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Methanogenic Fermentation of Cassava Peel Using a Pilot Plug Flow Digester

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Abstract

During the methanogenic fermentation of cassava peel, its composition (high starch content, high carbon:nitrogen ratio, presence of cyanogenic glucosides) usually results in excess acid production, nitrogen deficiency and the release of cyanide, which is highly toxic to methanogenic bacteria.

The utilization of a plug flow digester ('Transpaille') solved the problem of acidification through localization of the acidogenic phase in the first half of the fermenter and the problem of nitrogen deficiency because a permanent liquid phase allowed nitrogen accumulation. No perturbation due to cyanide (5–6 mg/l) was observed in the fermenter.

A fermentation yield of 0·661 m^3 biogas/kg volatile solids (VS) was obtained with a loading rate of 3·6 kg VS/m^3 day. Energy-saving calculations showed that a fermenter of 88 m^3 is needed to produce the methane necessary for drying one ton of cassava meal.

Key words: Cassava peel, anaerobic digestion, biogas, fermentation yield.

INTRODUCTION

The processing of cassava roots to produce cassava meal (fufu) in the Congo includes peeling, retting by soaking roots in water for three days and drying. During this process, large quantities of solid wastes (cassava peel) are produced. In the Congo, the annual production of 700 000 tons of cassava roots leads to 175 000 tons of unutilized cassava peel that could be used to produce biogas and to generate part of the energy needed for the mechanical processing of cassava (about 1200 kWh required to dry 1 ton of cassava meal). However, the high starch content (85% of dry matter), the high C:N ratio (76) and the presence of cyanogenic glucosides in cassava peel can induce excess acid production, nitrogen deficiency and the release of cyanide, which is highly toxic to methanogenic bacteria (Eikmanns & Thauer, 1984; Smith *et al.*, 1985). An inhibitory effect of high acid production and N deficiency on cassava waste methanogenesis in fermenters was reported by Wurster (1985) and Segretain and Bories (1987).

We studied the methane production potential of raw cassava peels in a 128-liter plug flow digester. The aim of the study was to define an appropriate fermentation technology so that biogas can be used instead of electrical energy to dry cassava meal.

METHODS

'Transpaille' digester

The digester used a continuous process patented by IRAT/CIRAD (France). It is based on the transfer of a heterogeneous substrate immersed in water in a horizontal cylindrical tank (Farinet *et al.*, 1987). In the fermenter used for the experiment the mobile solid phase undergoes a plug-flow pattern movement (Fadlalla, 1989) and is fermented in a nonrenewed liquid phase established once at the beginning of the process (Fadlalla, 1989).

The fermenter (Fig. 1) includes three parts:

— A feeding box in which the substrate is loaded. The feeding box is equipped with a

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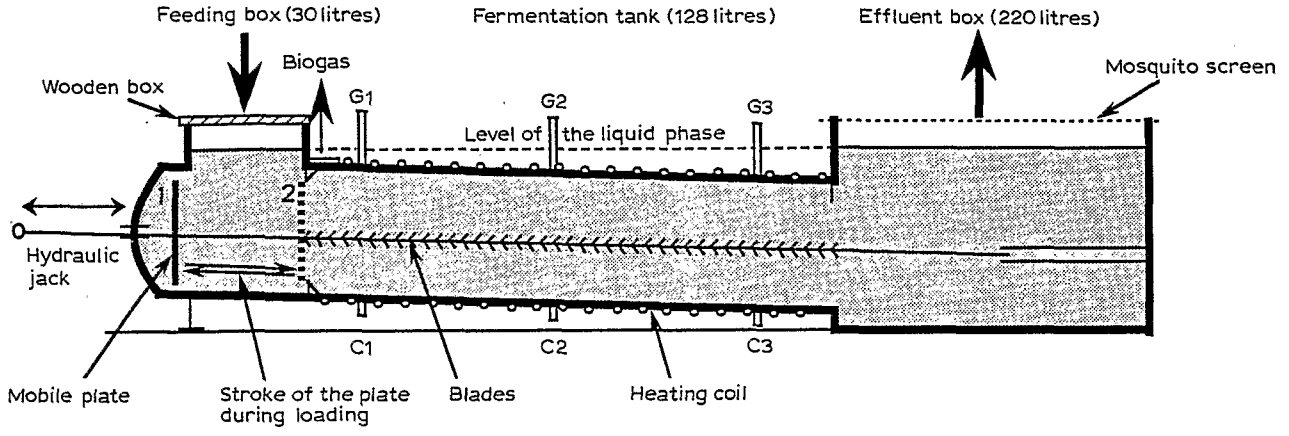

Fig. 1. 'Transpaille' fermenter — longitudinal cross-section. G1, G2, G3, Gas sampling points; C1, C2, C3, liquid sampling points; 1, position for loading; 2, position during fermentation. See text for detailed explanation.

mobile plate connected to a jack which pushes the solid substrate and ensures the closure of the fermentation tank after loading. Blades attached to the jack axis help to move forwards the solid phase in the fermentation tank during loading. When the fermentation tank is full of substrate, each new loading induces the evacuation of digested substrate in the effluent box.

— A fermentation tank. Three gas sampling points (G1, G2, G3) and three liquid sampling points (C1, C2, C3) are installed along the tank. Temperature (35–39°C) was maintained by circulating hot water in a coil surrounding the tank. A 4% slope of the tank allowed biogas collection in an exhaust equipped with a flowmeter.

— An effluent box open to the air.

The digester was completely filled with water. Straw (87–90% TS (total solid); 90–95% VS (volatile solid)) at twice the feeding box capacity was introduced into the fermenter to form a plug. Bovine rumen content (10% of the useful volume) was loaded for inoculation. No additional inoculum was needed.

During the four first months of incubation the fermenter was loaded every three days with a mixture (2·2 kg VS/m^3 day) of raw cassava peel — 90% TS — and straw — 10% TS. The retention time of the solid phase was about 45 days. Technical problems delayed the reaching of the steady state (deficiency of substrate, gas leak, etc.).

At steady state, the fermenter was loaded manually once every two days with cassava peel only. The criterion for determining that steady state had been reached was the stability of gas production. Cassava peel fermentation was studied for 600 days. Gas production was measured daily, pH and temperature were measured twice a week, chemical oxygen demand (COD), alkalinity and volatile fatty acid (VFA) were measured twice a month, and gas composition was measured once a month.

Substrate

Cassava peels were collected from an industrial cassava farm, located in an equatorial savannah region (Mantsoumba, Congo). Fresh peels were stored at 4°C until use.

Analytical methods

The total solid (TS) content of peels was determined by drying at 105°C for 24 h and the volatile solid (VS) content by calcination at 500°C. Nitrogen was measured using a Kjeldahl method. Chemical oxygen demand (COD), alkalinity to pH 4·2 and potassium and phosphorus contents were estimated using standard methods (American Public Health Association, 1985). Cyanide was determined as described by Cooke (1979). Biogas composition was monitored by gas chromatography on a DELSI 30-E chromatograph (Porapak Q column, 2 m, $\frac{1}{8}$ in, 80°C, carrier gas N_2 25 ml/min). The same apparatus was used for volatile fatty acid (VFA) analysis (Haye Sep Deb column, 1 m, $\frac{1}{8}$ in, 180°C, carrier gas N_2 25 ml/min).

Enumeration of digester microflora

Fermentation liquid (100 ml) was collected anaerobically from sample points of the digester. Media and inoculation techniques were as described by Hungate (1969) and Balch *et al.* (1979). Amylolytic, fermentative, sulfate-reducing and methanogenic bacteria were counted by the most-probable-number (MPN) technique with five

tubes per dilution. The organisms were grown in the medium of Balch *et al.* (1979). Starch (5 g/l) was used as substrate for amylolytic bacteria, glucose (5 g/l) for fermentative bacteria and sodium acetate (5 g/l) + methanol (0·5 g/l) for acetoclastic bacteria. For the growth of hydrogenotrophic bacteria, the N_2/CO_2 (4:1) atmosphere was replaced by H_2/CO_2 (4:1). Sulfate-reducing bacteria were grown in the medium of Widdel (1980). The substrate was either sodium lactate (2·5 g/l) or sodium acetate (2 g/l). Incubations were performed at 37°C. The rhodanese activity was determined as described by Singleton and Smith (1988).

RESULTS

The composition of cassava peel was 25–35% TS, VS was 90–97% of TS, starch 65–85% of TS, carbon 33–46% of TS, nitrogen 0·6% of TS, phosphorus 0·7% of TS, potassium 0·9% of TS and cyanide up to 400 mg/kg fresh matter.

Three levels of loading were studied during the methanogenic fermentation: the start-up loading rate averaging 2·2 kg VS/m^3 day with 10% straw and 90% cassava peel, and two steady states of 3·6 and 4·2 kg VS/m^3 day with 100% cassava peel. The average biogas production at 37°C was 1·40 m^3/m^3 day with a load of 2·2 kg VS/m^3 day, 2·38 with 3·6, and 2·57 with 4·2. The mean yield was 0·629 m^3 biogas/kg VS (0·661 from 3·6 kg VS/m^3 day), which amounts to 0·217 m^3/kg fresh cassava peel (or 0·065 m^3/kg cassava roots, with a peeling yield of 30%). The mean methane content of the biogas was 57%, but the level varied from one sampling point to another. The highest percentage was recorded at point G3 (75%).

During the start-up of the fermentation, the pH dropped to 5 in the first part of the reactor (feeding box, C1 and C2) and was corrected by adding Na_2CO_3. The pH was around 6·5 at sampling point C3 and in the pit (Fig. 2(a)). After 10 months of operation, when the loading rate was 3·6 kg VS/m^3 day, pH increased to about 7·0–7·6 in all parts of the fermenter (Fig. 2(b)). After 17 months when the loading rate was 4·2 kg VS/m^3 day, pH remained around 7·1–7·3 in the first part of the fermenter (feeding box, C1, C2) and reached 8 in the second part (C3 and pit) without any further pH correction (Fig. 2(c)). Dynamics of pH measured at the feeding box and C1, and at C3 and the pit were very similar. Therefore only values for C1, C2 and C3 are presented in Fig. 2.

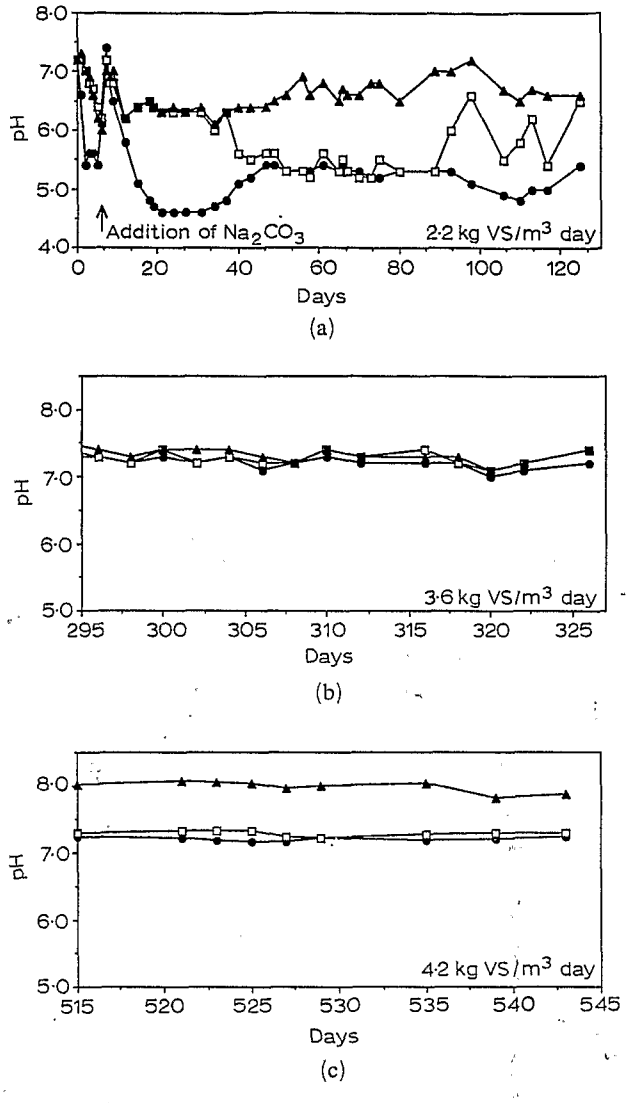

Fig. 2. pH measured at the liquid sampling points along the tank (● C1; □ C2, ▲ C3) during (a) the start-up of the fermentation and at stabilized loading rates of (b) 3·6 and (c) 4·2 kg VS/m^3 day.

The COD in the liquid phase was 5 g/l in the feeding box and 2·5 g/l in the pit at steady states. The total alkalinity varied around 3·8 g $CaCO_3$/l, when no VFA was measured.

Some acetate (0·3 g/l) and propionate (2 g/l) accumulated in the first part of the reactor when the loading rate was 3·6 kg VS/m^3 day. After one month, these VFA concentrations decreased and VFA were then no longer detectable.

During the longest period of stable loading rate obtained in this experiment (3·6 kg VS/m^3 day between 294 and 500 days) the NH_4^+-N increased slightly (0·05–0·2 g/l), while total-N markedly increased (0·8 to 2 g/l), without any addition of nitrogen (Fig. 3(a) and (b)).

The results of the MPN counts performed at the three liquid sampling points (C1, C2 and C3)

at stabilized loading rates (3·6 and 4·2 kg VS/m^3 day) showed that bacterial density increased with the loading rate (Table 1). In the first half of the fermenter (C1 and C2), glucose degraders predominated over the methanogenic bacteria, which were the main group in the second half (C3). As compared with other bacterial groups, sulfate-reducing populations were low and their number increased with the loading rate, mostly in the first part of the fermenter. The methanogenic microflora contained a variety of organisms including large cocci and aggregates resembling those of *Methanosarcina*, thin filaments similar to those in *Methanospirillum*, a large number of rods reminiscent of *Methanobacterium* and rods combined end to end in long filaments as in *Methanosaeta*. The methanogenic bacteria isolated were related to *Methanobacterium* and *Methanosarcina* and were highly sensitive to cyanide in pure culture (<1 mg/l). The cyanide levels in the digester reached 5–6 mg/l, without perturbing biogas production. We isolated a sulfate-reducing bacterium belonging to the genus *Desulfovibrio* that tolerated up to 25 mg CN/l and exhibited a rhodanese activity known to detoxify the cyanide-producing thiocyanate.

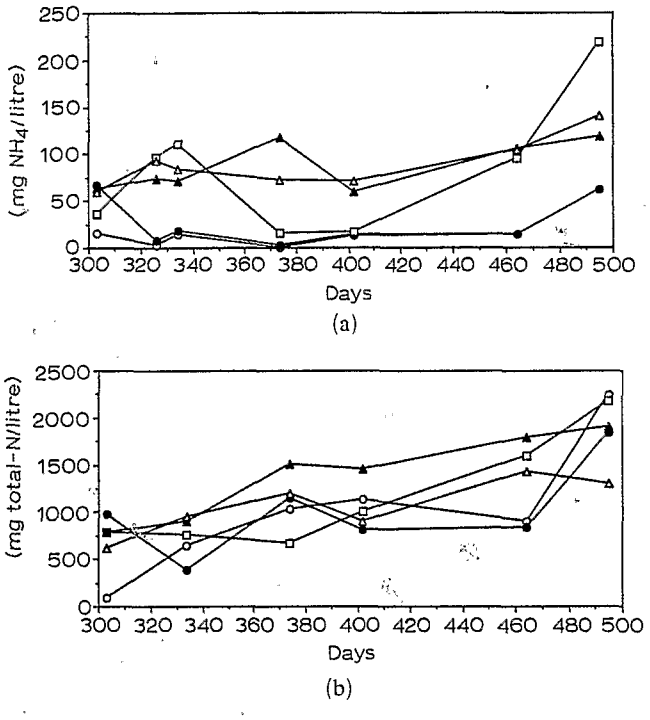

Fig. 3. Nitrogen levels, (a) NH_4^+-N and (b) total-N in the liquid phase (○ feeding box, ● C1, □ C2, ▲ C3, △ effluent box) during the anaerobic fermentation of cassava peel at the stable loading rate (3·6 kg VS/m^3 day).

Feeding was stopped for several weeks to improve the gas exhaust of the digester. At restart, a too-high loading rate resulted in acidification at the entrance of the fermenter. This allowed us to study how the digester responded to an accidental acidification. Chemical oxygen demand increased to 30 g/l in the feeding box, whereas pH decreased to 5, and 10 g/l acetate accumulated. This acidification increased along the cylindrical tank between points C1 and C2. The bacterial count showed 10 times less fermentative bacteria and 100 times less methanogenic bacteria than at the previous steady state. Biogas production was reduced to 20% of the normal production at the same loading rate before acidification. To correct this failure, loading was stopped and inoculum (rumen content) was added in the feeding box. After several days, the conditions (COD, pH, etc.) became optimal for methanogenic fermentation; only a marked increase in NH_4^+-N and total-N was recorded.

DISCUSSION

The COD and pH values of the liquid phase showed that most of the organic matter seemed to

Table 1. Enumeration of bacteria in fermenter juice from three liquid sampling points along the reactor (C1, C2, C3)

Metabolic group	*Substrate*	*Loading rate: statistical MPN evaluation of organisms (×10^7/ml)*					
		3·6 kg VS/m^3 day			*4·2 kg VS/m^3 day*		
		C1	*C2*	*C3*	*C1*	*C2*	*C3*
Amylolytics	Starch	nd	nd	nd	80	130	3·5
Acidogens	Glucose	5·0	35	0·80	50	50	3·5
Sulfate-reducers	Lactate	0·35	0·35	0·80	2·5	2·0	0·80
	Acetate	0·35	0·25	0·50	9·5	0·70	0·45
Methanogens	H_2/CO_2	8·0	25	35	25	35	250
	Acetate	0·13	0·17	0·25	3·5	0·40	25

nd, Not determined.

be degraded in the first part of the fermenter, whereas production of biogas occurred in the second part. Increasing CH_4 concentrations from G1 to G3 sampling points agree with this hypothesis. Bacterial counts showed that acidification occurred early on in the first part of the fermenter, where amylolytic and fermentative bacteria were predominant. Methane production was higher in the second part of the fermenter, where methanogens were predominant.

The piston flow of the solid fraction (Fadlalla, 1989) may favor the progressive elimination of intermediate acid compounds during substrate transit and prevent drastic acidification. The 'Transpaille' system showed a satisfactory capacity to cope with acidification. Nitrogen analyses showed a progressive nitrogen enrichment in the liquid phase. The cassava peel was loaded undiluted and the solid effluents were discharged after being drained; therefore the reactor liquid volume did not vary significantly. In the 'Transpaille' digester, a progressive nitrogen enrichment of the permanent liquid phase (Fadlalla, 1989) allows the utilization of N-deficient substrate without addition of nitrogen.

The isolated methanogenic bacteria were highly sensitive to cyanide in pure culture (<1 mg/l), but tolerated up to 5–6 mg CN/l during the methanogenic fermentation in the fermenter. The ability to adapt to cyanide was previously reported by Fedorak *et al.* (1986), Fedorak & Hrudey (1989), Parkin and Speece (1983) and Yang *et al.* (1980).

This study showed that methanogenic fermentation of raw cassava peel in a 'Transpaille' digester produced 85% of the theoretical biogas yield. The following calculation defines the digester volume needed to produce energy for drying one ton of cassava meal:

- 5 tons of cassava roots produce 1 ton of cassava meal and 1·5 tons of cassava peel.
- 1200 kWh or 121 m^3 CH_4 (calorific value of methane, 9·95 kWh/m^3 CH_4) are required for drying 1 ton of cassava meal.

With a loading rate of 3·6 kg VS/m^3 day,

- methane productivity of 1·37 m^3/m^3 day,
- a methane yield of 0·377 m^3/kg VS,
- a composition of cassava peel of 30% TS and 94% VS,

1·15 tons of cassava peel is needed to produce 121 m^3 CH_4. The amount of cassava peel generated from 5 tons of cassava roots is enough (1·5 tons) to produce methane providing 100% of the energy necessary for drying one ton of cassava meal. The volume of the 'Transpaille' digester needed to produce this 121 m^3 CH_4 would be 88 m^3.

The production of biogas from anaerobic digestion of cassava peel in a 'Transpaille' digester provides an important energetic potential, which should be of value in improving the economics of cassava processing.

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