive, Columbia, MD 21046, USA) equipped with a flame ionization detector (FID) and a 10 m Heliflex AT-1000 capillary column (Alltech associates, Inc. Deerfield, IL, USA).

Influent and effluent COD, pH and biogas production were daily determined during the reactor operation. The other parameters, namely TS, TSS, VSS, and methane were determined twice every week. Alkalinity and volatile fatty acids in the effluent were determined once every week.

Methanogenic activity test was performed at the end of the experimentation. The fixed biomass was carefully removed from the bamboo pieces in an anaerobic chamber (Coy Laboratory Products Inc., Grass Lake, MI, USA). Specific methanogenic activity (SMA) of biomass was determined following the methodology described by Soto et al. (1993), using a mixture of acetate, propionate, and butyrate (2:0.5:0.5) as substrate. Methane production was followed by gas chromatographic analysis of the headspace over a period of 2 days. Specific methanogenic activity (g COD-CH₄/g VSS d) was calculated by extrapolation of

the slope of the methane production curve versus time. All incubations were done in triplicate.

2.5. Statistical analysis

The data are presented in terms of arithmetic averages of at least three replicates values ± standard deviation. Statistical analysis (arithmetic average and standard deviation) was performed using Microsoft Excel 2000 (Microsoft Corporation, Redmond, Washington, USA).

3. Results and discussion

3.1. Characteristics of the wastewater

Cassava starch extraction wastewater resulted mainly from the draining of the sedimentation tanks in which the starchy slurry was left to settle. The liquid residue generated from the washing and peeling of cassava roots generally contains a large amount of inert material with low COD and does not need biological treatment. Each factory produces a wastewater having its own characteristics with respect to organic content and volume, depending on the efficiency level of the machines used.

The physicochemical characteristics of the wastewater are given in Table 1. Samples were taken from sedimentation tanks at 12 different starch factories. Wastewater characteristics were highly dependent on the level of technology of the plant, on the variety of cassava processed and on the retention time of water in the sedimentation tanks. The fluctuation was particularly noted for the pH values. The temperature of the wastewater varied between 20 and 25 °C. A relatively low COD value (4800 mg/L) due to the large volume of the drainage water and a high turbidity (250 NTU) characterized the wastewater. The soluble and colloidal fraction of the COD was approximately 80%. The COD:BOD₅ ratio was high, probably due to the

Table 1
Main characteristics of the cassava starch extraction wastewater

Parameter ^a	Range	Average value ^b	Wastewater used in this study ^c
pH	3.6–6.5	5.3 ± 0.7	5.5 ± 0.8
Chemical demand for oxygen, COD	4200–7000	4800 ± 810	5100 ± 320
Soluble COD, SCOD	3500–6100	3850 ± 740	4030 ± 180
Biochemical demand for oxygen, BOD	1100–3900	1680 ± 755	1730 ± 310
Total solids, TS	2300–6600	3800 ± 1305	3670 ± 650
Total suspended solids, TSS	700–2200	1350 ± 440	1280 ± 270
Volatile suspended solids, VSS	600–2050	1200 ± 560	1250 ± 130
Total carbohydrates	330–400	365 ± 19	375 ± 16
Lactic acid	1200–2000	1400 ± 240	1540 ± 180
Acetic acid	330–400	350 ± 19	380 ± 20
Total nitrogen	80–150	105 ± 16	112 ± 7
Total phosphorus	20–35	25.1 ± 8.1	28 ± 3
Cyanide	3–5	3.5 ± 0.5	3.5 ± 0.2
Water used/ton of cassava proceeded (m ³)	10–14	11 ± 1.1	10.8 ± 0.3

^a All parameters except pH are in mg/L.

^b Average value was taken from 12 starch extraction plants. All analyses were carried out with three replicates.

^c Results were means of 26 analyses with three replicates.

well-known inhibitory action of cyanide on the aerobic biodegradation process (Solomonson, 1981). The COD:N:P ratio (192:4:1) of the starchy wastewater was suitable for its bioconversion to methane; it was not necessary to add any nutrients. The volatile fatty acid and organic acid content was relatively high and had a strong influence over the pH of the wastewater. The lower pH values indicated that the acidification process of starch, due to lactic acid production, had started in the sedimentation tanks. The low carbohydrate content of the wastewater was in agreement with this observation. The cyanide content (average 3.5 mg/L) was low suggesting that the anaerobic microbial consortia could readily adapt to this inhibitor (Rojas et al., 1999; Gijzen et al., 2000). The chemical characteristics of the wastewater used in the experiment were close to the average values obtained from the analysis of the 12 starch industry wastewaters (Table 1).

3.2. Hydrodynamic study of the horizontal flow filter reactor

The flow pattern of the horizontal flow filter was determined at a HRT of 10 h during 30 h using a lithium chloride solution as a tracer. The overall flow pattern of the reactor was intermediate between the flow of a plug flow reactor and that of a continuously stirred tank reactor as evidenced by the slow decrease of the tracer curve, which corresponds to a wide longitudinal dispersion (data not shown).

3.3. Performance of the reactor

After the start-up period (days 1–60) during which the reactor was progressively adapted to the diluted wastewater (0.2–0.5 g COD/L), organic loading rate (OLR) was gradually increased and hydraulic retention time (HRT) decreased in response to evidence of stability of COD removal. At each loading rate, the reactor was operated until a steady state performance was reached as indicated by a constant gas production rate and COD removal efficiency. From day 105 onwards, the reactor was operated at HRT of approximately 9.5 h and OLR increased to assess the maximum loading rate for the process. The effect of varying OLR on digester performance in terms of COD

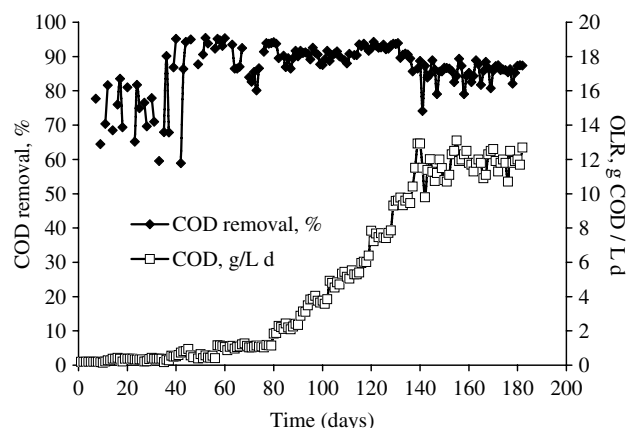


Fig. 2. Organic loading rate and COD removal efficiency during the operation period.

conversion efficiency is shown in Fig. 2. An efficiency of 87% was obtained at a maximum COD loading of 11.8 g COD/L d without any dilution of the wastewater. The slight decrease in COD removal efficiency observed at this applied OLR indicated the limitation of the digester capacity presumably due to the hydrodynamics of the digester.

The operational parameters and results obtained at the different OLR periods are presented in Table 2. During the longest period of stable loading rate obtained in this experiment (days 140–180) the TSS removal averaged 67%. The variations of influent and effluent pH values are shown in Fig. 3. The fluctuation of influent pH values does not affect the overall performance of the digester. It can be observed that the effluent pH at all the OLR studied remained between 6.9 and 7.8, even when the feed substrate had relatively low pH. Furthermore, the alkalinity of the effluent, which maintained between 1000 and 1500 mg CaCO₃/L after the first 60 days, was an indication of the considerable buffering capacity of the reactor (data not shown). We did not observe accumulation of VFA in the effluent at any moment during the operation of the reactor. The reactor maintained a stable process performance as was indicated by the low concentration of volatile fatty acids in the reactor effluent, which was 120 mg/L $\pm$ 20 mg/L at the highest loading rate. VFA concentrations

Table 2
Performance of the horizontal flow reactor at various organic loading rates

OLR (g COD/L d)	No of days at each OLR	HRT (h)	Removal efficiency (%)			Biogas production (L/L d)
			COD	TSS	VSS	
1.1 $\pm$ 0.1	11	43.2 $\pm$ 1.7	87.2 $\pm$ 13.8	51.3 $\pm$ 3.7	74.2 $\pm$ 2.5	0.52 $\pm$ 0.14
2.3 $\pm$ 0.1	9	20.5 $\pm$ 0.9	89.3 $\pm$ 2.7	55.9 $\pm$ 2.4	66.3 $\pm$ 2.8	0.81 $\pm$ 0.10
3.8 $\pm$ 0.2	8	13.4 $\pm$ 0.5	89.2 $\pm$ 2.4	70.8 $\pm$ 1.2	69.1 $\pm$ 1.9	1.72 $\pm$ 0.10
5.3 $\pm$ 0.2	8	9.2 $\pm$ 0.1	91.3 $\pm$ 3.1	70.2 $\pm$ 1.5	–	2.13 $\pm$ 0.07
7.6 $\pm$ 0.15	9	9.6 $\pm$ 0.2	90.5 $\pm$ 0.8	68.3 $\pm$ 1.1	70.2 $\pm$ 1.2	2.65 $\pm$ 0.16
9.6 $\pm$ 0.2	6	9.5 $\pm$ 0.1	90.3 $\pm$ 3.1	66.1 $\pm$ 0.9	68.5 $\pm$ 0.8	2.85 $\pm$ 0.10
11.8 $\pm$ 0.8	40 (15 ^a)	9.5 $\pm$ 0.3	87.1 $\pm$ 6.2	67.3 $\pm$ 1.8	68.2 $\pm$ 0.9	3.70 $\pm$ 0.17

^a Mean values at this OLR were calculated over a period of 15 d.

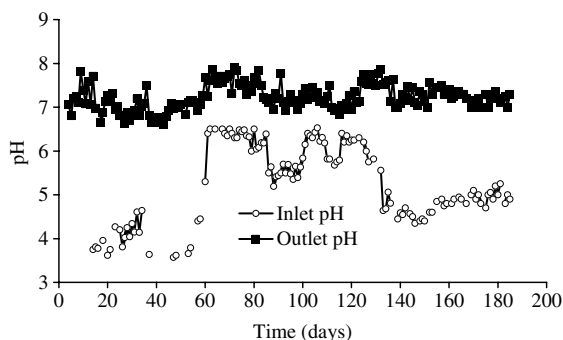


Fig. 3. pH variation (inlet and outlet) in reactor during the operation period.

approximately corresponded to 20% of the effluent COD. Thus, the horizontal flow filter seemed to have the ability to separate acidogenesis and methanogenesis longitudinally along the reactor.

The amount of biogas production (L biogas/L d) increased with the increase in organic loading rate and attained a steady state after 140 days (Fig. 4). At the maximum organic loading rate applied and hydraulic retention time (HRT) of 9.5 h, a gas productivity of 3.7 L/L d was achieved. The average biogas yield was 0.36 L/g COD removed; this value is comparable to data reported in the literature (Yu and Gu, 1996). Methane content in the biogas was in the range of 69–81%. The methanogenic activity of the biomass recovered at the end of the experimentation amounted to 0.42 ± 0.02 g COD_{CH₄}/g VSS d, which was slightly higher than that of the inoculum.

The biogas production was not affected by the cyanide content of the wastewater. The effluent cyanide concentration was always lower than 0.8 mg/L after the start-up period (data not shown). The inhibitory effect of cyanide on pure culture of methanogenic bacteria can be substantial at a cyanide concentration of less than 1 mg/L (Fedorak et al., 1986; Yang et al., 1980), but methanogenic consortia are able to adapt to cyanide concentrations as high as 100 mg/L (Gijzen et al., 2000; Rojas et al., 1999).

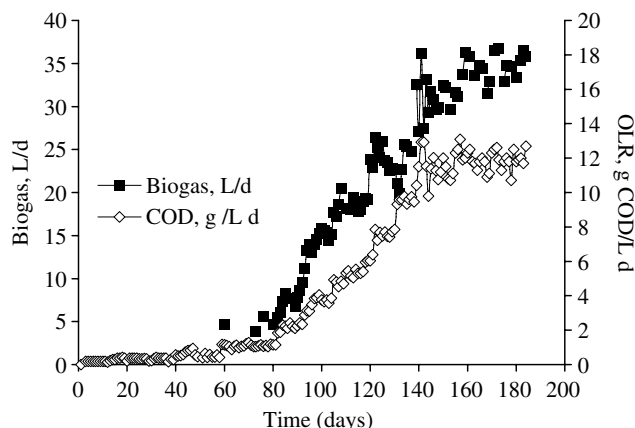


Fig. 4. Biogas production and OLR during the operation period.

We did not observe any degradation of the bamboo pieces at the end of the experiment. Camargo and Nour (2001) reported that the degradation of bamboo used as support stabilized after the first months of operation, once the more easily degraded organic compounds of bamboo had been metabolized. The lignin and cellulose remaining should not be subject to further degradation.

4. Conclusions

The wastewater generated by the extracting sour cassava starch process was susceptible to anaerobic degradation. A new anaerobic reactor configuration, the anaerobic horizontal flow filter packed with bamboo pieces was proposed for the treatment of cassava starch processing wastewaters. This configuration constitutes an effective solution for most of the small and medium size starch plants in Colombia, which possess low economic capacity to invest in environmental control. The use of bamboo pieces, as the material for the filling of the anaerobic filter and support for microorganisms, is appropriate because it is a local material easily available and furthermore non-biodegradable. The horizontal flow digester operated satisfactorily at an OLR of 11.8 g COD/L d, removing 87% of the COD. Biogas production was found to be near to the theoretical value and high COD and VSS reductions were achieved.

The following calculations could define the horizontal flow digester volume needed to treat wastewater generated by the starch extraction factory from which the wastewater used in this study went. The four tons of cassava roots daily processed generate a volume of wastewater of 44 m³ corresponding to a contaminant charge of 211.2 kg of COD/d. Then, on the basis of an OLR value of about 11 kg COD/m³ d, the volume of digester needed to treat the total volume of the wastewater would not exceed 18 m³. Anaerobic digestion of starch extraction wastewater could not only deal with the problem of environmental pollution but could also result in the production of a useful source of energy to be used, in the plant for internal combustion engines, or in the farmer's home for cooking, light, and refrigeration. We could approximately estimate the quantity of biogas for a typical facility to 65 m³/d.

An experimental anaerobic filter reactor with a capacity of 10 m³ should be built by the regional environmental and economic development authority (CVC) in order to evaluate the process from technical and economic viewpoints. The system studied could be efficient and reliable, and its full-scale use highly feasible in the geographical region of interest.

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