THE CHARACTERISATION OF PRODUCTION AND FUNCTION OF A 15m^3 RED-MUD PVC BIOGAS DIGESTER

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Following experience with costly and problematic concrete and steel-canopy digesters a relatively inexpensive "Red-Mud" PVC digester of 15 m total volume was imported from Taiwan (Union Industrial Research Laboratories). The cost of the digester, freight and installation totalled $US 890.50. Installation was simple and to date there have been no malfunctions. Biogas production stabilized after 6 weeks at around 5 m /day (0.5 m biogas/m^3 slurry volume). The raw material was cattle slurry at 6: total solids. The digester uses the plug-flow principle, is unheated (average slurry temperature was 27.4°C) and unstirred. The principal operating conditions are described and the biogas production elaborated. All capital and installation costs are tabulated. An economic assessment using biogas as the only costed benefit, gave a payback time for the capital and installation costs of 2½ years.

Key words: Biogas, digester, PVC

In order that anaerobic digesters be sufficiently attractive as a waste treatment alternative and as a source of fuel, particularly for the small farmer, a number of conditions must be satisfied:

a. The digester must be cheap.
b. The installation must be simple.
c. The management must be simple.
d. The digester must reliably produce a satisfactory quantity of biogas over an extended period of time.

Digesters constructed from concrete, fibreglass or steel are generally expensive. Concrete digesters often suffer from gas leakage problems and steel is susceptible to corrosion. The Chinese "dome-type" digester has proved very successful in a number of areas, but they are comparatively complicated to install.

Bearing the above points in mind, and having had first-hand experience of concrete and steel-canopy digesters, a 15m^3 Taiwanese "Red-Mud" PVC digester (Union Industrial Research Laboratories, Taiwan) was evaluated.

Design and installation: The design is shown in Figure 1 and Plate 1. The 15m^3 (total volume) digester is of the plug-flow type; charging is carried out daily and contents are unmixed and unheated. The construction material is 1.5mm "Red-Mud" PVC which is manufactured from recycled PVC, used engine oil and bauxite smelting residues. It is said to be resistant to damage by sunlight, whereas ordinary PVC is not. The digester came complete with entry and exit tubes (20cm diameter rigid PVC), a flexible gas outlet pipe (2cm diameter) and a gas pressure safety valve.

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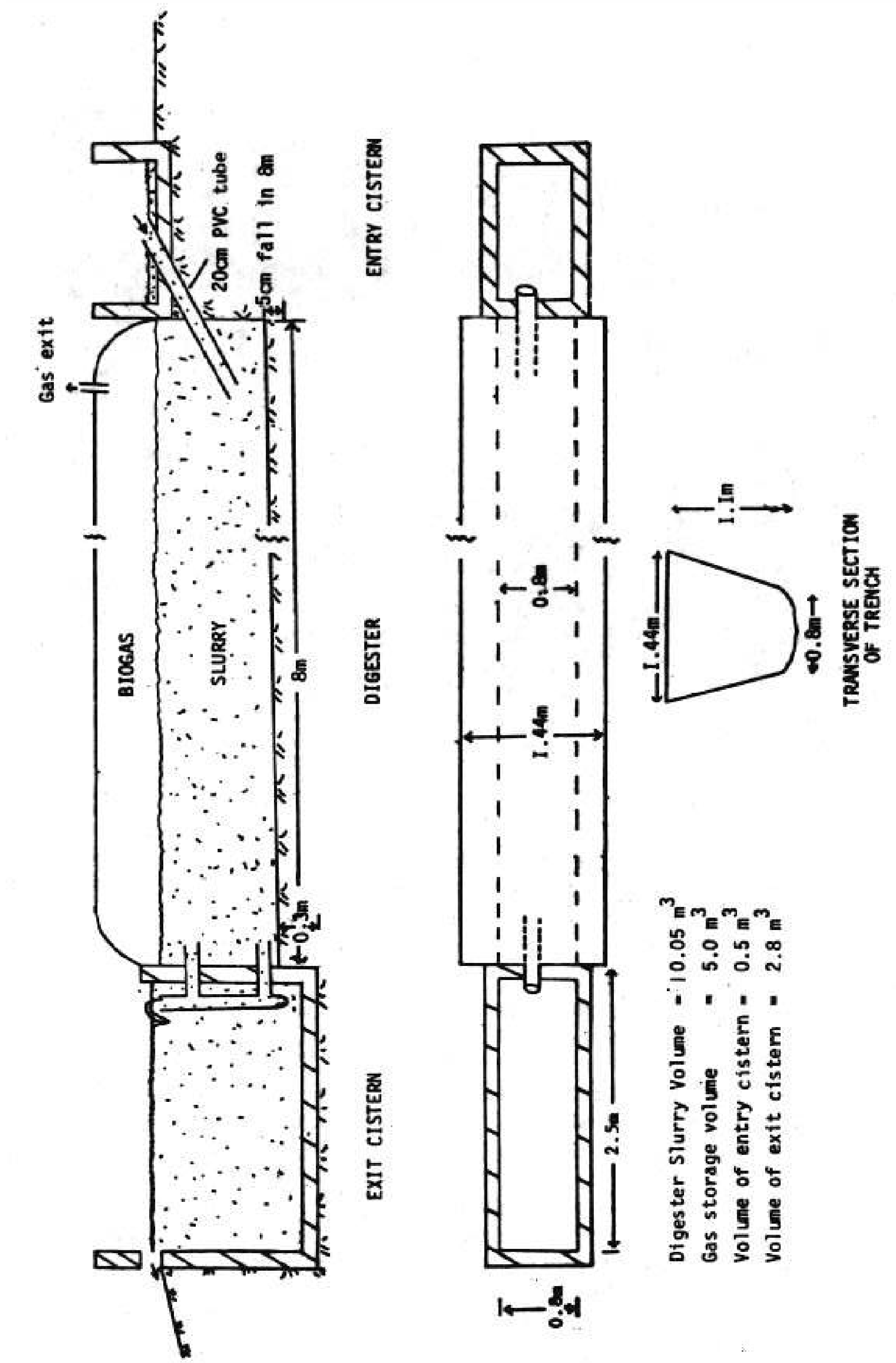
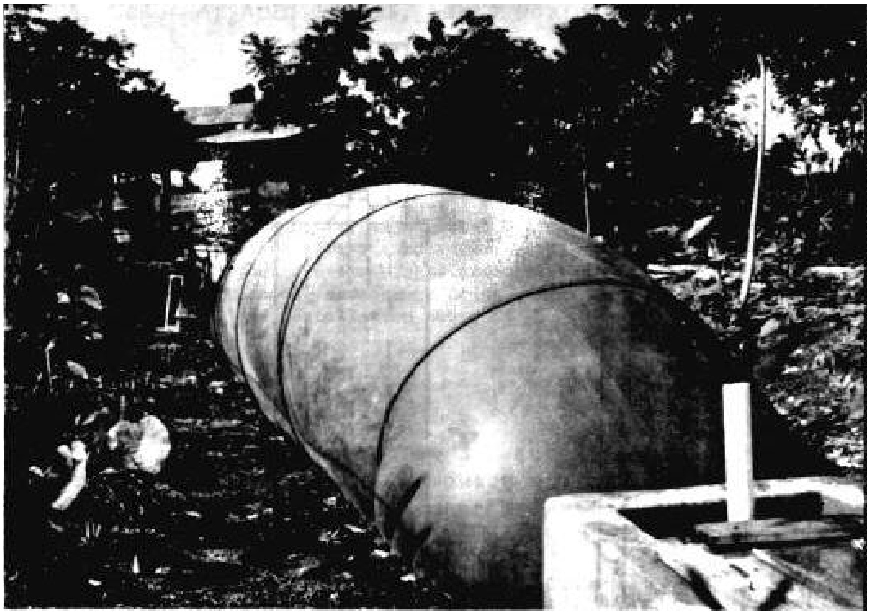


Figure 1:
"Red-Mud" PVC digester

Plate 1:
"Red-Mud" PVC digester



An entry cistern, big enough to take the whole days' charge and to allow mixing of the charge with water, and an exit cistern, with capacity to hold 5 days effluent, were constructed from 15cm concrete blocks with 9.5mm reinforcing rods every third row of blocks.

The trench into which the digester was installed was excavated according to the profile shown in Figure 1. This profile is recommended by the manufacturers in order to give sufficient support to the digester. The trench was unlined, although all sharp stones and roots were removed.

Installation procedure was as follows:

1. Excavation of the main trench, and inlet and exit cistern pits.
2. The digester was inflated using an air compressor and lowered into its trench.
3. The entry and exit tubes were cemented in place.
4. The entry and exit cisterns were lined with concrete blocks.
5. The air inside the digester was replaced with dilute, digested slurry effluent up to soil level.
6. Gas tubing and auxiliary equipment were installed, comprising, in order: gas meter for measuring volume of biogas produced, pressure release valve, water trap, U-tube manometer, modified propane gas stove. All gas tubing sloped towards the water trap to collect condensed moisture.

Capital and installation costs are shown in Table 1

Table 1:
Purchase and installation costs of 15 m^3 "Red Mud" PVC digester

	$US
Digester (exonerated from import tax)	315.00
Sea freight (Taiwan - Dominican Republic, 75 kg weight)	200.00
Insurance during freight	50.00
Installation	
400 x 15cm concrete blocks at 21¢ each	84.00
14 x 50 kg bags cement at $US 4.00 each	56.00
25 kg x 0.95cm reinforcing rods	14.00
12 mandays for excavation	60.00
3 mason mandays for construction of cisterns	60.00
6.1 m x 0.64 cm galvanized water pipe and fittings	30.00
3.1 m x 0.64cm galvanized water pipe and fittings	9.00
1.8 m x 1.9cm PVC rigid tube and fittings	2.50
1/2 plumber manday for installing of tubes	20.00
TOTAL	$US 890.50

If biogas production is 5 m^3/day and 1 m^3 biogas is equivalent to 0.5 kg propane, then at Dominican prices of approximately $US 0.50/kg propane the capital and installation costs are recovered in 2 1/2 years.

Management:

1. Raw material: The faeces from 15 bulls housed indoors on solid concrete floors was collected and water added to give a slurry with approximately 6% dry matter (see Table 2). The digester was charged once daily with this mixture. Daily faeces production from the young bulls (average 180 kg live- weight) was approximately 1.1 kg DM. The animals were fed diets based on sugar cane, molasses or grass. A 15cm grid was used to trap long fibres so that they did not enter the digester.

2. Effluent: The digested effluent overflowed automatically from the exit tubes of the digester into the exit cistern as fresh charge was being introduced at the entry, or as the gas pressure inside the digester rose. The level of slurry in the digester was maintained at ground level by use of an overflow weir from the exit cistern into a short, lined trench by which the effluent flowed by gravity to vegetable beds.

3. Usage of gas: The gas was piped 10 meters to a modified propane domestic cooker. The burners were modified by drilling out the jets to 1.5mm diameter and by restricting the air supply. Operating gas pressure was between 4 and 10 cm water gauge. The biogas was unscrubbed and burned with a blue, odourless flame. Consumption of the stove was 0.18m^3 biogas/burner/hour.

4. Retention time: A retention time of 40 days was used. The slurry volume being 10.05m^3, this gave a daily charge of 250 litres of slurry.

Daily checks: Daily checking was necessary to ensure that the levels of water in the pressure release valve and water traps were always satisfactory and that water did not collect in the gas transport line.

Operating conditions: In order to characterise the operating conditions of the digester and to quantify inputs and outputs the digester was closely monitored over a period of 10 consecutive days.

Measurements taken:

1. The weight of faeces and water added daily were recorded
2. Dry matter: Samples from the cattle faeces used to charge the digester (before mixing with a known quantity of water), and of the effluent, were collected daily and dried in an oven at 100°C to constant weight (normally 48 hours).
3. pH of fresh faeces and effluent were taken daily.
4. Kjeldhal and ammonia nitrogen levels were determined on fresh faeces and effluent every 2 days. Ammonia analysis was by steam distillation according to the method described by Minor et al (1977).
5. The temperature of slurry in the digester and of the gas were taken daily at 8.00 am and 12.00 am with a Cromark thermocouple probe.
6. The concentration of volatile fatty acids in fresh and digested slurries were determined using a Carle 311 analytical gas/liquid chromatograph.
7. The concentration of methane in the biogas was determined by 2 methods:
   a) A 10 ml sample was withdrawn from the gas outlet line using a syringe. A further 2 ml of ION NaOH solution was then sucked up and the two shaken for 2 minutes. The volume of gas remaining after adjustment of the syringe to atmospheric pressure was taken, this volume being taken as being pure methane.
   b) A sample of biogas was withdrawn by syringe and the syringe then stoppered by a method described by Blackburn (personal communication 1980). A normal syringe needle was cut so that only its plastic base remained. This was sealed using a piece of soft rubber septum. Sub-sampling of the gas from the syringe was done by 10~l micro syringe through the septum seal. The gas was analysed in the same chromatography used for the VFA's. The carrier carrier gas was hydrogen and the column packed with Supelco 60/80. Column temperature was 115°C. The methane peak comes off very clearly about 4 seconds after injection.
8. Parasite counts were taken for fresh and digested slurries.
9. Daily biogas production was measured on a Rockwell dry gas meter. This type of meter, although accurate, is unsuitable for humid, corrosive gasses such as biogas.
10. The temperature of the flame was recorded at the burner with a Cromark thermocouple thermometer.

Results and Discussion

The operating conditions during the test period are set out in Table 2, and the biogas production data for the same period in Table 3.

Conditions: The slurry of fresh cattle faeces and water entered the digester at a mean total solids content of 6.2% (+ 0.2) and after a retention time of 40 days the effluent emerged from the exit tubes at 4.9% (+ 0.5) total solids. This represents a total solids breakdown of 21%. There was still considerable production in the exit cistern and it is suggested that retention time could be lengthened to around 50 days by reducing the amount of washing water and raising the input solids content to 8.6%.

Table 2:
Operating conditions of "Red-Mud" PVC digester:

Parameter	Range		Mean	Standard error of mean
Weight of fresh faeces added daily (kg)	68 - 100	(n^1 = 9)	72.9	6.7
Weight of water added daily (kg)	140 - 200	(n = 9)	175.8	13.5
% Dry Matter of faeces	12.5 - 17.2	(n = 8)	15.1	0.5
% Dry Matter of slurry charge	4.2 - 5.7	(n = 8)	6.2	0.2
% Dry Matter of effluent	3.5 - 7.5	(n = 8)	4.9	0.5
pH of slurry charge	6.5 - 7.5	(n = 10)	7.1	0.1
pH of effluent	6.5 - 7.1	(n = 10)	6.9	0.1
Total N in slurry charge (%) 1)	1.29 - 1.73	(n = 10)	1.53	0.05
Total N in effluent (%) 1)	1.63 - 196	(n = 10)	1.73	0.05
Ammonia - N in slurry charge (mM/1)	4 - 10	(n = 8)	7.3	0.8
Ammonia - N in effluent (mM/1	7.1 - 25	(n = 8)	19.6	1.9
Slurry temperature in digester (°C)	26.0 - 28. 5	(n = 8)	27.4	0.2
Gas temperature at exit (°C)	24.0 - 34.0	(n = 20)	29.9	0.7
Strongyloides eggs in slurry charge	50 - 500	(n = 8)	194	53.0
Strongyloides eggs in effluent	0	(n = 8)	0	-
VFA's in charge (mM/1)				
Acetic	3.0 - 11.1	(n = 8)	6.6	1.0
Propionic	1.0 - 4.0	(n = 8)	2.1	0.4
Butyric	0.03 - 3.0	(n = 8)	0.9	0.3
VFA's in effluent (mM/1)				
Acetic	0.06 - 0.3	(n = 6)	0.17	0.07
Propionic	0.1 - 0.6	(n = 6)	0.33	0.15
Butyric	0.04 - 0.3	(n = 6)	0.1	0.05

[1] n = number of observations

Table 3:

Biogas production parameters of "Red-Mud" PVC digester

Parameter	Range	Mean	Standard error of mean
Biogas production/day, m^3	4.4 - 5.2 (n^1 = 10)	5.0	0.08
Biogas production, m^3/m^3 slurry volume	0.44- 0.52 (n = 10)	0.49	0.01
Biogas production, m^3/kg total solids	0.4 - 0.47 (n = 10)	0.45	0.01
% methane			
Chromatography method	52.0 - 67.0 (n = 10)	60.5	1.5
NaOH absorption method	46.0 - 54.0 (n = 10)	51.5	0.7
Flame temperature °C	775 - 840 (n = 5)	820	8.1

[1] n = number of observations

Gas pressure varied between 4 and 10 cm water gauge according to production, usage and temperature of gas. Biogas usage by the converted propane stove was 0.18 m^3/burner/hour

The long retention time was necessary because of the low temperature of the digester contents (27.4°C). There was no heating of the digester and no insulation between the digester and the soil.

The mean pH of the slurry charge was 7.1 (± 0.1), and of the effluent 6.9 (± 0.1). The effluent pH is considered slightly below optimum, although considering the gas production and quality it appears that the system is perfectly healthy.

The concentration of Nitrogen rose from 1.53% (DM basis) in the fresh faeces to 1.73% in the digested effluent due to the conversion of part of the organic material to biogas. The calculated loss of Nitrogen during digestion was 10.8%. The concentration of ammonia, although low in both fresh charge and digested effluent, was approximately double in the effluent at 19.6mM/l.

The only parasites encountered in the input charge were Strongyloides eggs. Nothing was found in the effluent.

Total VFA concentration entering the digester was low (around 9mM/l). During digestion this can be expected to rise to about 30mM/l in the acidification phase (Pound, unpublished data). The very low concentrations in the effluent suggest that either all VFA's being produced are used by the methanogenic bacteria or that all have already been converted to methane. In view of the observed fermentation activity in the exit cistern the former seems more likely.

Biogas production: From a slurry volume of 10.05m^3 an average production of 5.0m^3 biogas/day was maintained during the test period. This is sufficient to run a three burner stove with 1.5mm jets for 9 hours/day.

Production can also be expressed as volume of gas produced per unit slurry volume. This was 0.49m^3 biogas/m^3 slurry, which, although not as high as the values of up to 2m^3 biogas/m^3 digesta reported for sophisticated high temperature digesters (Taigenides 1980), it is very satisfactory for a simple, unheated digester. This commercial data agrees well with experimental data obtained using 200 litre oil drum digesters. In work by Santana and Pound (1980) gas production was between 0.38 and 0.45 m^3 biogas/m^3 slurry depending on the cattle diet.

Mean biogas production per kg total solids was 0.49 m^3/kg total solids. This was higher than that reported by Santana and Pound (1979), probably because retention time was twice as long. The value does, however, fall within the range cited in the literature (National Academy of Sciences 1979).

Gas quality was variable, but as measured by the gas chromatograph never fell below 50% CH_4 . The unscrubbed biogas burned with a blue, odourless flame which had a temperature of 820°C.

Gas pressure was limited to 10 cm water gauge to avoid damage to the digester. The flexible walls meant that pressure drop with usage was not as pronounced as for fixed-top digesters. The minimum pressure for cooking was 4 cm water gauge.

Conclusions

1. The "Red-Mud" digester under review was comparatively inexpensive, easy to install and with adequate management has performed without problems. Payback time was estimated at 2½ years , using propane as the basis for comparison.

2. An input solids content of 6.0% and a retention time of 40 days gave a biogas production of 5.0 m /day which is sufficient to fuel a 3-burner stove for 9 hours/day.

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