

BIOGAS SYSTEM DEVELOPMENT IN MAURITIUS

J Baguant, S Callikan and K Deepchand
University of Mauritius, Reduit, Mauritius

ABSTRACT

Experimental work on the anaerobic digestion of cow dung and sugar cane fibrous products (namely, cane tops and leaves, bagasse and filter mud) is reported. Cow dung proved a suitable raw material when anaerobically digested both under batch and semi continuous conditions in laboratory scale experiments. Results of the performance of a 2 m³ overground metallic digester with floating gas holder (SAT I model) operating in a semi continuous mode and using cow dung are given. Economic analyses of this model operating at retention times (R_T) of 10, 25 and 45 days and of an Indian KVIC model at R_T of 45 days indicate that the SAT I model at short R_T (of 10 days or less) is most attractive for cooking purposes in Mauritius.

INTRODUCTION

The potential of biogas demonstrated elsewhere, has aroused much interest in Mauritius and research has focused on the potential for generating biogas from readily available materials. Such materials include animal wastes in the form of cow, poultry and pig manure and sugar cane agricultural and industrial wastes. Availability of these wastes and potential biogas yields have been estimated (Deepchand 1984). The cattle population in Mauritius includes 8000 units in large flocks (> 100 units) and 17000 units in small flocks (< 5). The excreta generated from animal husbandry has been estimated at 125000 Dm/yr (1980). This would produce an estimated 23 x 10⁶ m³/yr biogas with an energy potential of 529 x 10⁹ KJ/yr.

The clientele for biogas has been identified to be that currently using kerosene for cooking purposes (Baguant *et al* 1984). This clientele is found especially in the rural areas where potential raw materials are available.

This paper summarises research work carried out at the University of Mauritius with the financial support of ODA/CSC under the African Energy Programme. It includes experiments conducted to determine the yield and characteristics of biogas obtained through the anaerobic digestion of cow dung and sugar cane fibrous products. Subsequently based on the laboratory-scale experimental results, a system is proposed for a family biogas digester and the economic benefits of switching over to biogas as an energy carrier in the local context is analysed.

EXPERIMENTAL WORK

Batch digestion of cow dung

As a first stage in this study, the anaerobic digestion characteristics of cow dung (CD) was studied in a 3-4 litre capacity digester. When required, starter culture was obtained from a batch digester at peak production and was mixed with CD:water slurry indicated on a total solid (TS) basis. Occasionally, foaming, scum formation and clogging of delivery tubes were encountered. Nevertheless, all experiments were performed in replicates.

To determine the effect of particle size, cowdung was sieved into three fractions: coarse (> 3.327 mm), medium (> 1.663 mm) and fine (< 1.663 mm) using a Tyler sieve shaker and all fractions brought to 10% TS prior to digestion. All digesters were stirred for 10 mins daily in the morning. Gas production was monitored daily and methane content at regular intervals by combustion in an Orsat apparatus.

In another experiment, a conventional drum type (100 l) digester with an inverted gas holder was used to monitor gas yield on a larger scale. Stirring was provided by daily rotation of the paddle fitted gas holder for about 10 mins.

Results

The 100 l digester operating on cow dung mixed with an equal volume of water (C-D 1:1 TS) for 120 days gave the following results. There was an initial latency phase (35-40 days) during which daily gas production rates averaged 0.5 l/kg TS. Thereafter, for about 2 months, average production was 2.5 l/kg TS and total gas extracted after 120 days of digestion was about 200 l/kg TS. This is comparable to those reported elsewhere for digestion under similar conditions (NRC 1977). Methane (CH₄) content of the gas produced ranged from 45 to 60% and mean calorific value 4-5 k cal/l after the latency phase.

The addition of a small amount of starter culture to the cow dung/water slurry considerably reduced the latency phase (Table 1). In the presence of 2.5% starter culture, latency period was reduced to about 6 days and cumulative gas extraction increased 4-fold by day 40 of digestion. No significant improvement was observed on increasing the percentage of starter culture to 10% TS. Consequently a 2.5% level of starter culture was routinely used in other experiments. Further addition of booster starter culture (between 2.5 and 10.0% TS) once digestion was established did not improve gas yield.

The optimum dilution for anaerobic digestion of cow dung under mesophilic conditions is 7.5 to 10% TS, which corresponds generally to a 1:1 cowdung to water ratio (Table 1). Sieving of raw material prior to digestion indicated that the finer portion of the cow dung is more easily digestible, although the differences as illustrated in Table 1 are relatively small.

The optimum temperature for anaerobic digestion of cow dung is about 35°C with a cumulative gas yield, after 20 days of digestion, of 104 l/kg TS or 4 times the yield at room temperature of 21°C (Table 1). Between 35 and 45°C there is marked decrease in gas extraction but under thermophilic temperature of 55°C after a slightly longer latency period (14 days) daily gas production rates were more than twice the corresponding values of digestion at 35°C. Under conditions reported here, optimum batch digestion at 35°C. Under conditions reported here, optimum batch digestion of cow dung at 35°C and in the presence of starter culture, would yield about 6 l biogas/kg TS/d after a latency period of one week.

Table 2 gives results of chemical analyses of digester input and output after various periods of digestion. The general fertiliser value of the slurry compared to the fresh cow dung is not diminished and, if anything, improved during digestion. Volatile solids and TS are reduced by about 25% during the 65 days of digestion and gas production (m³ per TS or kg VS digested) is of the order of 0.6. This represents a thermodynamic conversion efficiency of 80% for the transformation of TS to CH₄.

Semi-continuous digestion of cow dung

Laboratory studies

A 101 digester fitted with inlet and outlet delivery tubes and filled to an effective volume of 7 l with a 1:1 cow dung/water slurry and 2.5% starter culture was used for laboratory scale experiments. The digesters were kept at ambient temperature (19-21°C) and agitated once daily. Gas production was monitored over 21 days. After this, the digesters were loaded with the cow dung/water slurry at rates varying from 87g to 1400g (based on the mean retention time (R_T) of 6.5, 12.6, 25.1, 37.8, 47.8, 61.4 and 96.2 days) in a semi-continuous mode of operation with daily (except Sundays) loading and removal of slurry. Total solids and volatile solids (VS) in effluent and influent were determined daily. Gas production was followed over a four week period and mean production (1/kg TS added, dig. vol., D_V/d) calculated for the last three weeks.

The cumulative gas yield for the last three week period varied from 33.7 l (96.2 d R_T) to 72.5 l. (6.5 d R_T) and gas production (1/kg TS added) varied linearly (70-220 l/kg TS) with R_T (that is, $y = 1.85 R_T + 33$) varying from about 15-100 days (Figure 1). At shorter R_T or higher loading rate, the slope in the gas yield indicates a minimum R_T of four days for the successful operation of a semi-continuous digester. On the other hand, a gas yield in terms of D_V/d against R_T is a hyperbolic curve on the period 15-100 days R_T but slopes off at shorter R_T . Maximum yield under these conditions are observed at R_T of about 6 days (or 0.45 D_V/d). Extrapolation of the hyperbolic curve for R_T indicates the maximum extractable biogas under corresponding batch conditions to be about 0.21 D_V/d . This is in agreement with the results obtained on batch digestion.

Field Studies

To verify these results a digester was constructed to monitor biogas yield and characteristics under field conditions. The design consists essentially of a 2m³ above ground metallic (stirrer fitted) digester with a floating gas holder. It was loaded with a mixture (assuming $R_T = 25$ days) and operated at ambient temperature (mean of 22°C from January to April, 1984 with peaks of 25°C). The mixture was stirred twice daily for 10 mins.

Methane and CO₂ contents were determined at regular intervals. Tests on the possible utilisation of this gas (a) in a conventional household gas stove modified to operate on biogas and (b) to run a 4 KW, 4 stroke single cylinder diesel engine modified to accept biogas as a partial substitute to diesel, were also carried out.

The results in Figure 2 show that although mean ambient temperature varied between 21 and 25°C, the internal digester temperature was 34°C with occasional afternoon peaks of 40°C. Such temperature fluctuations are expected for that volume of water in a black metallic container during that period. No significant difference in pH was observed between the input and output slurry and it remained at around 6.9. The daily gas production rate was 0.5 dig vol/d and is twice that obtained under laboratory conditions (at 21°C) shown in Figure 1.

Methane and CO² contents were 45 and 55% respectively, and the calorific value ranged between 4 and 5 k cal/l which is to be expected of a gas with the above composition.

The efficiency of the modified stove based on the heat output (temperature rise for a given weight of water) and input (calorific value and volume of biogas used) ranged between 60 and 70%. This is higher than the efficiency of traditional kerosene cookers (40-50%). Diesel consumption in the single cylinder engine has been reduced by half at idling speed of 1500 rpm. Experiments are underway to reduce diesel consumption of the engine and operate at load conditions.

Anaerobic digestion of sugar cane fibrous products

In the first set of experiments, an attempt was made to digest fresh samples of cane tops and leaves (CTL), fibrous residues (FR) and bagasse (B) and these fibrous products mixed with 50% cow dung (TS basis). Fresh cow dung served as a control. All the mixtures were diluted to 8% TS and allowed to digest (after inoculation with a 2.5% starter culture) in 4.5 l digesters at room temperature (20-22°).

Fresh sugar cane fibrous products proved to be poor substrates for anaerobic digestion. Over a 130 day period, the cumulative gas yield, which ranged from 8 to 13 l/kg TS for the 100% treatment, was negligible compared to the control (140 l/kg TS).

In the subsequent experiment, CTL were prepared in a Jeffco cutter grinder and allowed to compost for 20 days, then mixed with different proportions of cow dung and digested as described above. Figure 3 shows the cumulative gas production patterns.

All the curves assumed a general exponential shape for the first 40 days with the average biogas yields of 1.5, 1.6, 1.7, 0.9 and 0.1/kg TS/d for treatments I-IV respectively. This was followed by a lag phase which was of progressively longer duration with increasing proportions of CTL in the mixture.

Cane tops and leaves even when composted, are not easily biodegraded although they may have contributed to a limited extent in the total biogas yield in the various mixtures with cow dung.

Finally, CTL was mixed with different levels of cow dung and filter mud (FM). The various mixtures were allowed to digest at room temperature and yield and composition of the biogas and the pH were monitored at intervals over 150 days.

Figure 4 shows the cumulative biogas yield from the mixtures. In the initial phase of digestion until day 50, the gas yield from treatment 1 (cow dung alone) was higher than any of the other mixtures. At day 150, the cumulative gas yield was 215 l/kg TS for treatments 4 and 2, 195 for 3 and 5, 175 for 6 and 1 and 146 for 7. Addition of CTL and FM to cow dung appears to bring about an increase in gas yield only in the later stages of digestion.

The pH dropped initially to 6.2 in all mixtures except cow dung alone (which remained between 7.1 and 6.8 throughout) and mixture 8 (which was below 5.8 until day 140). Significant gas liberation took place concurrently with rise in pH in all the mixtures.

No significant difference in the ratio CO^2/CH_4 was observed in the various mixtures over that period.

From the above experiments, it may be concluded that fibrous products are in general poor substrates for anaerobic digestion and have to undergo other forms of pretreatment prior to digestion. They are thus not considered in the next section dealing with the economic aspects of biogas production from cow dung and utilisation.

ECONOMIC ASPECTS

The economic aspects of using a cow dung based biogas system for daily cooking (effective) energy requirements were examined. The total annual charges (TAC) resulting from setting up and operating the family biogas plant with the annual substitution value of the biogas were compared with the present costs to the consumer using various traditional cooking fuels. The SAT I 2m³ digester used in the field trials described earlier and an Indian KVIC underground digester commissioned by the Rural Development Unit (Ramdin 1984) were used in the evaluation. Both are meant to provide 1.5 m³ of gas daily which would meet the daily cooking energy requirement of a typical Mauritian family.

The expected lift time (n) of the digesters is 10 years, the interest rate (i) on borrowed capital is 12.5%, operating and maintenance cost (a) is 4% and the fixed annual charges (FAC) is based on the levelised payment arrangement (Grant and Ireson 1984). The total annual charges (TAC) are given by the formula

$$\text{TAC} = \text{FCI} \left[\frac{i(i+1)^n}{(i+1)^n - 1} + \frac{a}{100} \right]$$

where FCI is the fixed capital investment. Total annual charges for the two models are shown in Table 3. It is assumed that the cost of cow dung, labour for its handling and storage and the spent slurry is zero. The TAC are included for the SAT I model operating at R_T = 10, 25 and 45 days which would require 64, 53, and 43 kg of cow dung daily. The FCI of these models is based on the power relationship (Peters and Timmerhaus 1968):

$$\text{FCI (expected)} = \left(\frac{V_e}{1750} \right)^{0.8} \times \text{FCI (actual)}$$

where V_e = effective volume of required digester, and FCI actual = Rs 6000 for a digester 1750 l effective volume.

The amount of money spent by the typical Mauritian family for cooking purposes is, Rs 420, 1585, 1880, 2710 and 3080 for firewood, kerosene, wood charcoal, electricity and LPG respectively (Baguant et al 1984).

Using the KVIC model, the family using firewood, kerosene or wood charcoal would suffer an annual net loss of Rs 1825, 771 or 506 respectively. The system seems only marginally attractive for electricity or LPG users with net differences of Rs 244, or 579 (or 20% of the domestic cooking energy bill) because such users belong to a class who can afford such a cooking energy bill.

With the SAT I model operated at high R_T (of 45 days), the same comments as above apply. However, with reduced R_T , the SAT I model becomes more and more attractive to users of high cost fuels (electricity and LPG). For example at $R_T = 25$ days, the net annual benefits increases to 25% of the domestic cooking energy budget for these two categories of users. At $R_T = 10$ days (or even 4-6 days) the system becomes attractive to all users (except those using firewood) with net benefits ranging from 25% for kerosene users to 57% for LPG users.

The foreign exchange involved in the construction and installation of the SAT I model operated at short R_T would also be comparable to that of the KVIC model (Rs 2800 and 3500 respectively).

With some further refinements in the operation of the SAT I model, it is felt that, with a biogas plant of 1.3 m^3 effective volume costing around Rs 5000, it would be possible to produce 1.5 m^3 of gas daily. Successful operation of such a unit (which is under way) would thus enhance the case for popularising biogas technology in Mauritius.

CONCLUSION

It has been demonstrated in this study that it is technically feasible to produce biogas from cow dung. It would be economically attractive to all categories of energy users for cooking purposes when it is operated at short retention times (10 days or less) in the SAT I model which would involve capital investment of around Rs 5000 and total annual changes of Rs 1027. The attractiveness of the family biogas systems in the local context would increase if it were possible to produce 1.5 m^3 of gas from a digester of 1.3 m^3 effective volume which would require a daily supply of 65 kg of cow dung (slightly higher than the 50 kg required in the KVIC model).

Such a system, if successfully popularised, would bring about significant savings in foreign exchange required for importing kerosene and would, at the same time, diminish the deforestation pressures. However, hasty marketing of technically inappropriate or economically unattractive family biogas systems carries with it serious risks of disenchantment and backlash against biogas technology as a whole. For example as shown in this study, biogas produced from the KVIC model is not competitive with either kerosene or wood charcoal unless massive levels of government assistance is envisaged. Accumulation of material at the bottom of the pit (underground) which would block digester operation and necessitate particularly difficult clean up procedures, is a technical problem that has yet to be resolved.

REFERENCES

- Baguant J, Callikan S, Deepchand K (1984) Biogas project - African Energy Programme. The University of Mauritius, Reduit, Mauritius.
- Deepchand K (1984) Systems study for the utilisation of cane tops and leaves. PhD Thesis University of Mauritius. In press.
- Grant F L, Ireson W G (1970). Principles of engineering economics, 5th Edition. Roland Press, New York.

National Research Council (1977) Methane generation from human, animal and agricultural wastes. Report of an adhoc panel of the Advisory Committæe on Technology Innovation. National Academy of Sciences, Washington DC, USA.

Peters M S, Timmerhaus K D (1968) Plant design and economics for chemical engineers. 2nd Edition, McGraw Hill, New York.

Ramdin O (1984) The biogas project. Rural Development Unit, Ministry of Economic Planning and Development, Port Louis, Mauritius.

TABLE 1: Batch digestion of cow dung

Experiment	Temp °C	Starter culture % by Wt	TS % by Wt	Cumulative gas yield (1/kg TS)	
				20 days	40 days
	28	0	10.0	10.1	36.7
Effect of starter culture	28	2.5	10.0	76.0	133.0
	28	5.0	10.0	80.6	138.0
	28	7.5	10.0	83.0	140.0
	28	10.0	10.0	83.1	137.0
Effect of dilution	23	2.5	2.5	23.0	63.0
	23	2.5	5.0	25.0	65.0
	23	2.5	7.5	26.0	64.0
	23	2.5	10.0	26.0	70.0
Effect of particle size	F 23	2.5	10.0	30.4	87.4
	M 23	2.5	10.0	28.4	73.0
	C 23	2.5	10.0	25.0	65.0
Effect of temperature	21	2.5	10.0	26.0	
	30	2.5	10.0	68.0	
	35	2.5	10.0	104.0	
	40	2.5	10.0	64.0	
	45	2.5	10.0	9.6	
	55	2.5	10.0	76.6	

TABLE 2: Fertiliser value of slurry at various stages of digestion

Sample (Days)	Total solids		Volatile		Cumulative gas		Nitrogen		Phosphorous		Potassium	
	%	% TS	% TS	L	Total % TS	Available % TS	Total % TS	Available % TS	Total % TS	Available % TS	Total % TS	Available % TS
0	8.92	88.19	0	0	1.25	0.37	0.50	0.50	0.55	0.49		
6	8.63	87.95	2.30	2.30	1.25	0.47	0.58	0.55	0.55	0.50		
10	8.59	87.55	5.15	5.15	1.08	0.47	0.58	0.55	0.55	0.54		
21	8.21	87.03	20.70	20.70	1.23	0.47	0.58	0.57	0.60	0.56		
41	7.47	85.20	44.26	44.26	1.50	0.65	0.73	0.64	0.61	0.58		
65	6.73	84.64	52.50	52.50	1.50	0.65	0.88	0.65	0.67	0.63		

TABLE 3: Total annual charges and net annual benefits in using biogas for the SAT I and KVIC digester models

	SAT I model			KVIC underground model
	Retention time (days)			
	10	25	45	40
<u>Total annual charges</u>				
V _e (l)	1280	2645	3855	3800
Daily cow dung required (kg fresh)	64	53	43	50
FCI (Rs)	4670	8350	11,300	10,000
FAC (Rs)	840	1503	2034	1806
Op & M (Rs)	187	334	452	400
TAC (Rs)	1027	1837	2486	2206

<u>Net annual benefits (Rs)</u>				
Firewood*	-647	-1457	-1056	-1826
Kerosene*	408	-402	-1051	-771
Wood charcoal*	673	-137	-786	-506
Electricity*	1423	613	-36	244
LPG*	1758	948	299	579

* If above fuel used throughout the year for cooking, the annual expenses are: Rs 420, 1585, 1880, 2710 and 3080 respectively.

FIGURE 1: R_T V/S gas production for semi continuous digester

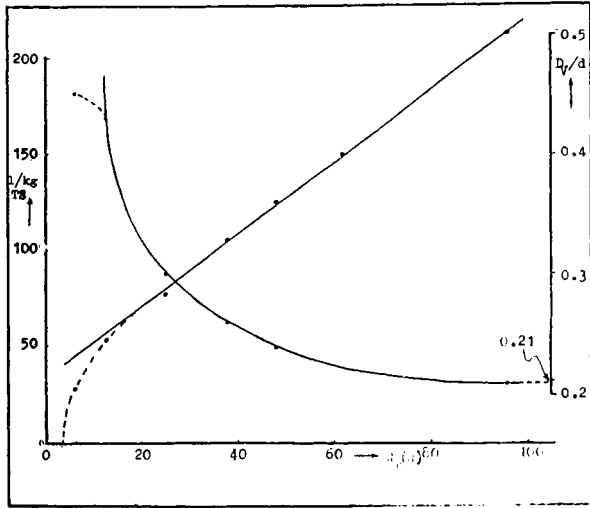


FIGURE 2: Performance of family size semi-continuous digester (SAT-I model)

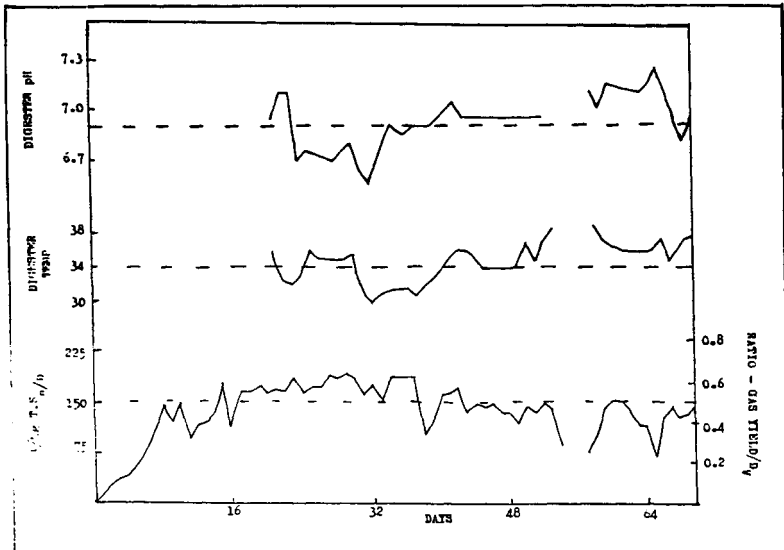


FIGURE 3: Batch digestion of composted CTL mixed with different levels of cow dung (cumulative)

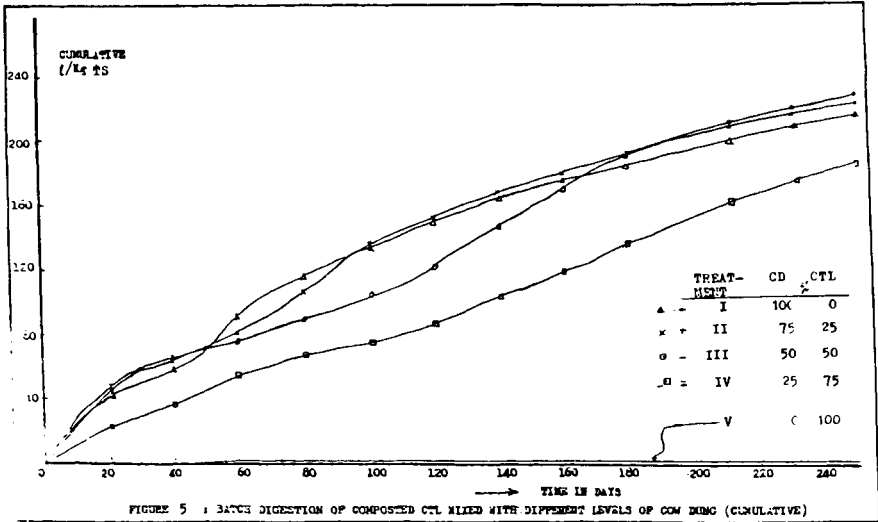


FIGURE 4: Cumulative biogas yield from different treatments

