PRODUCING METHANE GAS FROM EFFLUENT

Luke Jenangi

Adelaide University
Diploma in Agricultural Production

Individual Project

Supervisor - Mr. Paul Harris

1 Contents

2 Objectives

The purpose of this project is to set up a “ Plug Flow’’ Anaerobic Digester to:

- Monitor start up, check sensitivity to alteration in input, look at optimum loading rate for gas production and compare to a computer model.

- Look at methods of monitoring digester performance.

- Investigate the application of Plug Flow Anaerobic Digesters by small farmers in rural areas of Papua New Guinea (PNG) to produce methane gas for cooking, lighting, heating and internal combustion engines.

3 Introduction

Methane was first recognised as having practical and commercial value in England, where a specially designed septic was used to generate gas for the purpose of lighting in the 1890s (Cheremisinoff, Cheremisinoff et al. c1980). There are also reports of successful methane production units in several parts of the world, and many farmers wonder if such small scale methane production units can be installed at their farms to convert waste into something more valuable (Lewis 1983). Units to produce methane gas have been successfully applied in meeting energy needs in rural areas, particularly in India and China (Lewis 1983) and are more recently being installed in Vietnam (An, Rodriguez et al. 1997). Small-scale plant can be operated on farms and waste treatment plants in temperate and tropical climates.

In most of the South Pacific Island countries, livestock producers simply drain animal manure into creeks, streams and rivers. Because farmers lack skills and knowledge in livestock waste management, they are wasting potential organic fertilizers, livestock feed and energy resources. Small scale anaerobic digesters for farmers would better utilize livestock waste. The current disposal system for waste has created a negative impact through pollution and disease problems. Valuable marine resources and underground water are also threatened (Ajuyah 1998).

The concept of integrated biosystems incorporating livestock, anaerobic digesters and aquaculture is beginning to create interest in the Pacific region by Non Government Organizations (NGOs), Colleges and Universities with livestock farms. For example at Montfort Boys Town, Fiji, and The University of South Pacific College of Agriculture, Samoa, the integration of pig, talapia and biogas production is in progress (Ajuyah 1998). Anaerobic digestion is best seen as part of a system, but this project is specifically concentrating on anaerobic digestion (Harris, P.L., pers comm).

4 Digestion of Organic Matter

All organic matter, or biomass, can in one way or other be used as fuel. It is composed mainly of carbohydrate compounds, the building blocks of which are the elements carbon, hydrogen and oxygen. All ultimately derive from the process of photosynthesis in plants, but may be in many forms, vegetable or animal. Biomass from which energy can be reclaimed can be harvested as specifically grown crops or natural stands, as surpluses or waste from crops grown primarily for food or manufacturing, or as municipal and industrial waste (White and Plaskett 1981). There are a number of ways of utilising these resources, which are discussed below.

4.1 Direct Combustion

Direct combustion of biomass can be preceded by physical or chemical pre-treatment, or a combination of both. Physical conversion techniques are aimed of physically altering the biomass form, for example by chipping, drying to reduce water content or selecting specific species of the biomass for certain properties. Chemical conversion techniques are aimed at altering the molecular structure of the biomass to improve utilization. Examples include combustion operations to produce thermal energy and incomplete combustion to produce chemical products and synthesis gas (Cheremisinoff, Cheremisinoff et al. c1980.).

4.2 Gasification

(Bungay c1981.) stated that the reaction of carbonaceous materials with steam and oxygen to produce a mixture of carbon monoxide, hydrogen, carbon dioxide, methane, unreacted steam, some tar and char is termed gasification. When biomass is heated in the presence of some air or oxygen, but insufficient to combust it completely, gas formation is generally maximised and temperatures within the reactor rise on account of the oxygen consuming reaction. The resulting gases provide useful fuel for IC engines or other applications.

4.3 Aerobic Processes

Aerobic bacteria, those that require oxygen, are able to break down organic waste to CO_2 and water quite rapidly. Techniques developed in the pharmaceutical industry, which are usually aerobic, have been applied to improve treatment, but aerobic digestion of wastes produces CO_2 and bacterial sludge and uses energy for aeration. (Cheremisinoff, Cheremisinoff et al. c1980.).

4.4 Anaerobic Processes

The anaerobic bacteria responsible for digestion cannot survive with even the slightest trace of oxygen. Thus, because of the oxygen present in the manure mixture fed to the digester, a period of time passes after loading before actual digestion takes place. During this initial aerobic period, traces of oxygen are used up by oxygen loving bacteria.

After oxygen has disappeared, the digestion process can begin. That process involves a series of reactions by several kinds of anaerobic bacteria feeding on the raw organic matter. As these different kinds of bacteria become active, the by products of one type of bacteria provide the food for another bacterial population. In the first stages of digestion, often called liquefaction, organic material which is digestible (fats, proteins and most starches) is broken down by acid-producing bacteria into simple compounds. The role of acid bacteria is to excrete enzymes, liquefy the raw materials and convert the complex materials into simpler substances, especially volatile acids that are of low molecular weight. The most important volatile acid is acetic acid, a very common by-product of all fat, starch and protein digestion. In the second stage of the process, known as gasification, the methane-producing bacteria utilize enzymes that break down the acid. About 70% of the methane produced during fermentation comes from acetic acid (Fry 1975) with the balance coming from direct reduction of CO_2 (Lapp, Schulte et al. 1975).

5 Anaerobic Waste Treatments and Biogas Production

Methane is insoluble, already separated from the fermentation system and is easily collected in a gas container. Methane gas is readily combustible and is a valuable energy source. The gas is also explosive and high-care safety standards must be maintained at all times during the operation period. The pressure in the cylinder must be above 34,450 kPa for liquefaction of methane (Meuhling 1981), so gas is best used on site as it is generated, rather than being stored in bottles for mobile use.

The amount of gas produced increases with digester temperature, with retention time and with the percentage of total solid in the slurry. Typically for 25^{o}C to 44^{o}C, 0.25 to 0.40 m^{3} of methane gas is produced for each kilogram of volatile solids destroyed.

5.1 Temperature

Anaerobic digestion can take place at any temperature between 4^{o}C and 60^{o}C. There appear to be two main temperature ranges within this wider range corresponding to two different sets of bacteria, usually called the mesophiles, those which operate best at 20-40^{o}C, and the thermophiles, which prefer to live at temperatures between 40^{o}Cand 60^{o}C. Digestion can also occur in the psychrophilic range, 4-20^{o}C, but is much slower. The rate of gas production increases with increased temperature but there is a distinct break in the rise around 40^{o}C, as this favours neither the mesophiles nor the thermophiles.

As reported by (Pharaoh 1976), a small capacity digester can be used if supplementary heat is supplied to maintain a constant temperature of 35^{o}C, if it is to be loaded with one type of material (for example pig manure) and if it has some form of agitation to keep slurry gently stirred. Methane bacteria can tolerate a minimum temperature of about 4^{o}C but function best in higher temperature ranges up to 60^{o}C

The range most commonly used in municipal sewage treatment plants is 33- 38^{o}C Thermophilic temperatures of 55-58^{o}C have been investigated for anaerobic digestion but high heating requirements and unstable operation have restricted practical application of this technology. The methane forming bacteria are very sensitive to thermal changes and for optimum operation the temperature should be controlled within a narrow range of the selected operating temperature (Lapp, Schulte et al. 1975).

5.2 Retention Times

The length of time that volatile solids remain in an anaerobic digester is an important factor in the digestion process. The solids retention time (SRT) represents the average time microorganisms spend in the system. Minimum solids retention times for anaerobic digestion systems are in the range of 2-6 days, depending on the temperature. In completely mixed anaerobic digesters where no recycling occurs, the SRT is equal to the hydraulic retention time (HRT). Hydraulic retention times usually vary from 10 to 30 days depending on the temperature. If solid retention time is too short the microbes are “washed out” of the digester and digestion process fails, while a long retention time requires a large digester (Lapp, Schulte et al. 1975).

Table 1. Typical Hydraulic Retention Times of Anaerobic Digesters at Various Temperatures. (Lapp, Schulte et al. 1975)

Digester Temp (^{o} C)	Retention Time (days)
15	56
26	30
37	24
49	16

5.3 Loading Rate

The loading rate is also related to the residence time of slurry, that is, how many days it stays in the digester. Undigested slurry is heavier so it goes to the bottom. As it digests it rises to the top and to the overflow part (Pharaoh 1976). If the loading rate is correct the digestion is sweet, the pH of the content is maintained at 8 to 8.5 and the gas is good quality.

Loading rates reported in Table 2, for example, vary from (0.7 to 5.0 kg / m ^{3} / day). To maintain uniform gas production and to minimise the possibility of upsetting the balance between the two bacteria processes in the digester, the loading rate should be maintained as uniformly as possible. This is especially important when one considers the effects of age and management practices on liquid manure quantity and characteristics (Lapp, Schulte et al. 1975).

When loading rate is too high it inhibits gas production, but it may be possible to gradually increase the loading rate once the microbial population is properly established.

Table 2. Gas Composition and Production Rates from Pig Manure (Lapp, Schulte et al. 1975)

Gas Production m^3kg^{-1} vs added	VS Reduction (%)	CH4 (%)	Temp (^{0}C)	Loading Rate $kgm^{-3}day^{-1}$	Detention Time (days)
0.49-0.64	41-54	59	35	0.32-3.20	10-50
0.37-0.54	53-62	68	35	2.40-3.04	20
0.48-1.05	26-76	57-60	32-52	2.40-4.00	10-15
0.26-0.45	44-61	58-61	33	1.92-3.84	10-15

5.4 Volatile Solids

Volatile solids are that portion of the total solid that are organic in composition. The biological organisms utilise a portion of this material as a substrate and make volatile solids an important parameter in estimating potential gas production. Around 20 per cent of the volatile solids in pig manure are bio-degradable (Lapp, Schulte et al. 1975).

5.5 Size

The size of digester depends on the amount of manure to be disposed of. The amount of gas produced depends on the amount of volatile solids added per day. The amount of manure fed to a digester each day has an important effect on its operation. This is measured by volume added in relation to the volume of the digester, but the actual quantity fed to the digester also depends on the temperature at which the digester is maintained.

If a farmer wants to process all his manure he can calculate the size of his digester. The manure to go into the digester must be about 10 to 20 per cent solids. When undiluted fresh manure is used with an equal volume of water, slurry of the correct consistency results (Lewis 1983).

Alternatively, An, Rodriguez et al. (1997) recommend about 5kg of fresh manure (1kg solid matter) for every $1m^3$ of digester volume. To this amount of solids 15 litres of water should be added so that the solids content is approximately 5 per cent. On this basis, if the total amount of raw slurry per day is 50 litres the digester capacity must be from 10 to 40 times the daily volume of effluent produced, i.e. 500 litres if warmer temperatures can be maintained to 2000 litres at lower temperatures.

5.6 Digester Performance

Because of the interaction between volatile solids input, digester temperature and retention time a model, first proposed by (Chen and Hashimoto 1978), has been set up in Excel (Harris 1998). Using this model the graph in Figure 1 was produced to show that there is an optimum retention time for any particular temperature. For example at 20^{o}C a retention time of 20 days is required, while at 15^{o}C 28 days would be necessary.

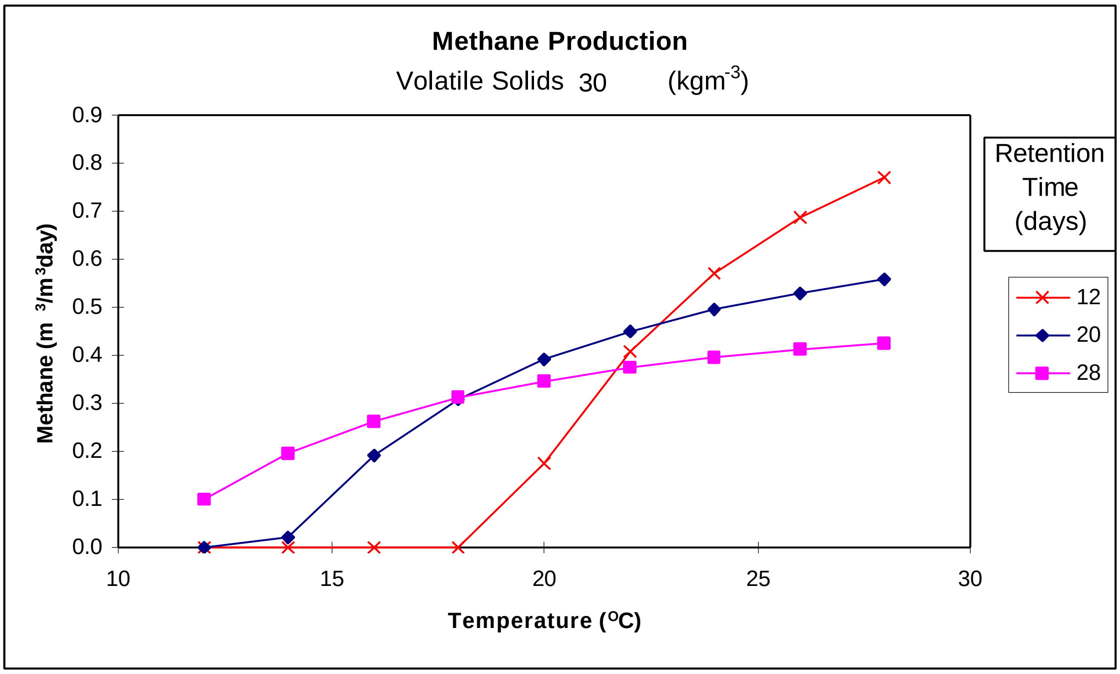

Figure 1 Relationship between Temperature, Retention Time and Methane Production

5.7 Digesters

In planning a digester there must be clear objectives. This will enable choice of the right type of digester and the criteria on which it must be designed. Commercial digesters are not widely available but producers can make their own quite cheaply, in line with their set objectives.

During the last century a number of different types of simple digester have been developed and they can be of the following kinds :

- Batch- filled in one go and allow to digest, then emptied and refilled
- Continuously Expanding- start one third full, filled in stages and then emptied
- Plug flow- waste added regularly at one end and over-flows the other
- Contact- a support medium is provided for bacteria
- Continuous Flow-filled initially and waste added and removed regularly

(Harris 1998).

There are many designs of biogas plants ranging from large commercial units to small plants. The most common are the floating canopy Indian type and fixed dome Chinese models (Lewis 1983), which are of self-mixing, continuous flow design.

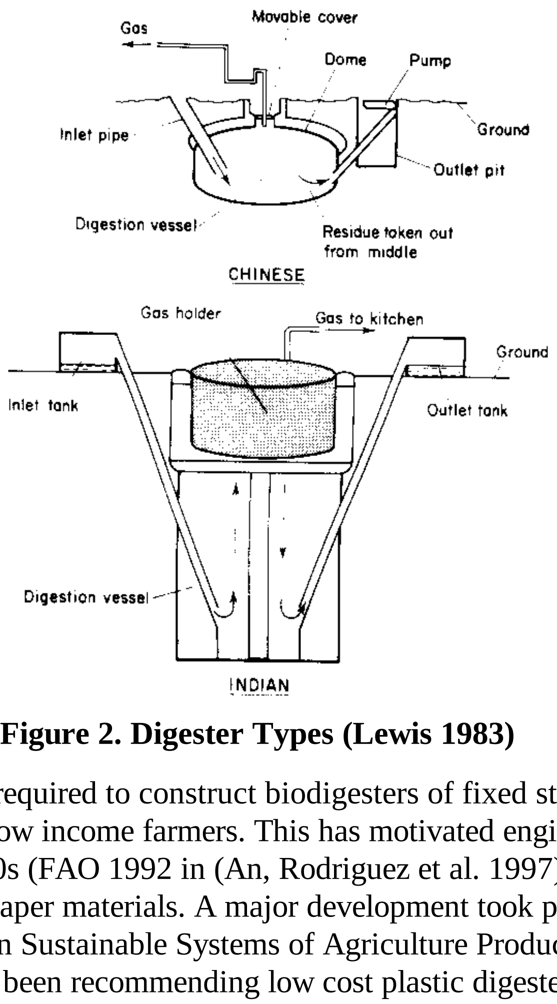

Figure 2. Digester Types (Lewis 1983)

The high investment required to construct biodigesters of fixed structure proved to be a major problem for low income farmers. This has motivated engineers in the province of Taiwan in the 1960s (FAO 1992 in (An, Rodriguez et al. 1997)) to make biodigesters from cheaper materials. A major development took place in 1986 at the Center for Research in Sustainable Systems of Agriculture Production (CIPAV) in Colombia, which has been recommending low cost plastic digesters as the appropriate technology for small scale farmers (An, Rodriguez et al. 1997).

The Indian type digester consists of a floating drum originally made of mild steel but later replaced by fibre-glass reinforced plastic to overcome the problem of corrosion. The wall and bottom are usually constructed of brick, although reinforced concrete is sometimes used. The Chinese type consists of a gas-tight chamber constructed of bricks, stone or poured concrete. Top and bottom are joined together by straight sides. The inside surface is sealed by many thin layers of mortar to make it gas-tight. (See Figure **Error! Not a valid link.**).

The type of digester this project is focused on is a small-scale anaerobic plug flow digester similar to the CIPAV design (An, Rodriguez et al. 1997).A polyethylene tubular film digester is designed like a sausage shape. Both ends are sealed off with PCV pipe “inlet” and “outlet”. The waste is added regularly at one end and overflows at the other end. This type of appropriate technology for low-income small farmers can be easily constructed and makes better use of livestock waste, reducing the pressure on natural resources due to pollution and fuel collection.

Photograph 1 Demonstration poly Plug Flow Digester - Initial setup

6 Other Operational Considerations

6.1 Nutrient Balance

Organic matter which is broken down by bacteria without oxygen will produce significant quantities of methane gas (CH4). All biological system requires sufficient supply of nutrients like nitrogen and phosphorus, although other elements are also required in trace quantities (Lapp, Schulte et al. 1975). Animal manure contains large quantities of well balanced nutrient supply, but crop residues such as straw and some food processing wastes may lack some of the nutritional requirements. The lack of specific elements required for bacterial growth will limit gas production. C:N ratio is one parameter considered to be significant and should be in the range 15-19 (Lapp, Schulte et al. 1975).

6.2 Seeding

Seeding generally is recommended as a start-up practice. Seeding consists of the addition of actively digesting material to a new digester to ensure that a culture of methane producing bacteria is present for start-up. The time to start-up, as stated by (Pharaoh 1976), is normally one to four weeks.

6.3 Mixing of Digester Content

Some method of slow stirring of the digester contents is necessary for efficient and rapid digestion. It is possible for the momentum of the daily load to give a stirring action. If the inlet pipe is set so that the force of the ingoing load makes the contents swirl, then some stirring is achieved. Self-mixing by gas generation may provide enough agitation in some situations. Where the daily load is pumped in, an even better stirring effect can be achieved by recirculation. When the digester is large and efficient digestion is required, a paddle system or gas recirculation is used so that stirring is gentle, constant and reliable.

6.4 Scum Formation

As the gas rises through the slurry it carries some of the lighter particles, which come to the top and form a scum. This scum always contains a certain amount of gas and therefore gas can pass through. Because it contains gas the scum is lighter and stays on top, gradually building up in thickness until it has to be removed, unless agitation is adequate.

One method of removal is to scoop it out at intervals through a trap door at the top of the digester. The time between intervals would depend on the loading rate. If paddles are used for agitation they might also be used to minimise scum.

Any material that floats, such as straw, hay or grass, is undesirable in a digester. Therefore, when the slurry is mixed, remove anything that floats. Floating material can also cause pump troubles unless it is chopped up finely before going into the digester.

6.5 Sludge Removal

Some solids do not digest and accumulate at the bottom, so the design of the digester should allow for their removal. A sludge pump may be used in larger installations. Access for removal of sludge in smaller installations may be gained by way of a trap door in the lid, which must be gas tight when not in use.

6.6 Alkalinity and pH

The alkalinity and pH relationships are very important in digester operation. Municipal digesters operate at a pH range of 6.6 to 7.6 with an alkalinity of 1000- 5000 mg / litre.

(Lapp, Schulte et al. 1975) have also indicated that pilot scale digesters at the University of Manitoba using pig manure as a substrate have operated successfully at levels up to pH 8.5 and alkalinity of 14000 mg/litter. If the digester is operating properly it will maintain itself at a suitable pH (Fry 1975).

7 Use of Biogas

Biogas, a mixture of methane and carbon dioxide, can be used in just as many ways as town or natural gas. If it is worthwhile installing a digester, it is equally worthwhile finding the most efficient use for the gas. Since methane is a greenhouse gas some 23 times worse than CO_2 any methane generated should be flared off if there is no other use. Obviously, as stated by (Meynell 1976), this depends in the first instance on how much gas is produced. Methane is fairly high-grade source of energy. It can provide intense localised heat compared to energy from solar panels. The important uses of high-grade energy are for heating, lighting, cooking and fuel for internal combustion engines.

If biogas provides energy for cooking, lighting and fuel, it also replaces wood for fires. Thus leads to conservation of forests, less labour requirement and fertile soil for farming, creates new businesses and is of course much cleaner for air contamination.

7.1 Removing Impurities from the Gas

When a digester is working well, the contents are alkaline rather than acid, with a pH of 7.5 -8.0. The gas has fewer impurities when this condition is reached, just carbon dioxide and a small amount of hydrogen sulphide.

(Pharaoh 1976) stated that it is better to remove the impurities, particularly hydrogen sulphide, which can cause corrosion of metals and create a foul smell if allowed to accumulate. Hydrogen sulphide (H_2S) can be removed by several different methods.

Two effective methods suggested by (Pharaoh 1976) are:

- To pass the gas through a solution of copper sulphate (bluestone) and water. H_2S combines with the copper and settles out in a black precipitate.

- To pass gas through a 51mm P.V.C pipe filled with steel wool. The indication of effectiveness is that the steel wool becomes corroded at the inlet but not at the outlet.

7.2 Storing Methane Gas

There are three methods available for storing gas:

- A water sealed gasometer made from galvanised steel sheet or fiberglass, preferably corrugated.

- Reinforced butyl rubber or heavy plastic bags made for the purpose.

- High-pressure steel or aluminium alloy cylinders, filled by a three-stage compressor.

(Pharaoh 1976) suggests the steel gasometer because it is sturdy. It consists of two tanks, one upside down and inside the other, which is filled with water. Gas is simply discharged into the top tank, which rises with the gas pressure. Gas cannot escape because the water seals it, providing a safety valve

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Methane, known as a permanent gas, does not liquefy at low pressure as L.P. gas does. Heavy steel cylinders or special aluminium alloy cylinders are necessary so the gas can be compressed to a high pressure of 28 to 35 MPa. This is the only way sufficient gas can be carried to give reasonably long operating periods for mobile use, so use in stationary application is simpler.

7.3 Using Methane Gas

Methane gas can either be burned directly as a source of energy for heating or cooking or it can be compressed and used for fuel for internal combustion engines.

7.3.1 Direct Combustion

Methane burns well in burners that were made for coal and LP gas, but those for natural gas need modification. Basically a large jet opening and a slow flame speed are required. Pressure of between 1 to 1.5 kPa is required for a slow flame speed (Pharaoh 1976).

7.3.2 Fuel for Internal Combustion Engines

Both petrol and diesel engines will run on methane gas. Gas carburetors are available for most engines and no other modification is need for a spark ignition (petrol) engine. (Lapp, Schulte et al. 1975) have indicated that it is also possible to fit a gas carburetor on the intake and still use the diesel injectors to fire the mixture, using10% diesel fuel.

The obvious use for methane as a fuel on a farm is in engines producing electricity and pumping. It is a simple matter to have a gasometer alongside the plant to fuel the engines.

8 Pilot Project Work

8.1 Introduction

Animal wastes contain large quantities of organic matter, which if processed by anaerobic digestion will produce significant quantities of methane gas, which can be captured and used as a fuel. The objective of this pilot project was to build a small scale “Plug Flow” anaerobic digester and operate with pig wastes at Roseworthy Campus, Adelaide University.

8.2 Materials Used

The materials that were used to construct the biodigester are listed below,

1. Transparent tubular polyethylene (400mm flat width) at a length of 1.8m with the volume capacity of approximately 113 litres.

2. Two pieces of 100mm PCV pipe with lengths of 38cm (inlet) and 56cm (outlet).
3. One used inner bicycle tube slit into 5cm wide strips.

4. Two 40 litres plastic bins, one 20 litre plastic bucket and a galvanized iron container.

5. Five meters of 12mm plastic irrigation pipe, four elbows, one cross joint, one 500ml bottle and 20 cm of plastic hose 8mm in diameter.

6. One burn back and back flow arrester.

7. One Bunsen burner, a gas stove burner, a home made burner and a burner enclosure.

8. A shovel, 1.5 litre plastic bottle, one billy can, two boxes of matches, a ruler and a tape measure.

9. A gas testing kit, 5 x 20 litre plastic buckets, pairs of rubber gloves, overalls and pairs of gum boots.

8.3 Methodology

When choosing a suitable location for a biodigester to be placed, a site close to the shed holding the livestock (pigs) is preferable. This project work was carried out near the old piggery sheds at Roseworthy Campus of Adelaide University.

Photograph 2 Gas Connections

Transparent tubular polyethylene was cut to a length of 1.8m and each end was rolled around the PVC pipe and tied firmly with the split bicycle tubes so that the gas and liquid would not escape. For convenience and portability, the pilot digester was set up in a cattle feed trough 2m long and 60cm wide instead of in a trench. Making sure that there were no holes or sharp edges in the cattle feed trough, the digester was placed into the holder and the inlet and outlet pipes supported firmly.

Next, a 40litre bin was placed beside the digester at the same height as the digester holder. A small hole was made in the digester for the gas outlet and 12mm irrigation pipe sealed off with water proof tape and a bicycle tube. The other end was connected to a "cross" joint. One side of the cross joint was then put into the 40litre bin by making a small hole and pushing the poly pipe through. An elbow was fitted to the poly pipe inside the 40litre bin and a poly pipe riser made to the top of the 40litre bin. A 20litre bucket was placed up side down into the 40litre bin (over the riser) as a gas collector and the 40litre bin was filled up with water. The gas collection pipe was fitted to the other side of the cross and the bottom of the cross was extended with poly pipe into the 500ml container, which was filled with water as a water trap/safety valve, as shown in Photograph 2 .

Making sure all connections from the digester to the gas collector were well sealed off the end of the gas outlet tube was placed into the water bottle. The first feeding with effluent from the sump was poured into the digester via the inlet end.

8.4 Results

From the first day of filling the digester started producing gas. Initially the digester was fed once weekly with 40 litres of effluent, and once a weekly gas production pattern was observed twice weekly feeding with 20 litres of effluent was commenced. Gas production data were recorded each day through the operation period, **Error! Not a valid link.** shows the performance during the test period after initial commissioning.

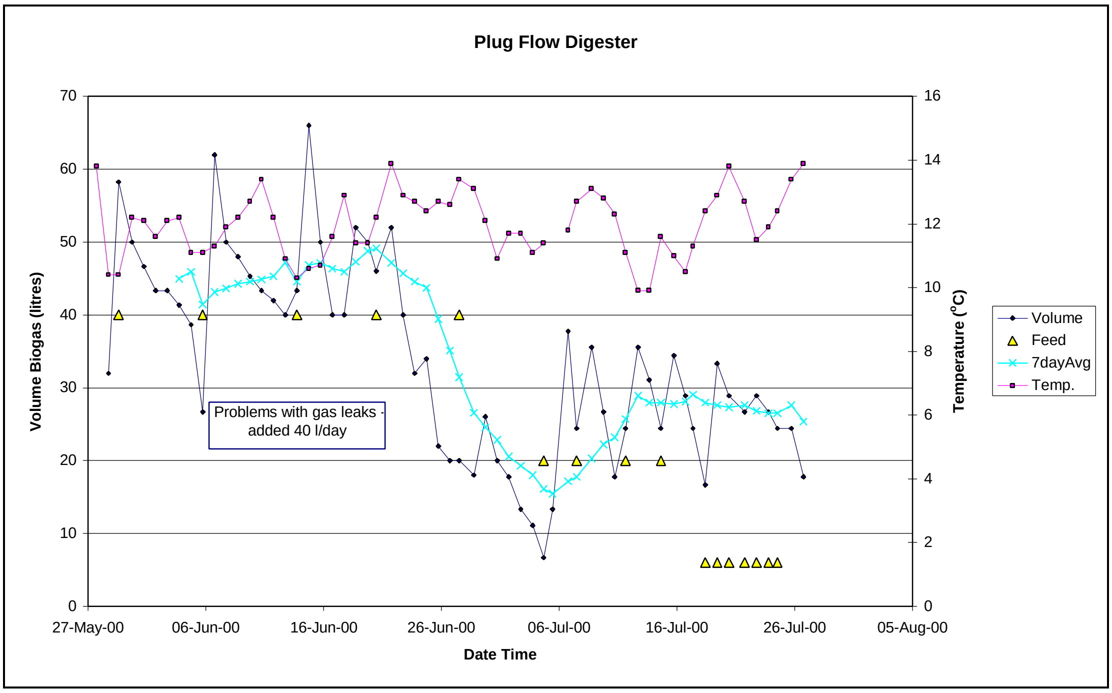

Figure 3. Gas Production, Feeding and Temperature for test period

Results showed that during the warmer months, at temperatures between 28 and 37 ^{o}C, the digester was producing more than 20 litres of biogas each day. This agrees with (Lapp, Schulte et al. 1975). Since gas production exceeded storage capacity, an unknown amount of gas was lost in the early part of the trial. This demonstrates that there is a high justification for adopting the technology, as discussed by (An, Rodriguez et al. 1997).

8.5 Discussion

With this small scale “Plug Flow” digester, the first seeding was collected from the piggery effluent collector tank to start up the digester. The digester did not take long to start up because the methane-producing bacteria were already present in the digesting material. After initial filling, the digester was not fed until gas production had began to drop off. After a couple of feeds from the tank it was decided to scrape up manure from the pen floor and dilute this with water, to get a more constant result and to use techniques like in Papua New Guinea.

Loading rate is another important factor to consider. It will relate to the slurry that stays in the digester. For this digester the slurry was digested slowly so it took a longer time. The feeding intervals were at 40 litres per week for 3 months, with 5kg of manure made to 20 litres of effluent with tap water. After mixing, the effluent was poured through a 20 mm opening mesh to strain out any lumps before it was poured into the digester at the inlet end. This was changed to 20 litres fed twice weekly and finally to 6 litres of effluent fed daily for a week.

Monitoring and collecting data from the digester is an important part of the operation. Gas production for this project was measured firstly from the gas drum that was placed into the water tank. A daily height measurement was taken by measuring the rising gas drum with a ruler. Another method of measuring was to connect the gas outlet tube to the bunsen burner and burn the gas off, noting the time taken to return the drum to starting level.

8.6 Check List

It is essential to draw up a checklist for day to day monitoring and observation for the digester. This will enable quick detection and fixing of faults. A suitable checklist for a simple plug flow poly digester can be:

- Check water in the backflow preventer. If the water is low then it can be filled up.
- Refill water in the second water trap and the water tanks when the water levels are low.
- Check any leakage from the joint connections if gas production appears to be lower than normal and digester is inflated.
- If digester is not under pressure, check the digester for any holes for the escape of gas.

8.7 Problems Encountered

Although the project work was successful, some of the main problems encountered during the operation period were**:**

- The inlet hole that was wrapped and tied to the PVC pipe got twisted and blocked up and effluent could not go through to the digester smoothly. This was overcome by inserting a smaller diameter pipe to hold the polyethylene open.

- Gas escaped through the digester because of the holes caused by cats. This was fixed by placing duct tape or plastic packing tape over the problem areas. A sheet of galvanised iron was also used to keep the cats off the warm digester at night.

- Gas collector bags had holes that were caused by small sharp objects or careless handling and the gas escaped as well. A second, larger, gas holder was added by using a 40 litre bin in a galvanised container.

9 Conclusion

Biodigesters can play a vital role in integrated farming systems by contributing to the control of pollution and at the same time add value to livestock manure.

The impact of the low-cost biodigester is variable. Adoption of the technique and successful results depend on aspects such as location (availability of traditional fuel) and the way in which the technology is introduced, adapted and improved according to local conditions.

Transparent polyethylene tubular film digesters, like the one this project used, provide a cheap and simple way to produce gas. They can appeal to small farmers because of low installation cost and also because of environmental advantages. The technology can be applied in rural or urban areas.

The technology has been developed sufficiently to justify large- scale implementation in countries where socio-economic conditions facilitate its rapid adoption, such as has occurred in Vietnam and Cambodia. Nevertheless, research should continue in close consultation with users so that the technology continues to improve.

10 Acknowledgment

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12 APPENDIX I - Glossary

From Whessoe Varec Product Catalogue 1996

Anaerobic Bacteria - Microorganisms that live and reproduce in an environment containing no "free" or dissolved oxygen. Used for anaerobic digestion.

Anaerobic Digestion

Decomposition process using microorganisms to stabilize organic solids or biosolids. This process generates biogas.

Biochemical Oxygen Demand (BOD)

Rate of oxygen utilized by wastewater under controlled conditions of temperature and time.

Biogas

By-product of anaerobic digestion. A saturated gas consisting of approximately 55 to 70% methane, 25 to 35% carbon dioxide, and trace amounts of nitrogen and hydrogen sulfide.

Biosolids

Old term used was "Sludge". It is the waste material from animal or vegetable sources. Waste contains mainly carbon and hydrogen.

Check Valve

A device to prevent the reversal of gas flow.

Chemical Oxygen Demand (COD)

Amount of oxygen from potassium dichromate required to chemically oxidize wastewater.

Cogeneration

Gas-driven turbines produce heat in the process of generating electricity. The heat is fed to generators that produce steam. This steam is used to generate more electricity.

Complete Combustion

Products arising from the combustible elements carbon, hydrogen, and sulfur. May include nitrogen brought in with the air and oxygen in excess of air. The products of complete combustion are principally $C0_2$, H_20, $S0_2$, N_2, and 0_2. Usually, the presence of CO indicates incomplete combustion.

Condensate and Sediment Trap

Device used to remove liquid and solids entrapped in the biogas.

Dead Weight Loaded-Valve

Pressure or vacuum relief setting is achieved by loading properly weighted discs on top of pallet or disc in a valve.

Design Pressure

Maximum Pressure above which tank or piping may sustain structural damage or fatigue.

Diaphragm

Thin, flexible disc that moves in response to changes in pressure.

Digester

Tank used to contain biosolids during the anaerobic digestion process.

Differential Pressure

Difference between inlet pressure and outlet pressure of a device.

Downstream

In the direction of the gas flow.

Drip Trap

Device used to safely remove accumulated condensate from gas piping without interrupting gas flow.

Exothermic
Chemical reaction that releases energy in the form of heat. May cause an increase in temperature.
Explosive Range
A mixture of gas and oxygen capable of combustion.(Note - 5%-15% for Methane)
Extensible
Can be extended. A flame arrester bank frame is referred to as "extensible" because the frame can slide apart providing access to individual bank sheets.

Flame Arrester
A device that prevents flame propagation.
Flame Check
Similar function as a flame arrester, except it is used in smaller diameter lines with low gas flows.
Flame Propagation
A flammable mixture from ignition source spreads through the gas pipe train starting at low flows and increases in speed as it travels through a long pipe run.
Flame Trap Assembly
An assembly consisting of a flame arrester and a thermal shut-off valve.

Gas Collection
- A network of wells and trenches that "honeycomb" the landfill.
- At an anaerobic digester, the gas piping system taken from the top of the digester.

Gas Purifier
A device that removes H_2S from biogas.
Gas Storage Holder
Low-pressure gas holder or high-pressure sphere used to maintain uniform gas system pressure during periods of varying biogas production or consumption.
Gas Utilization
Biogas may be burned as fuel by engine generators to produce electrical power for the plant. Heat recovered from the engine coolant and exhaust provides heating for the plant and the digesters. Biogas-fired boilers may be provided for supplemental heat when necessary.

Hydrogen sulfide (H_2S)
A flammable, highly poisonous gas having an unpleasant odor.

Ignition Temperature
Minimum temperature required that initiates or causes self-sustained combustion.

Landfill Gas (LFG)
By-product of the natural decomposition process occurring at a landfill. Comprised of 50 to 60% methane, 40 to 50% carbon dioxide, and less than 1- percent hydrogen, oxygen, nitrogen, and other trace gases.
LEL (Lower Explosive Limit)
Minimum concentration of gas vapor in air or oxygen where propagation of flame does not occur on contact with a source of ignition.

Municipal Landfill

Piece of land where household waste and/or treated domestic sewage biosolids are disposed.

Net Free Area
Total surface area of passageways permitting flow through a flame arrester bank.

Operating Pressure
Pressure of the gas system or digester during normal operation.
Overpressure
The amount of pressure above the desired pressure setting necessary to relieve full flow capacity.
Oxidation
The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound.

Pallet
A disc or round plate that fits over a valve seat port opening.
pH
An expression of the intensity of the alkaline or acidic strength of water. Values range from 0-14, where 0 is most acid, 14 most alkaline, and 7 neutral.
Pressure Drop (Head Loss)
Difference between inlet pressure and outlet pressure of a device. Also, loss of pressure through a length of pipe.
Pressure Relief Valve
A valve which opens upon rising inlet pressure.
Pressure and Vacuum Relief Valve
A device for the relief of excess pressure or vacuum on the digester or gas holder cover.

Regulator
A device which controls either valve upstream or downstream pressure.

Sampling Hatch
Small access cover installed on digester or gas holder roof, which allows sampling of contents.
Sanitary Landfill
A landfill permitted to accept household and commercial waste (solid and liquid non-hazardous waste).
Saturated Gas
Gas containing maximum water vapor for a given pressure and temperature. If more water vapor is added to the gas stream, or the pressure increases or temperature drops, condensation will occur.
Seat Insert
A soft material which improves the seal between the valve cover and seat, or pallet and seat ring.
Seat Ring
The part of a valve where the pallet rests and allows for gas-tight sealing.
Sediment
Solid particles entrapped in the biogas stream.
Sludge
Biosolids separated from liquids during processing. May contain up to 97% water by volume.
Specific Gravity

The ratio of the density of a particular gas to that of air.
Spring Loaded
Valve relief setting achieved by properly compressing a spring against the top of the pallet.
Stoichiometric Pilot
A pilot having a perfect theoretical fuel to air ratio.

Thermal Shut-off Valve
A valve that immediately shuts-off gas flow when the fusible element is subjected to excessive heat.

Upstream
In the opposite direction of the gas flow.

Waste Gas (see Biogas)
Waste Gas Burner
A device that safely combusts biogas.

13 APPENDIX II - Photographs

Photograph 3 Manure collected from pen floor

Photograph 4 Slurry ready for digester

Photograph 5 Filling the digester while stirring

Photograph 6 Measuring gas production

Photograph 7 Simple burner

Photograph 8 Flame trap/Pressure relief

Photograph 9 Final setup, with cat protection, extra storage and burner housing