BIOGAS PRODUCTION FROM MIXTURES OF CATTLE SLURRY AND PRESSED SUGAR CANE STALK, WITH AND WITHOUT UREA

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Eight two-litre glass jars were used as anaerobic digesters in a trial to compare biogas production from mixtures of cattle slurry and pressed sugar-cane stalk. It was found that as the percentage of pressed cane stalk (PCS) was increased, the initial pH of the mixture decreased and initial gas production was impaired. The PCS was degraded much more slowly than the cattle slurry, although total production was not reduced significantly by the presence of up to 56.7% PCS (dry-matter basis) in the fermentation mixture. Gas production was seriously reduced when the level of PCS rose to 80%. Initial pH of this mixture was 4.6 and 4.4 for the treatments with and without urea respectively. The addition of urea had the effect of increasing pH, and substantially reducing the length of the lag phase of the cumulative biogas production curves.

Key words: Biogas, anaerobic digestion, digester, cattle slurry, sugar cane, pressed sugar-cane stalk, urea, pH

The economics of the production of biogas (a mixture of approximately 60% methane: 40% carbon dioxide) are becoming more favourable as oil and fertilizer prices rise. Furthermore, biogas production units provide a decentralized fuel supply and waste management system,both of which are becoming increasingly attractive, particularly in rural areas of developing countries.

The majority of work done on biogas has used animal wastes as the raw material. Additives to this basic raw material can be viewed from two points of view - either as ameliorators of gas production, by improving conditions for gas production, or as a means of utilising potential gas producing wastes. Amongst such non animal-origin wastes are coffee pulp, straw and domestic rubbish. Some raw materials with potential for methane generation are listed in Table 1. (National Academy of Sciences 1977). This study arose as part of an investigation into an integrated crop/ livestock/energy system whereby sugar cane, as a high yielding crop, would form the basis of the diet of confined cattle in which it is proposed that the sugar cane juice, which is high in metabolizable energy, would be fed to the cattle and the cattle slurry would be used for biogas production, and after digestion as a fertilizer. Although there are several ways in which the pressed cane stalk residue could be utilized (eg to make charcoal, producer gas, particle board or paper) one simple alternative would be to chop it and add it to the slurry in the digester to augment biogas production. This study was designed to show by how much slurry could be substituted by pressed cane stalk, by monitoring its effect on pH and biogas production.

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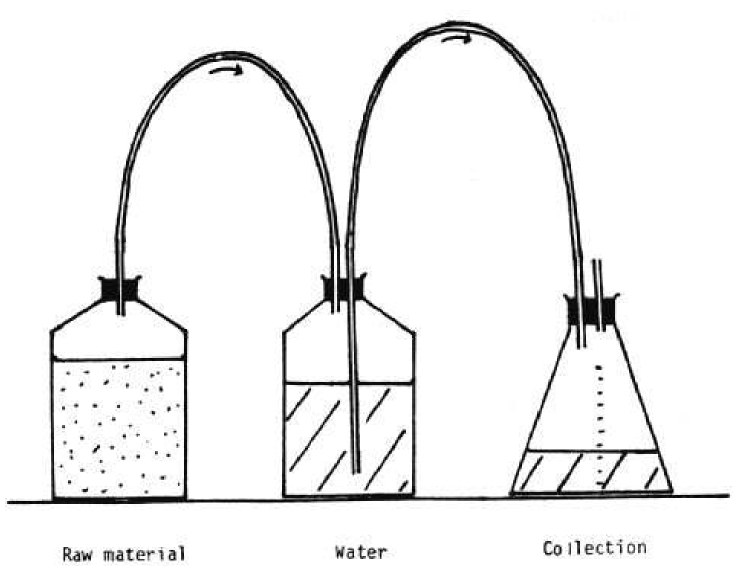
Table 1:
Organic materials with potential for biogas generation (Adapted from National Academy of Sciences 1977)

Crop wastes	Sugar cane trash, weeds, crop stubble, straw, spoiled fodder, haulms and tops, silage liquor.
Animal wastes	Excreta and urine from man and domesticated animals, slaughterhouse wastes, fishery wastes, tannery wastes, wool wastes.
Municipal wastes	Sewerage, kitchen wastes, domestic refuse
Agro-industry wastes	Oil cakes, sugar cane bagasse, rice bran, tobacco wastes, fruit and vegetable processing wastes, tea wastes, coffee pulp, textile wastes, sisal pulp, brewery and distillery wastes, sawdust.
Forestry litter	Leaves, twigs, bark.
Aquatic sources	Marine and freshwater algae, water hyacinth and other aquatic plants

Materials and Methods

Eight two litre glass bottles were used as digesters in a 4 x 2 unreplicated design. Gas collection was by displacement of water from a plastic four litre container into a graduated conical flask (see Figure 1).

Figure 1:
Diagram of the experimental digester apparatus



Treatments were:

A. Relative proportions of slurry:stalk (on a dry matter basis by weight)

1. 20% inoculum, 80% fresh slurry, 0% stalk
2. 20% " , 56.7% " , 23.3% "
3. 20% " , 23.3% " , 56.7% "
4. 20% " , 0% " , 80% "

B. Additions of urea

1. No addition of urea
2. Urea (46%N) added at 4% (Dry matter basis) of the weight of the pressed cane stalk.

The clear glass digesters were each charged with two litres of the relevant mixture. The dry matter of the mixtures was 8%.

The inoculum was digested cattle slurry (30-40 days old). Fresh slurry was obtained from the faeces of young bulls fed on a sugar cane/molasses diet. The sugar cane stalk was first pressed in a three-roller mill which extracted about half the weight of the cane as juice (19 ^{o}Brix), and then cut into pieces of 1-3cm length to facilitate entry into the digester bottles. The digesters were charged once only during the duration of the experiment. At this time the contents were mixed as thoroughly as possible; thereafter there was no mixing. Temperature was ambient shade temperature throughout the trial; the temperature range was 20-31^{o}C.

Gas production was measured daily from day 0 to day 120 although results were worked out using five day totals.

pH was measured at approximately weekly intervals.

Results

The accumulative biogas production curves from the treatments receiving and not receiving urea are depicted in figures 1 and 2 respectively.

The shape of the curves, which signify the pattern of gas production over the 120 day period, suggest that the slurry-only curves and asymptotic whereas the shapes of curves of treatments in which slurry was substituted for 23.3 - 56.7% PCS appear to be sygmoid.

The substitution of slurry by PCS up to the 56X level did not impair total biogas production,as shown in Table 2. However biogas production was severely impaired at the 80% level of PCS.

The lag-phase increases with increasing % of PCS . Table 2 also shows that the addition of urea to the PCS reduces this lag-phase roughly by half.

pH varies with treatments and with time as shown in Figures 3 and 4 which are with and without urea treatments respectively. The initial pH's of the slurry/PCS mixtures were affected by the level of PCS. As the level of PCS rose so the pH fell. Urea reduced this drop in pH.

The slurry-only treatments start at a near optimum pH and maintain this for the whole 120 day period. However the 23.3 and 56.7% PCS levels start with a lower than optimum pH and it is only after a period, apparently dependent on the level of PCS and the presence or absence of urea, that the pH approached 7.0.

Figure 1:
Accumulative biogas production for different percentages of pressed cane stalk. With urea added added at 4% to the pressed cane stalk..

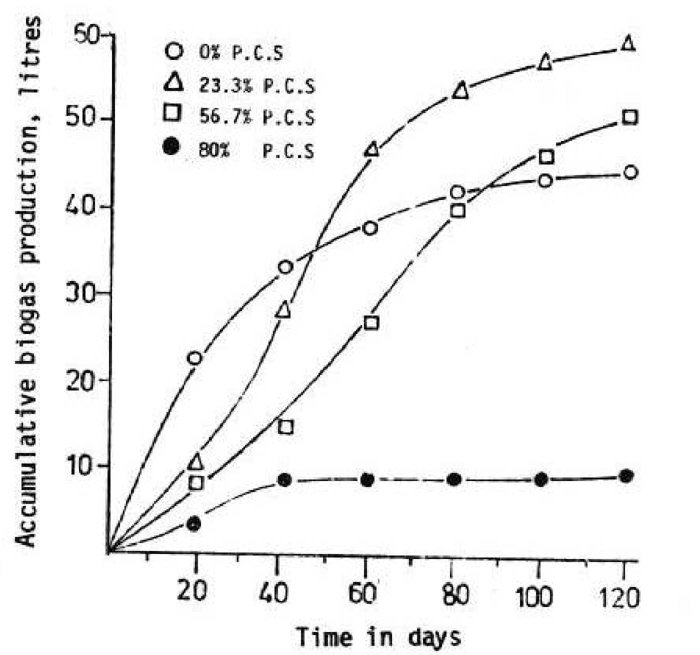


Figure 2:
Accumulative biogas production for different percentages of pressed cane stalk. Without added urea

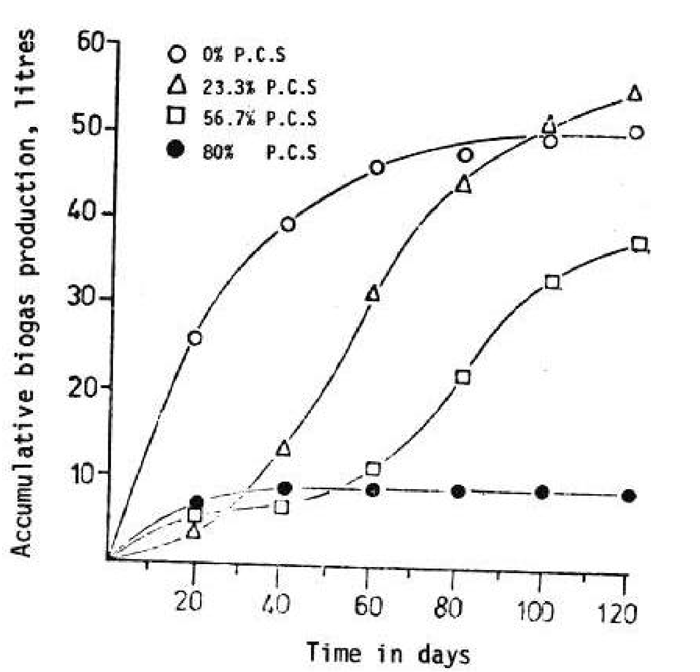


Figure 3:
Variation of pH with time and percentage of pressed cane stalk.
With urea added at 4% to the pressed cane stalk

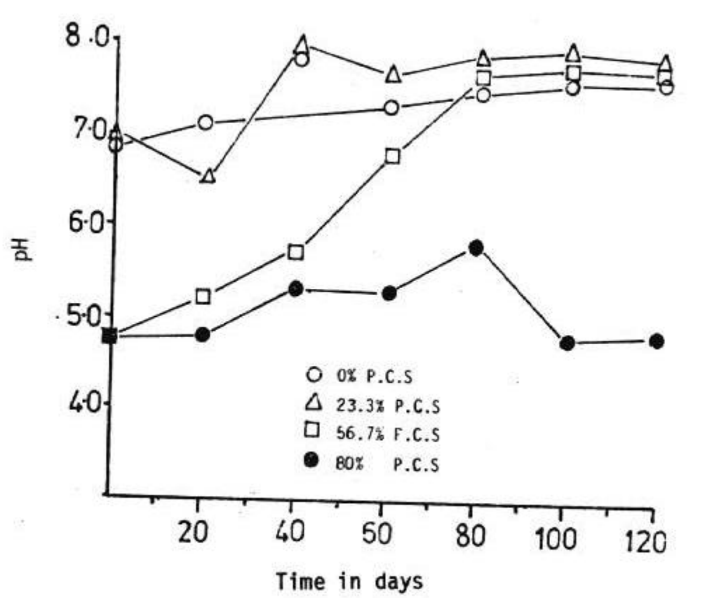


Figure 4:
Variation off pH with time and percentage of pressed cane stalk.
Without urea added.

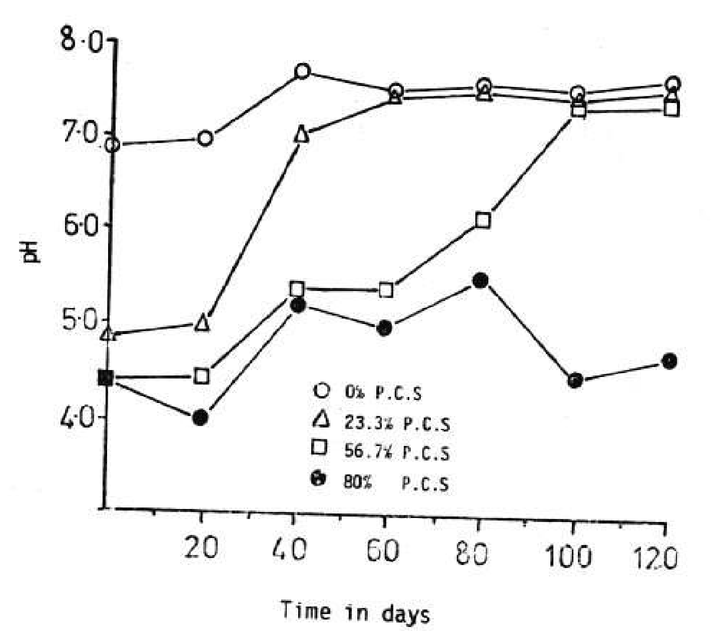


Table 2 :
Biogas production data from mixtures of slurry and PCS

Production parameter		% of PCS in mixture			
		0	23.3	56.7	80
Total gas production at 120 days (m^3/kg total solids)					
	With urea	0.28	0.37	0.32	(0.05)[1]
	Without urea	0.32	0.34	0.24	(0.05)
Mean daily gas production to 120 days (m^3/m^3 digester vol.)					
	With urea	0.46	0.41	0.24	(0.34)
	Without urea	0.55	0.27	0.15	(0.16)
Time to 70% total gas production (days)					
	With urea	34	51	74	(9)
	Without urea	34	71	88	(18)
Estimated duration of lag phase (days)	With urea	0	15	25	120
	Without urea	0	30	50	120

[1] Figures in brackets have been included for completeness, but probably represent CO_2 production - not biogas production

Comparing the Figures 1 and 2 with Figures 3 and 4 there is an apparent correlation between the point at which the pH starts to rise steadily and the end of the lag-phase.

Discussion

The total biogas production expressed as m^3 biogas/kg total solids (TS), ranges from 0.24 to 0.37 m /kg TS for treatments containing less than 80% PCS. This range is similar to the figures for cattle manure cited in the literature (Table 3). It is thought that the very low gas production from the 80% level of PCS was due, not to methanogenesis, but to alcohol fermentation and consisted mainly of CO^2. No gas analyses were undertaken. There was no clear cut improvement in total gas production due to the addition of PCS. Other work has shown that the C:N ratio of cattle slurry is below the optimum of approximately 30:1. (Singh, Ram Bux 1971).

Table 4 lists the C:N ratio of a range of potential biogas producing raw materials . The addition of a high-carbon source should optimise this ratio and so improve biogas production. The improved gas production is said to be due to the reduction of ammonia production which is toxic to bacteria, and to the ready availability of carbon for CO^2 and CH^4 synthesis. Laura and Idnani (1971) found that the quantity and quality of biogas was increased by the addition to fresh cow dung of small amounts of cane sugar and urea, and cane sugar and Calcium carbonate. Urine also increased

Table 3:
Biogas production from various organic wastes

Substrate	m^3/kg Total Solids	m^3/kg Volatile Solids
Animal origin		
Farm yard manure (cattle)	0.26-0.28[1] , 0.33[2]	0.09-0.3[4]
Cattle manure	0.2-0.5[2]	0.09-0.31[3]
Beef manure	0.86-1.11[2]	-
Poultry manure	0.31[2/5], 0.52[2/6]	0.31-0.62[3], 0.34
Swine manure	0.56[1], 0.69-1.02[2],0.49[2/7]	0.37-0.5[3], o.35-0.48[4]
Sheep manure	0.3- 0.61[2]	-
Horse manure	0.2-0.3[1]	
Human origin		
Night soil	0.38[2]	-
Sewage sludge	0.64[1]	0.31-0.74[3], 0.6[4]
Vegetable origin		
Forage leaves	0.5[2]	-
Sugar beet leaves	0.5[2]	-
Algae	0.32[2]	-
Elephant grass	-	0.42-0.54[4]
Rice husks	0.62[1]	-
Fresh grass	0.63[1]	-
Straw	0.34[1]	-
Potato plants	0.26-0.28[1]	-
Sunflower leaves and stalks	0.3[1]	-
Industrial origin		
Distillery wastes (distillate)	0.3-0.6[1]	0.68[3]
Meat packing wastes	-	0.5-0.66[3]
Maize wastes	-	0.67[3]

1. Chinese biogas manual (1979)
2. National Academy of Sciences (1977)
3. Meynell P J (1976)
4. Barnett et al (1978)
5. Based on volatile solids (VS) fed
6. Based on volatile solids destroyed
7. Includes both faeces and urine.

gas production over the cow dung control, and the percentage of methane in the biogas was raised by up to 16 percentage points to 70% by these additives. Slurry arising from different animal diets will undoubtably vary in their C:N ratio. The slurry used in this study was from young bulls fed on a chopped sugar cane/molasses based diet and this would have contained undigested fibre. The degradability of pressed cane stalk is very low as demonstrated by the slow gas production. Thus, the lack of an obvious stimulatory effect of the addition of a high carbon source may be due to the fact that the C:N ratio of the cattle slurry was high and that the Carbon in the PCS was relatively unavailable. Even after 120 days the fibres were observed to

Table 4:
Total Nitrogen content and C:N ratio for some organic substrates

Substrate	Total Nitrogen (Dry matter basis)	C:N ratio
Animal wastes		
Urine	15-18[1]	0.8[1]
Blood,	10-14[1]	3.0[1]
Fish scraps	6.5-10[1]	5.1[1,c]
Mixed slaughterhouse scraps	7-10[1]	2
Poultry manure	6.3[1]	
Sheep manure	3.8[1], 0.55[2,a]	29[2]
Pig manure	3.8[1], 0.60[2,a]	13[2]
Horse manure	2.3[1], 0.42[2,a]	25[1,c], 24[2]
Cow manure	1.7[1], 0.29[2,a]	18[1,c], 25[2]
Farm yard manure	2.15[1]	14[1]
Household wastes		
Night soil	5.5-6.5[1], 0.85[2,a]	6-10[1], 2.9[2]
Domestic rubbish	2.2[1]	25[1]
Plant wastes		
Young grass clippings (hay)	4.0[1]	12[1]
Grass clippings (average)	2.4[1]	19[1]
Peanut vine stalks	0.59[2]	19[2]
Lucerne	2.4-3.0[1]	16-20[1]
Soyabean stalks	1.3[2]	32[2]
Seaweed	1.9[1]	19[1]
Dry rice stalks	0.63[2]	67[2]
Cut straw	1.1[1]	48[1]
Dry straw	0.53[2]	87[2]
Wheat straw	0.3[1]	128[1]
Maize stalks	0.75[2]	53[2]
Sawdust	0.1[1]	511[1]
Bagasse [b]	0.3[2]	150[2]
Potato tops	1.5[1]	25[1]

1 National Academy of Sciences (1977)
2 Chinese Biogas Manual (1979)

a Fresh weight basis
b Reference Barbett et al (1978)
c Non-lignin carbon

have retained their strength and appeared to have been hardly touched by the digestion process. Indeed this fact may be useful commercially as a method of cleaning the fibres prior to paper or board manufacture. Table 2 shows the number of days to 70% estimated total gas production for the different treatments and gives some idea of the likely retention time that would be recommended for the different mixtures. When designing anaerobic digesters it is important to try and keep the retention time as low as possible as this reduces the volume of digester and therefore the capital costs.

Hobson (1976) has suggested that if fibrous residues are used in digesters then the bacterial population needs time to adjust before being able to degrade the fibre component efficiently. In our case the slurry was derived from animals eating sugar cane fibre as part of their diet and this adjustment period was possibly unnecessary.

In this trial the PCS was chopped into 1-3 cm lengths. The surface area available for degradation is important as demonstrated by Levi (1959). He demonstrated that reducing the length of different types of straw from 3 cm to 0-2 cm increased biogas production at 30 days by around 30%.

It would seem logical that biogas production from fibre such as chopped sugar cane or grass should be greater in its original raw condition rather than as slurry after digestion in the rumen, where conditions are very similar to those in a digester. Indeed the rumen has a good mixing system, substrate particle size is quickly reduced and the temperature is near the mesophyllic optimum. It is perhaps because of this efficiency that it is often worthwhile feeding fibrous wastes to ruminants rather than introducing them directly into the digester. Laboratory and pilot studies have shown that grass may be fermented in digesters (Boshoff 1965; Hadjitofi 1976), but other studies (Anon 1976) found that digesters were not able to handle sugar cane bagasse, coconut fibre and insoluble cellulosic wastes.

The small glass digesters used in this trial were unmixed. Even so, although some treatments had a high fibre content, there was no obvious scum formation. With a larger digester volume and with different types and sizes of fibrous materials, scum problems could well increase with increasing substrate fibre content. (Barrett et al 1978). Scum problems were also reported by the Instituto de Investigaciones Elictricas (1980) who found it necessary to stir the digester content two to three times a day, when using mixtures of cattle slurry with maize cob sheaths, groundnut shells and rice straw. The addition of maize sheaths increased total gas production, whereas the addition of groundnut shells and rice straw decreased total gas production. They also found that the smaller particle size resulting from milling gave more and better quality gas than that from chopping.

The most convincing evidence that biogas production from substrates high is fibre is feasible comes from the Chinese experience. Most Chinese family size digesters have as their major Carbon source grass, leaves and crop residues, and as their major Nitrogen source human and animal wastes. (FAO 1978). The C:N ratios under these conditions varies between 1:15 and 1:20. In most cases the mode of charge of household units is intermediate between batch and semi-continuous; The C-source material is typically loaded in batches whereas the N-source material is added slowly day by day. In other cases the two are bulk mixed before initial loading and then more night soil and/or animal manures are added daily. The C-source materials is usually replaced every 3 -6 months. In some cases pH is adjusted with lime or ashes.

One obvious effect of addition of PCS to slurry in this trial was depression of pH. This is not a generally reported effect of addition of high C-sources. The extraction rate of juice from the cane was only about 50% and a substantial amount of sugar remained in the PCS. The fermentation of this sugar may have led to the reduction in pH. Urea helped to neutralize this acidification. In the case of the 80% PCS treatments (both with and without urea), pH remained very low (with a range of 3.3 - 5.8) and biogas production never got under way satisfactorily because conditions were too severe for the methanogenic bacteria. Other PCS treatments recovered from the low pH and a lag-phase was followed by an exponential gas production phase. (The length of the lag-phase appears to have been closely linked to the pH). One treatment recovered from a pH of 3.9 and two others from 4.8 - conditions which, according to most sources, would be considered too severe for the survival of methanogenic bacteria. Barnett et al (1978) states that methane formation is inhibited below a pH of 6.6 and that conditions become toxic below 6.2. This source goes on, however, to cite Borchardt (1971) as saying that under exceptional conditions methane formation can continue down to a pH3 of 4.5, In this trial rates of gas production of 0.25 and 0.29m3/m digester volume were obtained at pH 6.2. These results were úor the 56.7% level of PCS (with and without urea respectively). It seems possible that there may be some adaptation of methanogenic bacteria to low pH over a period of time.

Conclusions

From the results of this trial it is suggested that pressed cane stalk is a potential source of raw material for biogas production, and that it can be mixed with cattle slurry up to the level of 56.7% on a dry matter basis without seriously reducing total gas production. However the fibrous PCS degrades slowly and a longer retention time would be needed to extract the same volume of gas as for pure slurry. The addition of PCS depresses the pH of the mixture and this leads to a lag phase whose length is related to the pH. The lag phase can be reduced by the addition of urea.

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