Proceedings of the Sixth International Permaculture Conference
September-October 1996, Perth, Western Australia

Biogas

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[Submitted Paper]

Introduction

There are a variety of gases useful as fuel. The three most commonly used worldwide are Liquified Petroleum Gas (LPG, propane, butane), Natural gas and Biogas. LPG is a mixture of volatile fractions from petroleum refining; principally propane, butane, propylene and butylene. This is often used as a substitute for petrol in motor vehicles because it is easily liquified, has a reasonably high fuel (or calorific) value and is readily available if you own an oil refinery. A product of oil recovery is Natural Gas which usually gushes to the surface from the oil well and is composed mainly of methane. This gas is a by-product of anaerobic decomposition of vegetable and organic matter and occurs naturally, too, as 'Marsh Gas' in swamps.

For small-scale production of fuel gas, the choice is definitely Biogas because of it's relative ease of production by anaerobic digestion of animal wastes and other organic matter. The active or main flammable component of Biogas is methane which has a little-recognised attribute; although it is in itself a notorious 'Greenhouse' gas, when used as fuel it is the kindest of all because it burns to minimal carbon dioxide and water. True, carbon dioxide is also a greenhouse gas but methane gives off only half as much for a given fuel value than most. Another advantage of methane is that unlike most other fuels, it does not give off poisonous carbon monoxide when burnt, so it is safer to use in the home than other gases for cooking and heating. Biogas can be used as a fuel for gas heating, steam generation or directly as a replacement fuel in internal combustion engines. Methane has a very slow flame-propagation speed of about 430 mm per second. This means that it burns with a 'whoosh' rather than a 'bang' so it makes a very mild-mannered, tractable fuel for internal combustion engines. For the technically minded, it has good anti-detonation properties (effectively a high octane rating) and can be used to power petrol engines or as 95% of the fuel for a diesel. Since a diesel lacks spark ignition the 5% of diesel fuel is needed to ignite the gas although there are spark ignition conversions available.

Unlike commercially available Natural Gas, Biogas contains a large proportion of carbon dioxide along with water vapour, some ammonia, some hydrogen sulphide and a few traces of other gases which are insignificant for practical purposes. Because of the hydrogen sulphide and the carbon dioxide, biogas needs to be preprocessed in an operation called 'scrubbing'. The main purpose of scrubbing is to remove as much as practicable of the corrosive gases which combine with the water vapour to form acids and hence corrode all metal parts of the gas system, and to get rid of the unburnable carbon dioxide that simply 'takes up space' for no useful return.

> **WARNING:** *Biogas forms an explosive mixture with air or oxygen. When there is unburnt Biogas in the air* ***do not use naked flames*** *or* ***any spark-producing tools*** *or* ***devices****! Gas concentrations of about 5% to 20% by volume in air can ignite.*

Further to the above warning, normal hand tools such as spanners, pliers and screwdrivers can cause sparks when struck against steel or iron, even hob-nailed boots! Electric hand tools like electric drills, saws, etc normally produce sparks from the motor when running. Think carefully before under-taking work in a gas-contaminated atmosphere. Better still, wait for the gas to clear first before starting work or leave it to professionals.

> **CAUTION:** ***methane*** *can be* ***narcotic*** *in effect, leading to errors of judgement and reason. In high concentrations it can also asphyxiate or anaesthetise you.* ***Be wary of gas; it can kill!***

If you are in any doubt of your ability to handle working around gas producers, then don't! You only die once.

Having thoroughly frightened everyone into some semblance of caution, let me further warn that in some states (of Australia) it is only legal for a qualified gas fitter to work on gas installations.

Gas production, processing & storage methods

The production method we will discuss here is 'bio-digestion' which is an artificially maintained version of what goes on inside a cow. Normally this is done in a 'Digester' which is simply a large container of a size to supply the amount of gas you need. The gas is then 'scrubbed', stored, pressure regulated and piped to the appliance using it, such as the kitchen gas stove, hot water system or lounge-room gas heater.

The digester

Digesters can be as varied as the wind from a mere plastic bag to a complex piece of engineered machinery. The necessary functions of a digester are to:

- Contain the 'charge' of water and solids.
- Collect the gas for processing and storage.
- Regularly stir and mix the charge.
- Accept new quantities of charge.
- Keep the charge at operating temperature.

– Provide a means to discharge the spent contents.
– Allow access for repairs and maintenance.

These necessary functions can be varied in form depending on the basic type of digester; either ‘batch’ or ‘continuous’. There are two ‘flavours’, as well; *Mesophilic* and *Thermophilic* which refer to the operating temperature ranges of particular bacterial types. Mesophilic digesters operate at around ‘blood-heat’ or 38°C, give or take 10°C, while the thermophilic types work at hot-water temperatures of around 60°C. Needless to say, the thermophilic digesters require extra heating which translates into extra running costs, while a mesophilic one will only need a little extra heating (for most Mediterranean climates). Thermophilic digesters have a place in industry, however, when the feedstock temperature has already been elevated by the industrial process, such as the hot water used for washing-down in abattoirs and fruit canneries.

A Batch Digester operates on a single charge until it is exhausted, producing gas via a scrubber to a storage device. At the end of the digestion cycle, the Batch Digester is emptied, cleaned, recharged and restarted for a new cycle then left until done. This cycle time may be as long as six weeks. Operating the batch digestion system requires that you have two or more digesters to be able to have a more or less continuous gas supply. Three is more practical. Batch digesters have the quality of predicability because once started they are not disturbed or interrupted.

On the other hand, Continuous-Feed Digesters have increments of charge added and subtracted on a daily basis to provide an ongoing replenishment of charge materials and water. It is obvious that the amounts withdrawn and replaced should be exactly the same or the digester may become either overloaded or underloaded. Knowledge of your feedstock, that with water makes up your digester charge, is vital. One daily increment that contains a bacteriacide will kill off the bacteria, necessitating a time and energy consuming cleanout of the entire digester system and a restart from ‘scratch’. In the intervening two to three weeks there will be no gas production. Continuous-feed digester systems are less expensive to set up due to lower capital costs (you only need one digester, not several) but they do require close monitoring of feedstock solids. On the other hand, they are easier to automate due to their incremental nature.

What equipment is needed? You will need a large container with particular characteristics. It must not allow any metals but iron (steel), nickel and cadmium to come in contact with the digester contents or the bacteria will be poisoned and die. (Remember that steel water tanks are often galvanised with a coating of zinc which is highly toxic to the bacteria) Nickel and cadmium both aid methane production by some (probably) catalytic process although the exact mechanism is unknown and both metals can be a problem after digestion is finished since they are poisonous. The iron, too, can be a problem, but only because the hydrogen sulphide/sulphuric acid will corrode it if it is not protected by some acid-proof coating such as a bituminous paint or similar.

The digester must allow for the input of ‘feedstock’, the ‘fuel’ or ‘food’ for the bacteria to live on and convert to gas and, of course, for the removal of spent stock and detritus. The digester contents will have to be warmed up to the operating temperature range and preferably maintained near the optimum of 35°C for mesophilic systems. In cold climates this presupposes some form of insulation and in most climates a means of heating the feedstock and digester contents. In hotter temperate areas you may need to shade the digester in summer. The mesophilic bacteria will be killed after less than fifteen minutes at a temperature of 50°C or greater. If the heating fails, a digester will typically cool down at about 0.5°C to 1.0°C per day, depending on the prevailing 'shade' or ambient temperature of the location.

What does the well-fed digester feed upon? Typical solids consist of animal manures, vegetable scraps, food scraps, ground-up straw or grass and the odd dead rabbit, although this latter one will tend to block the pump. Ideally, all digester feed-stocks should be minced or ground up (chewed?) to a uniform size for best operation. This aspect is not absolutely vital to digestion but it will slightly increase gas production and it is vital for preventing pumps and plumbing becoming clogged. Total Solids contents over about 5.0% will cause pump problems and accelerated wear because of blockages and compaction.

Typical 'recipes' consist of about 2.0% to 12.0% of solids by weight with the rest being warm water. Above about 6%, gas quality may begin to degrade due to the digester contents becoming more 'acid' and this may require intervention to correct the pH level either by feeding back into the input side some of the spent charge or by direct chemical means such as limestone, etc. Below 2% will not provide sufficient substrate to support an active enough bacterial population and gas quantity per unit solids will decline. If pumps feature in your design, keep the Total Solids percentage down in the range of 2.0% to 4.5% and it will pay to eliminate all right angle bends from plumbing that carries the feedstock+water charge, too. If you are loading the digester directly by hand through a chute, Total Solids up to about 12% will provide greater gas production, albeit at lower quality, because there is more 'fuel' for the bacteria to feed upon but beware the 'acid stomach' syndrome!

Because the chemical reaction is to combine the carbon in the organic matter with the hydrogen from water to form methane, it follows that for the optimum gas production the ratios of the raw materials should be also be optimum. This is extremely difficult to quantify because the feedstock solids can be so variable. A handy 'rule-of-thumb' to determine feedstock efficacy is the carbon/nitrogen ratio. Bear in mind, however, that a straight chemical analysis will give a result that takes into account *all* the carbon and *all* the nitrogen. Not all may be in an available chemical form, though, so this will tend to give misleading results for the purpose of determining gas production capability. For instance, for wood shavings and straw, a lot of the carbon is bound up in lignin which normal digester bacteria cannot breakdown in any reasonable time. Those feedstocks that are 'light-on' for either carbon or nitrogen will tend to give more useless carbon dioxide in the final biogas output.

Carbon is the stuff of life and without it the bacteria will tend to die off whilst a shortage of nitrogen leaves them without the means of building new cell structures to replicate their replacements. The net result is that a shortage of nitrogen results in ammonia being produced, while lack of carbon slows down the process of gas production. This is why low-carbon feedstocks require a longer 'retention time' in the digester. According to Fry, 1973 (Methane Digesters for Fuel Gas & Fertilisers), the lack of nitrogen results in an effluent sludge lacking in fertiliser capability compared to other effluents. For information, the effluent sludge from a properly operated digester loses none of it's fertiliser efficacy to the gas production process.

The solids may be of any organic matter although once the types of matter have been decided upon, the same types should continue to be used as feed-stock. The reason for this is to allow for the many different types of bacteria that take part in the process. Each type of 'fuel' in the charge will (usually) need specialised bacteria to break it down. In changing the feed-stock types, you may have to wait for the correct bacterial population to establish and stabilise itself, as during start-up and, in the meantime, carbon dioxide flourishes at the expense of methane production. (indigestion?). Obviously you should avoid getting any bactericidal substances into the system such as Anti-biotics, Dettol, Pine-o-clean and others or the digestion may stop, as will the gas. The faeces from some commercial piggeries are badly contaminated by excreted, excess anti-biotics. Don't use these. Other pig manures are excellent, producing by far the best quality gas. (ie. percentage of methane)

Successful charge solids for digesters have been:

- Green vegetable matter, including weeds and grass.
- Animal manures, the best of which is from pigs; the worst, cows except as noted above.
- Stable refuse (ie straw, manure and spilt feed).
- Sewerage effluent.
- Wash water wastes and by-product wastes from abattoirs & food processing.
- Fruit cannery wastes.
- Flour mill wastes.
- Sugar mill bagasse and liquors.

Storage

To store the gas you will need a 'gasometer' or a compressor and some gas bottles. The compressed form of the gas is not as compact as would be the liquid, but is marginally useable for local vehicular travel. The liquified form would be ideal for vehicles, but to liquefy methane requires a considerable energy expenditure of about 20% to 33% of production, depending on operational scale, and needs expensive cryogenic equipment. The cost of the gas-filling and compressing equipment for compressed gas handling is not cheap, either, and requires a licence to operate in most Shires in Australia. The gasometer route is the one to take for most home use scenarios. It won't allow you to use it in your car, but it can be used for small stationary engines for various purposes such as pumping water, driving fixed machinery or generating electricity.

What is a gasometer? A gasometer is simply a variable-volume storage tank for gas, normally at a fairly low pressure suitable for the appliances that use it (see Figure 1). A fixed dimension container for gas suffers from a problem when delivering it's gas to the user site in that the pressure will vary from quite high when the container is full, to quite low when it is nearly empty. A gasometer combines the functions of storage, over-pressure safety valve and pressure regulation in one structure – an ideal permaculture device! This is achieved by having one gas-tight tank float upside-down in another tank of water with the gas being stored beneath the floating tank. As more gas is produced, it is stored in the gasometer and the floating tank rises to accommodate the increased volume. Conversely, as gas is consumed, the floating tank floats lower. In this way, the gas pressure is kept constant at a pressure determined by the weight of the floating tank no matter what the volume of the stored gas.

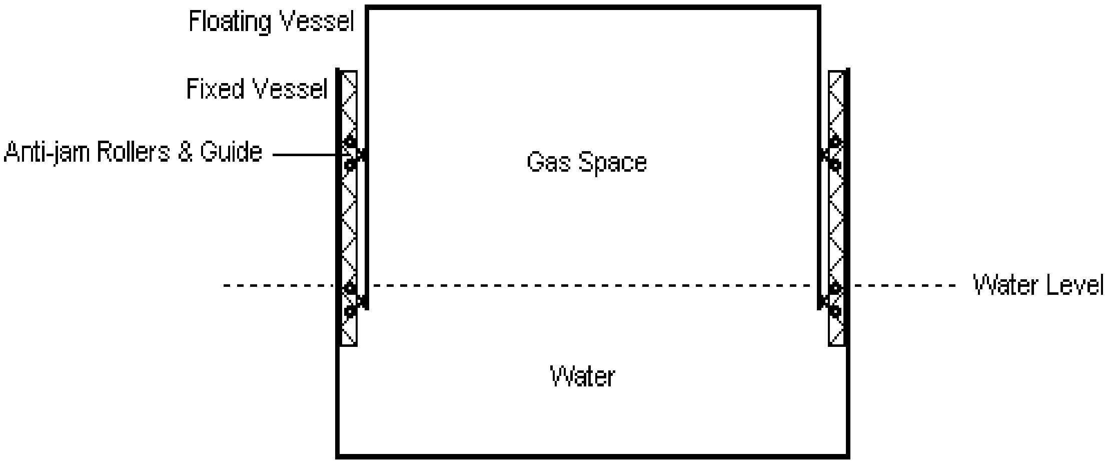

Figure 1: *Typical basic gasometer*

The safety function of the floating tank system works like this: if the gas volume produced is too much, the floating tank lifts up until the bottom edge is clear of the water and the excess simply blows out from under the lower lip to release over-pressure conditions and then allowing the floating tank to settle back down again in the water. A bit like a monstrous mechanical burp when it happens. It's fairly obvious that the two functions of digester and gasometer can be combined in the one device by having the floating tank float in the (mainly liquid) digester contents (see Figure 2). This represents a substantial saving in construction costs but it does mean that the floating tank will have to be acid-proofed both inside and out since both surfaces come into contact with the (mildly) corrosive digester contents. The disadvantage of the floating tank gasometer system is that it wont shut off the supply at low pressures. For that safety feature you will need a supply pressure regulator of the spring-loaded diaphragm type plumbed into the gas supply-line before the appliances and after the gasometer.

Note the increasing taper on the inlet chute and diverging taper on the effluent chute. This is necessary to prevent clogging. An auger might be fitted to the effluent chute to ease removal of the spent solids. This auger may be hand operated.

Regulation of the supply pressure is critical for safety and must be reliable. What is supply pressure? Pressure is the force that causes fluids to flow from one place to another. ie down a pipe. If the supply pressure was not fairly even, then sometimes your gas stove would burn fiercely while at other times it would hardly burn at all. These two states correspond to high and low supply pressures respectively. In the worst cases, the gas flame could blow itself out, filling the house with gas or it might not light at all, again filling the house with gas but more slowly.

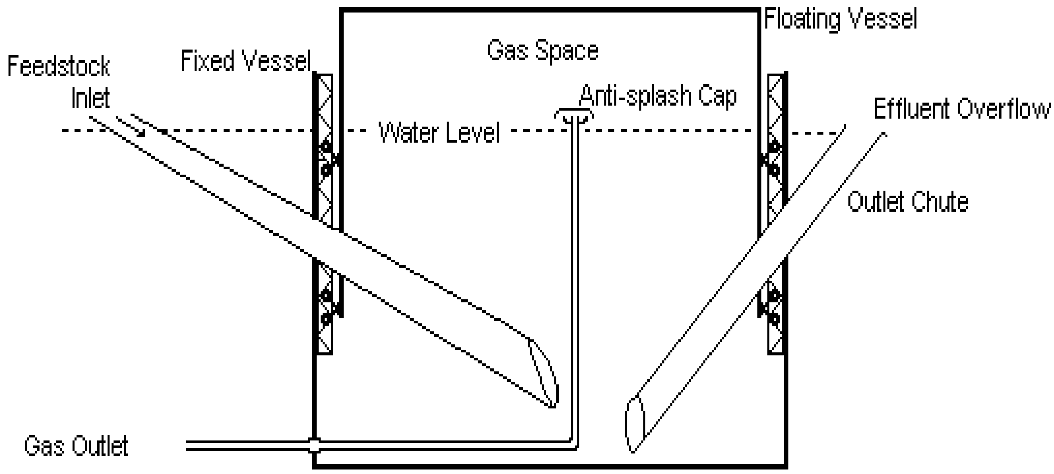

Figure 2: *Basic gasometer modified for use as a digester*

It is a good idea to use properly designed regulators. A regulator is a device which connects into the supply line between the source (the storage device) and the destination (the gas burning device). The regulator can accept a widely varying inlet gas pressure and smooth it out to a very constant pressure at the outlet. If the outlet pressure should exceed the inlet pressure (ie you are nearly out of gas) then the regulator will shut down the supply for safety's sake. Commercially available line pressure regulators are also designed to "fail safe" (ie shut off the gas if they, themselves, break).

Scrubbing

Scrubbing is the operation that removes unwanted compounds from the biogas before it is used. Usually these compounds are those that will cause us some grief in some way. The main culprit to be scrubbed will be Hydrogen Sulphide, or 'Rotten Egg' gas, because this will combine with the moisture in the biogas to form sulphurous acids and these can corrode almost anything. The way to get rid of it is to give it something to corrode that you don't want; like some steel wool, for instance, in a wide-necked bottle or flagon. It must be of clear glass with the gas inlet pipe running down to the bottom of the container and an outlet pipe coming away near the top. Of course, the whole thing needs to be gas-tight. As you use the gas, the steel wool will corrode from the bottom upwards taking up the hydrogen sulphide by conversion to black iron sulphide which can later be reused after being oxidised to rust (ferric oxide) by exposure to air, although the process is slower than the initial scrubbing one was. When the black corrosion reaches 75% of the height of the container, or so, it's time to change the steel wool or ferric oxide for fresh, sacrificial stuff. It's probably better to run two or more similar bottles or containers connected one after the other to give some flexibility by providing some 'back-up' scrubbing capability if you are away for a period.

To get rid of the Carbon Dioxide (CO_2) requires that the digester biogas be diffused through a water (or lime-water) spray tower. This action dissolves the CO_2 in the water which is then collected at the bottom of that tower and then sprayed down a second column to release the carbon dioxide gas from the water which is then

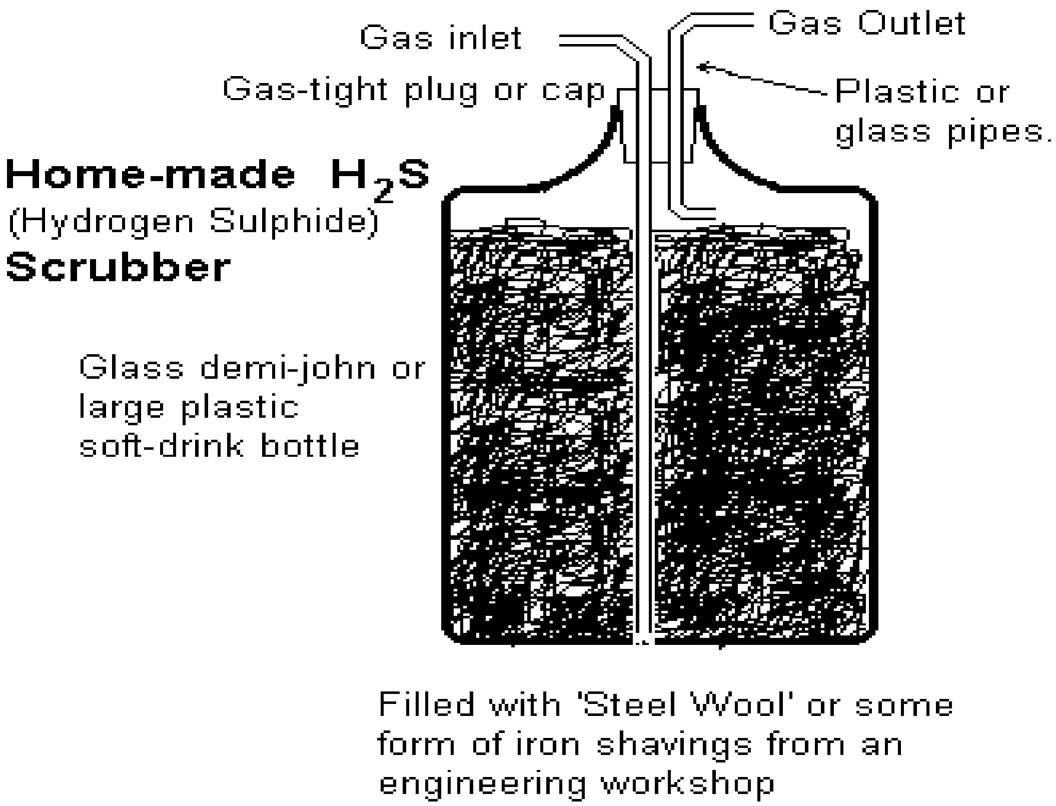

Figure 3: *Hydrogen sulphide scrubber*

vented to atmosphere, preferably via your greenhouse to give the plants a boost. The water is then recycled back to pick up another load of carbon dioxide.

It is not absolutely necessary to eliminate Carbon Dioxide from the methane, but CO_2 has no intrinsic fuel value and can complicate the jet and air settings of user appliances. The reason is that CO_2 percentage can vary considerably from week to week of normal operation, particularly where differing feedstock constituents are used from time to time. This can vary appliance performance from 'not at all' to 'explosive', neither of which is desirable.

In the situation where digester output quality is fairly consistent, CO_2 scrubbing may be dispensed with and the appropriate flow settings of user appliances adjusted to suit the overall lower fuel value of the combined CO_2/Methane mix. Care will have to be taken to maintain that exact CO_2/Methane balance in future, however. The only exception to this I can think of is where the digester gas is used exclusively as fuel for a methane fuel cell (electrical generator) system. These systems can be made relatively tolerant of quality-variability in fuels.

The scrubber system needs to allow a fairly free flow of gas to minimise pressure losses in the gas system since the operating pressures are so low to start with that little reduction can be tolerated before the whole thing stops flowing. Typical system pressures are around 0.5 Kp to 2.0 Kp. Since appliances usually operate at around 0.6 to 0.7 Kp, there's not much room to manoeuvre. In a system requiring Carbon Dioxide scrubbing, the low-pressure route will not work well. Instead, a series of pumps or a multi-stage pump/compressor is needed to pressurise the

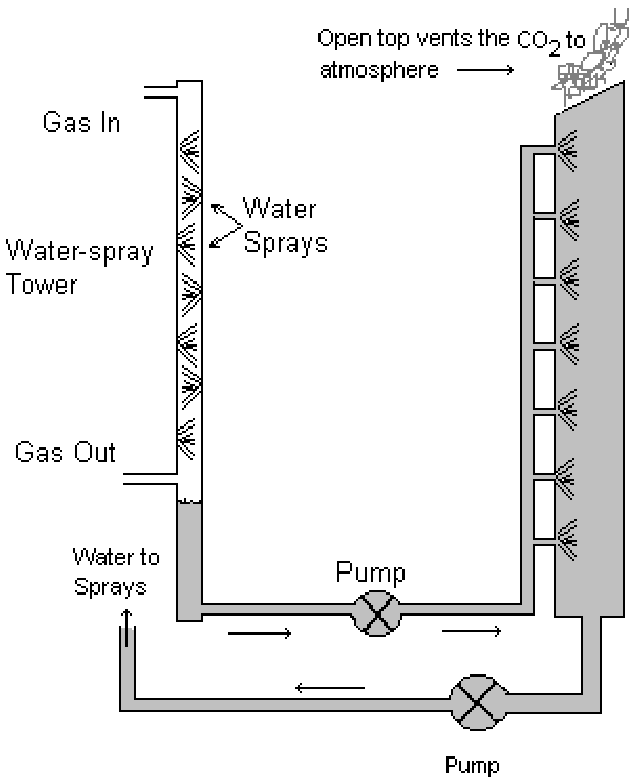

Figure 4: *Carbon dioxide scrubber*

carbon dioxide scrubbing operation and for later methane compression for storage in high-pressure steel bottles. This more expensive storage method is usually only needed for use with vehicles to allow sufficient useful fuel to be stored or carried conveniently. A cubic metre of methane is roughly equivalent to a gallon, or 4.5 litres, of petrol, so more than one large gas bottle will be needed for a vehicle to have much range, even when compressed to twelve atmospheres.

Starting up the digester

Starting up is a process requiring patience. To get a digester going can be a problem initially although it's not unusual to get one started by simply adding feedstock at the calculated feed-rate, provided the water is warm enough. Because it can take up to several weeks for a digester to stabilise, they often need a little nursing along at first. The correct bacteria are normally already present on the feed-stock as you prepare it and time is needed to build up bacterial population numbers to full production levels, as well as to stabilise the digester pH, or 'acid balance'. The way to determine if the process is under way is to monitor gas production by means of a tube from the top of the digester to a clear bottle of water. Once a stable and continuous stream of bubbles coming from the monitor tube can be observed in the water bottle, you can assume gas production is working. It might be an idea to discard the first two weeks worth, though, because the first two weeks or so tend to produce more carbon dioxide than methane until the pH balances out at about 7.5 to 8.5.

Remember the explosive nature of methane when mixed with air!

Be absolutely satisfied that all remaining air has been purged from the gasometer storage space before you connect up the gas outlet pipe to it. In the case of the combined Digester/Gasometer, make certain that the floating gasometer tank is completely 'sunk' in the digester liquid before start-up commences to exclude all air from the storage space.

If nothing appears to be happening after a week or so, obtain the rumen (stomach) contents of a freshly killed cow and add that to the digester feedstock. This will give the kick-start it needs, assuming all else is in order. The contents should be at a temperature above 25°C and preferably around 35°C. Don't initially overload the digester. Begin adding feedstock on a daily schedule at the calculated feed rate for the system which will depend on the digester size and gas production rate. Some authorities even recommend starting off at half the calculated feed rate until gas production rate stabilises then gradually increasing to the full rate over a period of two to three weeks. At low temperatures, excessive feed rates at start-up can cause an inhibiting scum to form on the surface of the digester contents, stifling gas production.

Operation

Feeding the digester is a matter of grinding up the feedstock to a suitable size with a chaff-cutter, an old industrial mincer or a garden shredder, mixing it with the right proportion of preferably warm water and putting it in. You must then take out an equivalent volume of spent stock from the discharge port at the bottom of the digester. That's it! It wont matter if you sometimes miss a day, either, unless it becomes a regular thing. A missed feed wont substantially affect gas production much, if at all.

Keep an eye on the scrubber to ensure that the sacrificial material is still intact and sufficient for the purpose. Replace and rejuvenate as required.

Maintaining biogas digesters consists mainly of regular cleaning and the inspection for, and replacement of, corroded metal fittings and components. Digesters operate in a warm moist environment. This is a recipe for corrosion in any one of several ways, so bear in mind that the vapour drawn off as 'Biogas' contains conspicuous amounts of corrosive sulphurous and carbonic acids with traces of various other corrosive gases

Design

Ensure there are no copper or brass fittings inside the digester tank. Most metals except iron, nickel and cadmium will poison-off the bacteria.

Heating & cooling

Heating is probably most easily provided by solar warmth in most Mediterranean climates and this is accomplished by wrapping twenty to thirty turns of 19mm black "poly" pipe, as used in trickle irrigation systems, around the outside of the steel tank used for a digester and coupling this to about the same length of 13mm poly pipe used as a solar collector. Wrap some form of thermal insulation over the outside of the digester and the 19mm heater pipe. To arrange the 13mm pipe, simply loosen the coils and spread them out on the ground or preferably on a support to keep the pipe clear of the ground by about 300 – 500mm. In either case, the 13mm pipe needs to be lower than the bottom-most coil of the 19mm pipe on the digester so as to allow for convection siphoning of the warming water from the 13mm solar collector coils to the 19mm warming coils. This should not be too hard to organise since the bottom of the tank will be mounted clear of the ground to allow gravity drainage of spent charge from the discharge cock. If it is not, then a pump may be required to circulate the warming water.

Another possible source of warmth would be an aerobic compost as this just happens to operate at the correct temperature for optimum mesophilic digester function at 37°C. This is also the optimum operating temperature of liquid piston fluid pumps, too. There's scope for a long-lasting and successful marriage of technologies in this information.

Problems may arise from the formation of a gas-tight blanket of sludge on top of the digester contents. This will inhibit gas production and will have to be broken up. How this is accomplished will depend on the feed-stocks used to form the slurry or charge in the digester. For the most recalcitrant blankets, mechanical stirrers will be needed because the upper surface of the blanket gets a tacky, dry 'skin' of dead bacteria which only a paddle can break up. This type of blanket is mainly a problem where stable wastes and animal bedding materials are used. Such things as feathers, hairs, straw and feed grains will float to the surface forming an interwoven matrix on which an impervious layer of other components can settle.

Sometimes a fairly light, flocculent layer will blanket the surface, especially where animal manures are the predominant feed-stock component. This kind of blanket, while causing much the same problems, is easily broken up by a stream of bubbles formed by pumping in the collected biogas or by an up-welling of slurry formed by pumping the slurry around. This latter idea also ensures an even temperature and bacterial distribution, which is desirable for optimum gas production and may be necessary in a Mediterranean winter if the warming coils are wrapped around the outside of the digester. This form of heating causes another nuisance, too, and that is the formation of deposits of bacteria killed by the locally elevated temperatures on the inside of the digester tank wall adjacent to the warming coils. These deposits lower the efficiency of the heat transfer from the outside to the slurry inside but pumping the nutrient liquid or slurry around the tank will help to dislodge the bacteria and spread them through the slurry for more active operation. This only becomes a major problem when the temperature of the warming fluid is above about 43°C, or so, but will also be influenced by feedstock types.

If you want to get real fancy, you can utilise an external 'heat-exchanger' mechanism and slurry-pump to more or less continuously move the sludge from the digester through the heater and back again. This provides ease of access for maintenance of those parts most easily blocked-up in normal operation but is also asking for trouble because of the necessary bends in the plumbing and restrictive flow in the heat exchanger. The digester then can go back to being a simple tank with no interior mechanisms. This is a boon in the event of a break-down because the charge and gas wont have to be emptied (usually) since the trouble-prone areas are all external to the tank. This idea is energy-intensive, however, and the maintenance costs of providing repairs and motive power for the pump need to be taken into account as well as the extra installation costs for the plumbing, pump, etc.. All in all, keep it 'bog-simple' for reliability's sake, even if you have to sacrifice a little efficiency here and there. After all, isn't this supposed to be so that you can lead the easy life? Why make it difficult for yourself?

How much gas will you need? This will depend on your gas appliances and how often you use them, but the heaviest consumer of gas will be space heating followed by water heating, followed by gas fridges and finally the gas stove. Gas barbeques get through a lot, too, but they are not often used. A very small gas space heater, say of 26 MegaJoule rating, will consume about 1.0 m^3 for each Hour of operation. For, say, two hours in the morning and six hours at night that's 8Hrs $\times 1.0m^3 = 8.0m^3$ of gas each day! This would require a 24 to 30 m^3 digester (4800 – 6000 gallons) volume. If you add in a gas stove (~0.5), a gas fridge (~2.0), a gas freezer (~2.5) and hot water booster (~3.0) your total maximum gas 'draw' would be about 16 m^3 per day. The need for machinery to handle the daily required feedstock input (48 Kg of hen manure) is getting very close and this is getting to be a very expensive and capital intensive installation, not to mention the labour involved. The size and the cost could be halved by not using the gas heater.

Appliance	**Approximate Consumption in m^3/hour**		
	Biogas	**Natural Gas**	**LPG**
Stove-top Burner (9Mj)	0.5	0.25	0.1
Oven (8.5 – 10Mj)	0.40 – 0.60	0.20 – 0.30	0.08 – 0.12
Small, two-panel heater (11Mj)	0.55	0.30	0.11
Large, flued heater (44Mj)	2.20	1.10	0.44

Table 1: *Typical consumption figures – domestic appliances*

Terminology

m^3 Means 'cubic metres' of volume which directly translates to 1000 litres (of water), or 220 gallons Imperial.

Mj The abbreviation for "MegaJoule" (millions of Joules), a measurement unit for heat energy. Hence a '44 Mj' heater gives out 44 MegaJoules of heat per hour. A 22 Mj heater is sufficient for a small Australian house.

Total Solids The term describing the non-liquid portion of the feedstock recipe. For instance, a 5.6% Total Solids brew of hen manure contains 5.6% of hen manure and 94.4% of water by weight. Bear in mind that hen manure may not necessarily be dead dry in itself. This extra moisture content will have to be taken into account to get the recipe exact. In practice, it doesn't matter much, so long as the pump can cope without blocking up.

Turn-over Time Sometimes known as 'retention time', and is the time required for a complete change-over of solids content in a continuous feed Digester.

Convection Siphon That flow of a liquid caused by the tendency of the hotter portion of a liquid to rise and the colder portion to sink in a closed system or container.

Slurry A runny mixture of liquid and finely chopped-up solids. It can be pumped like (thick) water.

Feedstock The particular type of solids used to make up the slurry along with water.

Charge The slurry mixture of solids and water used in the digester to produce gas.

Figuring it out

The chemistry of methane production is very simple; carbon combines with the hydrogen in the water to produce methane (CH_4) while the left-over oxygen combines with the rest of the available carbon to form carbon dioxide. Note the word 'available'. For useful calculations in the real world, carbon may be present but not be available for the chemical reaction because it is 'locked up' in materials such as lignin in wood or straw. Lignin takes a long time to break down chemically; much longer than the normal digestion time of mesophilic bacterial systems. Why is this important? Because the amount of methane gas produced per unit weight of solids will depend on the amount of available carbon (and hydrogen, too)

If we are producing 0.5 m^3 of gas per day from a 5.6% Total Solids brew of hen manure, we will need to add an extra 1.5 Kg of manure mixed with 30 litres of warm water per day to maintain gas production at our chosen rate (0.5 m^3). If we allow about one third of the digester volume for gas collection, then our digester will have to be about 1.5 cubic metres in total volume. 0.5 m^3 of gas = 1/3 of volume so total volume is 0.5 * 3 = 1.5 m^3). Now, each daily charge increment added is 30 litres and two thirds of our digester's 1.5m^3 is liquid feedstock which is 1.0m^3 (= 1000 litres). In the liquid volume of the digester we will have 1000 / 30 = 33.3 days turn-over time. This sounds about right and produces up to 0.60m^3 of gas per day in a 1500l (330 gallon) tank from 1.5Kg of hen manure which is about enough for one burner of the average Australian gas stove to burn for an hour. This does not mean we are limited to 0.60m^3 of gas per day for this sized tank provided that we can store the excess over and above this amount, can keep the digester from 'going acid', keep the pumps (if any) running and prevent the formation of, or remove, any gas-suffocating surface blanket.

A timely warning: for any human engineered adaptation of natural processes, remember that natural processes have their own, in-built time-tables and capabilities. If you try to push these processes beyond their normal operating parameters they will baulk, hence the need to break up surface blankets, to unblock pumps, etc. If you are prepared to put up with these inconveniences, you might get away with 'stretching the envelope' but your system will be trouble-prone, unreliable and probably short-lived. On the other hand, if you allow these natural processes their natural progression, your system will be 'low stress', low maintenance and trouble-free. Who would want to have it any other way?

Returning to our hypothetical digester giving 0.60m^3 of gas per day from a volume of 1.5m^3, it may be easily deduced that this is the limiting size, in a natural world, for this digester recipe. A larger volume digester will be required to process more solids than 1.5 Kg each day without trouble. Use the hypothetical 1.50m^3 digester as a model and scale up from this to give the size of digester you must have for the gas amounts you need. In other words, should your needs amount to 6.0m^3 of gas per day, make your digester ten times larger than our model one. Our model gave 0.60m^3 of gas per day for a total volume of 1.5m^3, your digester will need to be 10 * 1.50 = 15.0m^3 in volume to give you your 6.0m^3 of gas per day. It will also need, daily, 15 Kg of hen manure to provide this amount of gas, along with ten times the water, too. OK, so you know the volume, but what ratio of height to width is best? The Greeks figured this one out four to five thousand years ago; it's the so-called Golden Ratio of 1.6 : 1.0 for width to height. You don't have to be exact, but get as close as practicality will allow. ie. 1.2 : 1 to 2.0 : 1 would be the limits I would use.

How much feed-stock?

The amount of gas increases with digester temperature, with retention time (up to a point) and with the percentage of total solids in the slurry. Typically, for 25°C to 44°C, 0.25 to 0.40 m^3 of gas for each Kilogram of solids. Retention times approach the point of diminishing returns at around 32 to 35 days for a well-run mesophilic system. After 42 days there's virtually no gas to be had in the solids, in most cases. For Total Solids below 2% and over 6% the amount of methane will decrease. At the low end because there is insufficient 'substrate' or solids to build up an active bacterial population and at the high end because the digester slurry begins to tend towards an acid condition which increases the percentage of carbon dioxide and ammonia in the gas mixture at the expense of the methane, the active ingredient we are seeking to generate. In either case, daily methane production suffers compared to other slurry recipes in the middle of the recommended range (about 3.5 – 4.0 % Total Solids).

Pig manure is slightly different in recipe and retention times to other solids. See the recipe section below.

What recipe?

The Chook Recipe: 1.5 Kg (about 45 chooks worth/day) of fresh, runny hen manure plus 30 L of water to give a Total Solids of 5.0%. This will be difficult to pump. Gas production will be about 0.35 to 0.40 m^3 of gas per Kg of Total Solids for a digester turn-over time of about 32 Days. About 0.014 m^3 of gas per chook per day, maximum.

Cow Manure: bulls – 0.25 m^3 of gas per Kg solids (2.0% – 4.5%), Dairy Cows – 0.15 m^3 of gas per Kg. (Straw mixed into the cow brew decreases gas production.)

The Pig Recipe: for a 2% Total Solids slurry at 35°C, gas = 0.3m^3/Kg at a 10-day digester turnover rate. (Faeces from pigs injected with Antibiotics kills the digester bacteria.)

From straw, alone: using oaten straw @ 35°C digester temp, 1 Kg produced 0.40 m^3; wheat straw, chopped produced 0.40m^3/Kg; ground-up produced 0.55m^3/Kg.

From dried kelp: up to 0.40m^3/Kg.

Turnover = 36days (approx) in all cases except for pigs @ 10 days.

Compressed storage

Compressed methane storage appears to be the most appropriate for farm use if the gas is to be used for vehicles. This will require a gas compressor, storage bottles, safety storage buildings and safety areas plus a scrubber to remove unwanted gas impurities. Regular inspections by qualified gas-fitters are required by law and gas bottles and other equipment have a defined life-span. For a given-sized gas bottle, methane will provide about half the 'mileage' of the same bottle filled with LPG due to the compression limits on methane. All that aside, though, methane is, by a country mile, the best fuel for any internal combustion engine given it's fewer 'greenhouse' emissions and slow flame-propagation rate. This latter one results in vastly extended engine life and reliability due to lower operating stresses and fewer corrosive exhaust gases. Cold-start wear is reduced since gas will not flush the lubricating oil off the cylinder walls like liquid petrol will on a cold morning. This further extends engine life.

Liquid storage

For liquid storage of methane, refrigerate it to -178°C (!) For anything other than the high-tech. approach, liquid methane storage is impractical. It is the most compact form of storage, though.

Bibliography

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