Biogas Notes

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Introduction

Before talking about biogas and anaerobic digestion there are a few things I would like to discuss.

Anaerobic digestion is a waste conversion process - it is not a waste "disposal" process. In fact there will be little reduction in volume of waste but the treated waste will be less smelly, contain less pathogens and be better as a plant fertiliser than untreated waste. You will also have the benefit of renewable energy released during the pollution reduction process.

As a result anaerobic digestion may be regarded as part of a waste treatment system, assisting in the "reduce, reuse, recycle" approach to lessening the pollution load we currently place on our planet. An anaerobic digester is really a "primary" waste treatment, taking waste and making it easier to handle in later stages of secondary and tertiary treatment prior to release back into the biosphere.

These notes are meant as a brief introduction to biogas in general, but with an emphasis on simpler processes and the "poly plug flow" digester in particular. The "DIY Poly Digester " Manual provides details of constructing a small digester (that can easily be scaled up) and there are a number of books and internet resources available, Fulford (1988) covers most of the areas necessary at an understandable level.

There are a few things that are not directly "biogas" but are worth keeping in mind.

First an Albert Einstein quote that I really like – "Things should be as simple as possible, but no simpler". Humans seem to have a remarkable tendency to make things complicated and this is one reason why biogas is not very popular – it is seen as complicated and expensive (I hope to show you otherwise!). Another Albert Einstein quote that I use a fair bit is "If we knew what we were doing it wouldn't be research, would it?".

Then I propose "Harris' Law" – "The harder you push any system the more unstable it becomes and the more management it requires". In biogas (and life) this means that you can increase the load (usually quite a bit) and all appears well, but you do reach a point when the digester (or any other system) will "fall over".

Relating back to the fact that AD is part of a system (and leading in to my final point very nicely) I believe that our "reductionist" scientific training encourages us to focus on just the immediate problem, rather than considering the systems around the problem. This leads to Harris' Corollary of Murphy's Law – Solving any problem immediately creates at least two new problems!

My final philosophical point is that minds are like parachutes, they only function when open (and both are often only used in emergencies!). I hope you can broaden your outlook (if necessary) and expertise as we progress through this course together.

What is Biogas?

Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. Since biogas is a mixture of methane (also known as marsh gas or natural gas, CH_4) and carbon dioxide (CO_2) it is a renewable fuel produced from waste treatment. Anaerobic digestion is basically a simple process carried out in a number of steps by many different bacteria that can use almost any organic material as a substrate - it occurs in digestive systems, marshes, rubbish dumps, septic tanks and the Arctic Tundra. Humans tend to make the process as complicated as possible by trying to improve on nature in complex machines, but a simple approach is still possible.

As methane is very hard to compress I see its best use as for stationary fuel, rather than mobile fuel. It takes a lot of energy to compress the gas (this energy is usually just wasted), plus you have the hazard of high pressure. Variable volume storage (flexible bag or floating drum are the two main variants) is much easier and cheaper to arrange than high-pressure cylinders, regulators and compressors.

Brief History

These items have been collected mainly from e-mail contributions, to which credit is given.

Anecdotal evidence indicates that biogas was used for heating bath water in Assyria during the 10th century BC and in Persia during the 16th century AD.
"Philip D. Lusk" <plusk@pipeline.com>

Marco Polo mentions the use of covered sewage tanks. It probably goes back 2,000-3,000 years ago in ancient Chinese literature. Roos.Kurt@epamail.epa.gov

The technology, or process, dates back a long time. 1630 (van Helmont), 1667 (Shirley) are some who mention about the gas as such. In 1808 H. Davy made experiments with strawy manure in a retort in a vacuum and collected biogas. He was not interested in the gas but rather rotten or not rotten manure (from Tietjen C 1975 "From biodung to biogas - a historical review of European experience" pp 207-260 in "Energy, Agriculture and Waste Management", Chawla 1986, Ann Arbour Science Publications). mathias.gustavsson@he.gu.se

Daniel Defoe tells about biogas on his lost island. Fabrizio De Poli, http://www.lafrancesca.it

Jan Baptita Van Helmont first determined in 17th century that flammable gases could evolve from decaying organic matter. Count Alessandro Volta concluded in 1776 that there was a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced. In 1808, Sir Humphrey Davy determined that methane was present in the gases produced during the AD of cattle manure.
"Philip D. Lusk" <plusk@pipeline.com>

A digester was built in the 1840's in the City of OTAGO, New Zealand.
christian.couturier@solagro.asso.fr

The “first” digestion plant was built at a leper colony in Bombay, India in 1859. AD reached England in 1895 when biogas was recovered from a "carefully designed" sewage treatment facility and used to fuel street lamps in Exeter. The development of microbiology as a science led to research by Buswell and others in the 1930s to identify anaerobic bacteria and the conditions that promote methane production. "Philip D. Lusk" <plusk@pipeline.com>

India, as one country with many biogas reactor installed, has a quite long history of biogas development. The first unit usually referred to in literature is the biogas unit at the Mantunga Homeless Lepers Asylum near to Mumbai. It could be discussed whether it should be called a biogas unit or not as the primary function seems to have been sewage treatment, but the gas was used so... Most refs date this plant to 1897. mathias.gustavsson@he.gu.se

I think you have the spelling of the place wrong - Matunga, rather than Mantunga..."Sircar, Sanjay" <Sanjay.Sircar@dcita.gov.au>

I thank Dr Sanjay Sircar for the following comments, also relating to the above item:
(a) there is an interesting potential area of investigation here, in relation to this biogas plant, on intersections between Western/colonial/Christian/Enlightenment science, progress and social emancipation on the one hand and Hindu "pollution" (both disease-related and Christianity-related);
(b) it is probably true to say that Indians generally do not know of this "first" for India (albeit a colonial-period first), possibly as a result of the vagaries of history compounded by current anti-Christian/Western sentiment. (9/9/02)

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). Refs Cheremisinoff, N. P., P. N. j. a. Cheremisinoff, et al. (c1980.). Biomass: applications, technology, and production. New York :, M. Dekker,. Lewis, C. (1983). Biological fuels. London:, Arnold,.
Luke Jenangi http://www.roseworthy.adelaide.edu.au/~pharris/biogas/project.pdf

The first sewage sludge digester was built in Exeter, UK around 1900. There is a reasonable history in "Anaerobic Digestion" 1979, Stafford Wheatly & Hughes. Prof Hughes always credited the Babylonians. I thought the first agricultural digester pioneer of recent times was L John Fry who welded oil drums together in Africa in the 1940's. Stephen Etheridge "EBL" <info@ebl.co.uk>

Uses of biogas

Biogas is best used directly for cooking/heating, light or even absorption refrigeration, rather than the complication and energy waste of trying to make electricity from biogas. You can also run pumps and equipment off a gas powered engine rather than using electricity.

Both spark ignition and diesel engines can use biogas. A spark ignition engine only needs a suitable carburettor to handle gas rather than liquid, but keep in mind that biogas will probably be supplied at a lower pressure than LPG and definitely CNG. As well as needing a gas carburettor a diesel engine requires at least 10% diesel to initiate combustion and to cool the injectors (so they will still work if you have to go back to liquid fuel).

Table 1 Biogas Equivalents

Biogas Equivalents				
Imperial (US)			**Metric**	
100	cubic feet of equals	biogas	2.8	cubic metres
		is equivalent to		
60	ft^3	natural gas	1.7	m^3
0.66	US gal	propane	2.5	litres
0.59	US gal	butane	2.2	litres
0.47	US gal	gasoline	1.8	litres
0.43	US gal	#2 fuel	1.6	litres
4.4	lb	bituminous coal	2.0	kg
10	lb	medium dry wood	4.5	kg

Anaerobic Digestion

Anaerobic digestion breaks down readily degradable organic matter in a series of steps, where the product of one step becomes the substrate for the next step. The initial step is usually considered to be “hydrolysis” – where extra cellular enzymes break complex organic molecules like fats and starches into simpler molecules like glucose. These simpler molecules are then utilised by “acetogenic” bacteria to produce acetic acid, with carbon dioxide as another product of the breakdown. “Methanogens” are then able to use the acetic acid and produce methane. There is also another group of “methanogens” that convert carbon dioxide to methane. As a result of these steps “biogas” is mainly methane (typically 60%, but less if the digester is not operating properly and sometimes up to about 80%) and carbon dioxide with traces of hydrogen sulphide, ammonia, water vapour, other organic volatiles and possibly some nitrogen gas.

Being a microbiological process the presence of any toxic or inhibitory substances will reduce, or possibly end, biogas production. Antibiotics are a potential problem, as are some cleaning chemicals and heavy metals.

One of the advantages of AD is that the process destroys a large proportion of pathogens that may be present in the waste, so reduces the risk of disease transmission.

Safety

There are a number of safety issues to be considered when working with a biogas system.

Fire/Explosion

Methane (CH_4), which is makes up from 0% to 80% of biogas, forms explosive mixtures in air, the lower explosive limit being 5% methane and the upper limit 15% methane. Biogas mixtures containing more than 50 % methane are combustible, while lower percentages may support, or fuel, combustion. With this in mind no naked flames should be used in the vicinity of a digester and electrical equipment must be of suitable quality, normally "explosion proof". Other sources of sparks are any iron or steel tools or other items, power tools (particularly commutators and brushes), normal electrical switches, mobile phones and static electricity.
If conducting a flammability test take a small sample well away from the main digester, or incorporate a flame trap (see below) in the supply line, which must be of suitable length (minimum 20 m).

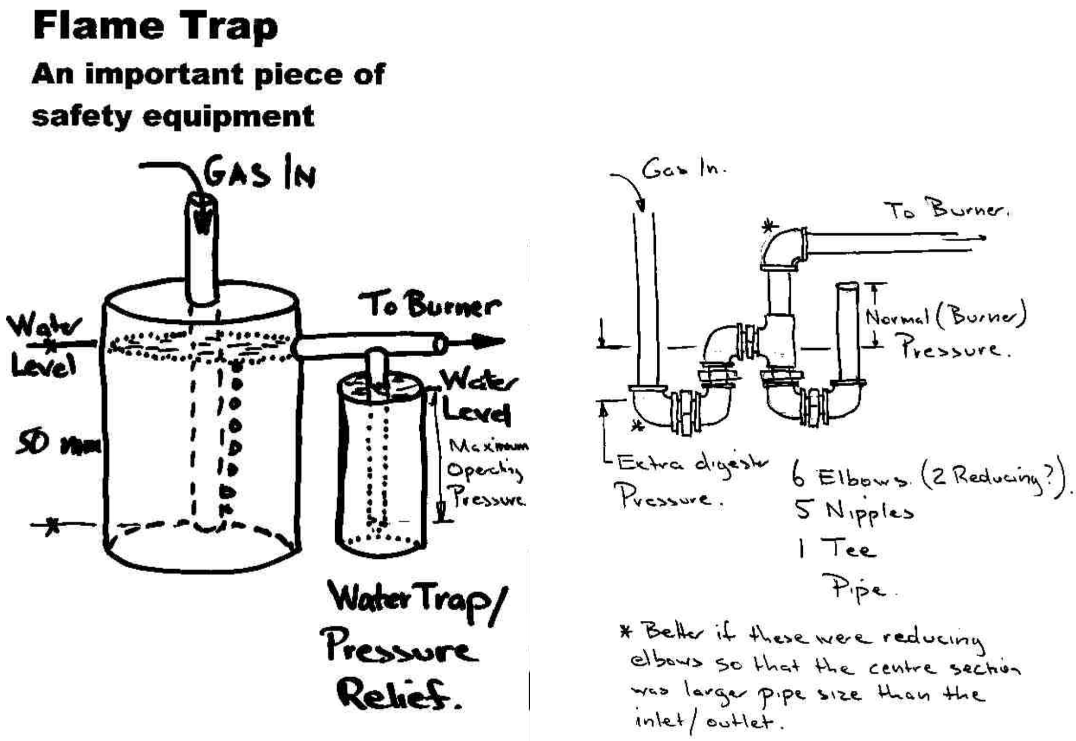


Figure 1 Two designs for a flame trap/backflow preventer.

Disease

As Anaerobic Digestion relies on a mixed population of bacteria of largely unknown origin, but often including animal wastes, to carry out the waste treatment process care should be taken to avoid contact with the digester contents and to wash thoroughly after working around the digester (and particularly before eating or drinking). This also helps to minimise the spread of odours that may accompany the digestion process. The digestion process does reduce the number of pathogenic (disease causing) bacteria, particularly at higher operating temperatures, but the biological nature of the process needs to be kept in mind.

Asphyxiation

As biogas displaces air it reduces the oxygen level, restricting respiration, so any digester area needs to be well ventilated to minimise the risks of fire/explosion and asphyxiation.

Biogas consists mainly of CH_4 and CO_2, with low levels of H_2S and other gases. Each of these components has it's own problems, as well as displacing oxygen.
CH_4 - lighter than air (will collect in roof spaces etc), explosive (see above).
CO_2 - heavier than air (will collect in sumps etc), slightly elevated levels affect respiration rate, higher levels displace oxygen as well.

H_2S - (rotten egg gas) destroys olfactory (smelling) tissues and lungs, becomes odourless as the level increases to dangerous and fatal.

H_2S - Hydrogen Sulphide

The odour threshold is a few parts per billion in air and it smells of bad eggs. However, at higher concentrations - 1-3ppm you may not smell it as H_2S numbs the olfactory nerves and effectively at these concentrations is odourless.

If the H_2S is above 3ppm it may cause you health problems. At 10ppm the law limits the exposure to 8 hours per day - and from experience you will feel terrible after this level of exposure. At 15ppm the law limits your exposure to 15 minutes per day.

At a few hundred ppm -H_2S in air you may pass out in less than an hour At a few thousands of ppm - H_2S in air you may die on contact with the gas as the nerves around the heart and lungs are paralysed.

H_2S when it enters the human body may split up to give a free HS (-) ion The HS (-) ion has the same destructive reaction in the body as CN = cyanide. Just think of H2S as a gas which may have the same consequences as cyanide and you get the general picture.

H_2S detectors are available on most sewage works sites and you might like to borrow one.

Les. Gornall, Director, Practically Green Environmental Services

Summary

Adequate ventilation, suitable precautions and adequate protective equipment will minimise the dangers associated with biogas, making it a good servant rather than a bad master.

Like water, electricity, automobiles and most of life biogas is not completely safe, but by being aware of the dangers involved you are well on the way to a safe and happy digestion experience.

Uses for liquid/sludge

As anaerobic digestion is not a method of “waste disposal” but a “primary” treatment method the amount of material out of the digester is almost equal to the amount in, but the properties do change. In fact only carbon, oxygen and hydrogen leave via the gas stream in any quantity and each cubic metre of gas removes less than two kilograms of mass, so all the other nutrients remain in the liquid/sludge.

Soluble elements like potassium and nitrogen are found mainly in the liquid phase, along with fine suspended particles, but larger particles and less soluble elements such as potassium remain largely in the sludge. The anaerobic treatment process tends to break down a lot of the finer material, so the treated solids are free draining. It also makes a lot of the elements more plant available and less likely to cause damage when applied to vegetation.

This means that the output of a digester is a good source of nutrients for plants and there are papers showing better performance for AD fertilised plants compared to synthetic fertilisers or raw manure. Digester output can also be used in aquatic systems as well as land based systems and is safer for those involved in working in the field.

Digester performance

When looking at an anaerobic digester as a biogas production unit the performance depends on the type of waste used, the amount of Volatile Solids (VS) put in per day, the operating temperature (T) and the Retention Time (RT). Since VS reduction is directly related to both biogas production and Chemical/Biological Oxygen Demand (the pollution load) the same variables apply to the digester as a pollution treatment unit anyway.

A number of publications recommend 35 °C as the optimum temperature and most designers aim for maximum gas per unit volume of digester (high rate designs to minimise digester size/cost), but digesters operate quite well at lower temperatures and longer retention times also give better gas production. The two diagrams below, based on a model proposed by Chen (1983) illustrate this.

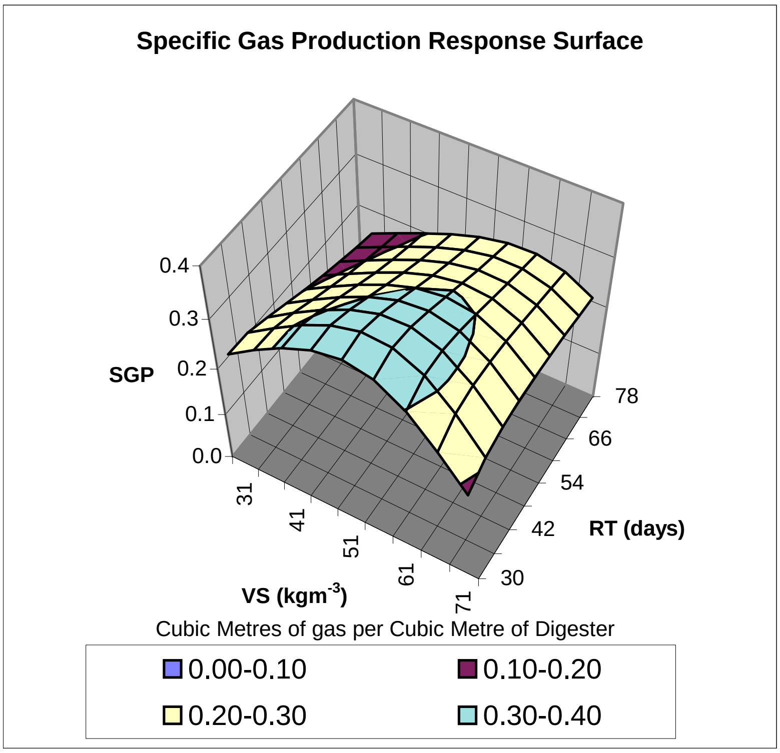


Figure 2 Gas production per unit digester volume at 15 °C (piggery waste)

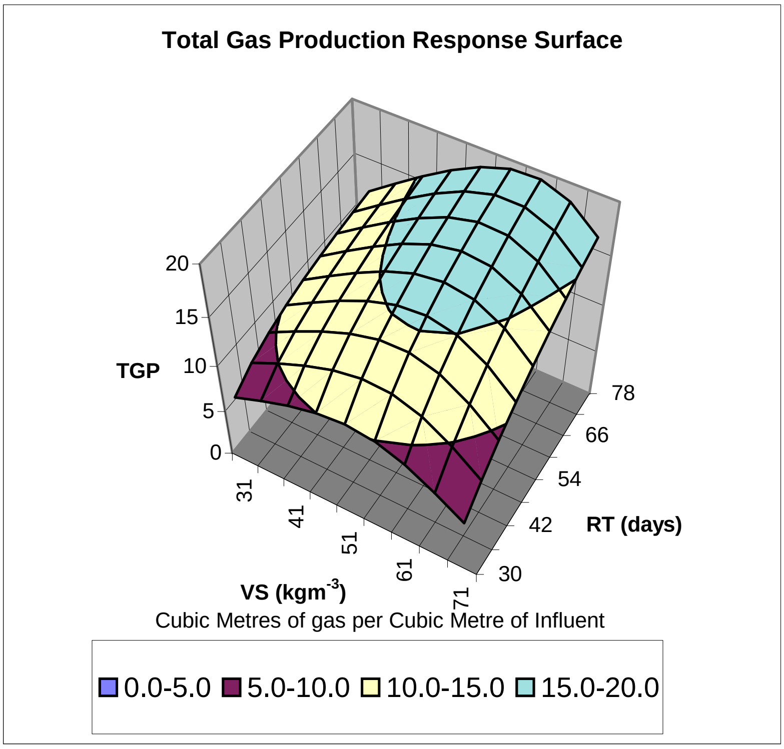


Figure 3 Gas production per unit effluent added at 15 °C (piggery waste)

This model has been incorporated into simple equations and a set of tables so you don’t have to have a computer to work out what is likely to happen.

As the example shows, once you know the type of waste you are going to treat you can look up the Bo value and how much waste each animal will produce per day. The dilution factor, normally 2-4, will then give you the Volatile Solids value to use for your waste type.

You then use the digester Operating Temperature to determine the Retention Time to use – based on the “Safety Factor”, which is suggested should be 3 or more. The combination of VS and Safety Factor (from above) then result in a Konst that is used in the SBP equation to give Biogas per unit digester volume (the Specific Biogas Production). Once SBP is known you can calculate Biogas per day and Digester Volume.

As a guide you will need about 400 litres of biogas per person per day for cooking, so now it is possible to calculate what size digester you need and how much waste will have to be collected to cook for the family building the digester, using information from the Tables below.

Waste Required = Design Biogas /[**SBP** X (**dilution** + 1) X **RT**]

Digester Volume = Waste Required X (**dilution** + 1) X **RT**

Biogas Tables

Table 2 Biogas Tables - Part 1

Biogas Tables © Paul Harris, October 2006 Version 1.0

Chen, Y.R. "Kinetic Analysis of Anaerobic Digestion of Pig Manure and its Design Implications" Ag Wastes 8 (1983) 65-81

If VS is measured in grammes and waste is measured in kg -

Specific Biogas Production = Bo X VS X Konst / RT (l/digester/day)

(assumes 60% methane)

Tot. Biogas = SBP X Waste X (dilution + 1) X RT (l/day)

Table 1

			Optimum	Optimum	Waste/Animal		VS for different Dilutions (extra water added to scraped manure)				
Waste Type	Bo	Source	Dilution	VS	Tot. kg/day	VS g/day	0	1	2	4	6
Dairy	0.2	Hill, DT. Trans ASAE v25 pp226 (1982)	1.2	53	40	5000	120	60	40	20	20
Beef	0.35	Hill, DT. Trans ASAE v25 pp226 (1982)	1.2	56	30	4000	120	60	40	20	20
Piggery	0.45	Hill, DT. Trans ASAE v25 pp226 (1982)	1	51	6	600	100	50	30	20	10
Broiler	0.39	Hill, DT. Trans ASAE v25 pp226 (1982)	2.5	57	0.2	40	200	100	70	40	30
Municipal Refus	0.2	Chen Y.R.& Hashimoto A.G. Biotech & Bioeng Symp									
Sewerage Slud	0.406	Chen Y.R.& Hashimoto A.G. Biotech & Bioeng Symp									

Table 2

	Safety Factor	2	3	5	1
Temperature (°C)	GrwthRt (day^{-1})	MaxSGP RT (days)	RecomRT (days)	Long RT (days)	Min RT (days)
6	0.023	88	133	221	44
8	0.028	72	108	180	36
10	0.034	59	88	147	29
12	0.042	48	72	120	24
14	0.051	39	59	98	20
16	0.062	32	48	80	16
18	0.076	26	39	66	13
20	0.093	22	32	54	11
25	0.150	13	20	33	6.66
30	0.233	8.6	13	21	4.29
35	0.336	6.0	8.9	15	2.98
40	0.434	4.6	6.9	12	2.30
45	0.502	4.0	6.0	10	1.99

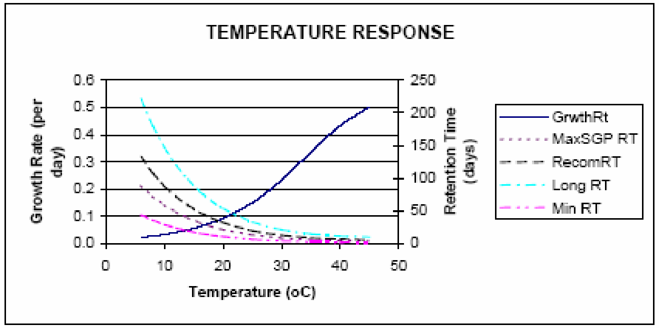
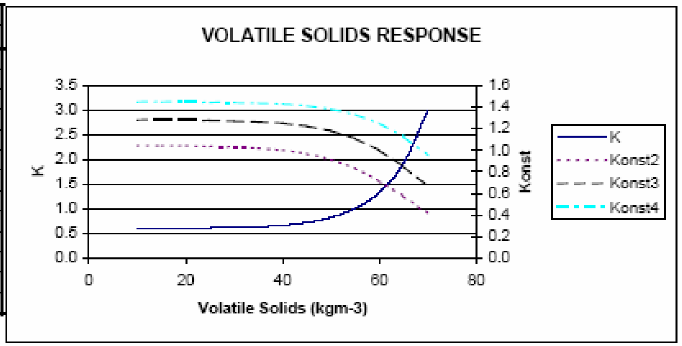


Table 3 Biogas Tables - Part 2

Volatile Solids (kgm^{-3})	K	Konst2	**Konst3**	Konst4	Konst1
10	0.602	1.041	**1.281**	1.449	0.000
15	0.604	1.040	**1.281**	1.448	0.000
20	0.606	1.038	**1.279**	1.448	0.000
25	0.612	1.034	**1.277**	1.446	0.000
30	0.621	1.028	**1.272**	1.443	0.000
35	0.638	1.018	**1.264**	1.438	0.000
40	0.669	0.999	**1.249**	1.428	0.000
45	0.724	0.967	**1.224**	1.411	0.000
50	0.825	0.914	**1.180**	1.382	0.000
55	1.006	0.831	**1.109**	1.332	0.000
60	1.334	0.714	**1.000**	1.250	0.000
65	1.928	0.569	**0.849**	1.125	0.000
70	3.002	0.417	**0.666**	0.952	0.000



Example

If waste from one pig is being diluted with two volumes of water
and treated at 15 C how much biogas is expected?

Bo = 0.45, VS will be about 30 kg/m^3 and 6 kg of manure will be treated per day.
Recommended Retention time is about 54 days and Konst3 = 1.272

SBiogasP = Bo X **VS** X **Konst / RT**
SBP = 0.45*30*1.272/54
= 0.32 cubic metres biogas per cubic metre digester per day

Tot. Biogas = SBP X **Waste** X (**dilution +** 1) X **RT**
Tot. Biogas = 0.32*6*3*54 (waste in kg or litres)
= 309 litres of biogas per day

Digester Vol = Waste Required X (**dilution +** 1) X **RT**

EQUATIONS

Growth Rate = 0.566*(1+1110*e^(-1*0.187*temp))^(1/(1-2.83))

Retention time = Safety Factor/Growth Rate

K = 0.6+0.0006*e^(0.1185*Volatile Solids)

Konst = 1.667*(1-K/(Safety Factor-1+K))

Note:-
Each kg VS destroyed in the digester gives 500 litres of methane

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Types of Digesters

Digesters can come in all types, shapes and sizes. The common versions for small-scale rural use are the Indian “floating drum” type and the Chinese “fixed dome” type, both of which have many thousands of installations. The “poly plug flow” design is a relative newcomer but is widely used in several countries, due largely to the work of Dr Reg Preston.

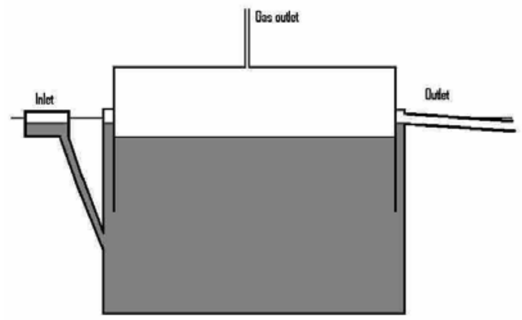

Figure 4 Indian type digester

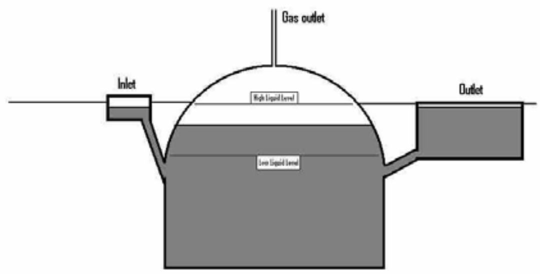

Figure 5 Chinese type digester

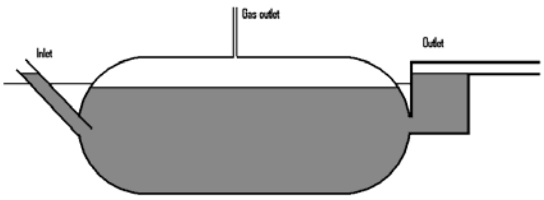

Figure 6 Plug Flow digester

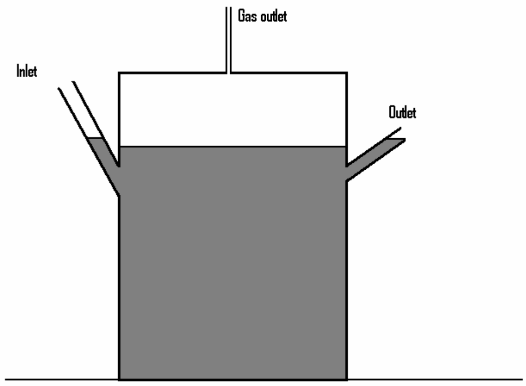

Figure 7 CFST type digester

The next level up is a Continuous Flow Stirred Tank (CFST) digester and then you get into Upflow Anaerobic Sludge Blanket (UASB) and packed bed digesters as well as anaerobic filters, but these are more suitable for high rate industrial applications and usually have heating and possibly stirring devices.

Construction Tips

As well as the obvious things to look out for, such as avoiding punctures/leaks and having the inlet higher than the outlet, there are a few other things to watch. One of the most important is to have gas lines laid on a fall with a drain point in the low spot, to allow any condensation to get out of the way of gas flow. When building a plug flow poly digester you also have to make sure the digester body at both the inlet and outlet projects far enough below liquid operating level to hold in the gas pressure (but not too much further, so they provide extra over pressure protection) and that the gas outlet will remain above liquid level, even when there is no gas pressure. There are some notes from the first Biogas Course in Appendix 1.

The “flametrap” design given in the Safety Section also acts as a pressure relief, drain point (more so if installed at a low point) and backflow preventer, which is useful for stopping the burner supply pressure pushing liquid out of the digester while using the biogas, if a separate gas storage with variable weight is used.

Startup

Starting an anaerobic digester is relatively easy if a few points are kept in mind.

1. You need to have the appropriate bacteria present. In cattle and pig waste there are usually the right bacteria but poultry waste and vegetable waste may need inoculation, so you may have to start with cattle or pig manure and gradually introduce the other waste form.
2. Startup will be slow. The actual process is fairly slow and proceeds in a series of steps, just like AD itself. First the oxygen in headspace air has to be used up to get anaerobic conditions, so the first gas collected will be carbon dioxide (which will extinguish a flame). Acetogenesis then generates more CO_2 and acetic acid, so if this stage gets too advanced methanogenesis can be inhibited. Once there is some acetic acid methanogenesis can start, but of course some initial bacteria must be present.
3. Any sudden changes can upset the process. If you need to change the amount of waste added per day, the concentration or the type of waste it is better to make the change gradual so the bacterial population has time to adjust. While the change is underway monitor gas quality (see Monitoring), as a drop in quality (more CO_2 and/or less CH_4) is often the first indication of possible digester failure. If the gas quality does deteriorate it is best to stop feeding and give the digester a chance to recover.

The preferred way to start a digester is to part fill with water (so you can check operation and make any alterations necessary without having to deal with effluent) and then put in half the working volume of dairy or piggery effluent (or active digester sludge if available). Wait until the digester is producing flammable gas, which may take a few weeks if temperatures are cool, before starting feeding at half the design rate. Once operation has settled down increase to full rate, still using the initial waste and wait for operation to settle down again. If you want to use different waste use a 50/50 mix for at least one retention time before changing over completely, again monitor the digester performance and wait until you are satisfied that the operation has adjusted before making any further change.

Monitoring Digester Operation

One of the best indicators of proper digester operation is that the gas volume produced per day is consistent with the waste input and that the gas will support combustion (which indicates at least 50% methane).

As the digester is a well buffered system a simple pH measurement will really only tell you that the digester is in trouble, usually well after the gas quality/volume has dropped.

A syringe body fitted with some flexible tube and some dilute sodium hydroxide solution can be used to estimate carbon dioxide percentage, as NaOH absorbs CO_2 but not methane. Draw up 20-30 ml of biogas and put the end of the tube into the NaOH solution, then push out excess gas to get a 10 ml gas sample (you have to allow for the gas in the tube, which may be 4-5 ml). Now draw up approximately 20 ml of solution and keep the end of the tube submerged while you shake the syringe for 30 seconds. Point the syringe downwards and push out excess liquid, so the syringe plunger reaches 10 ml. Now read the volume of liquid, which should be 3-4 ml indicating about 30-40% of gas absorbed so we assume the balance is methane. If you get over 50% methane (a reading of less than 5 ml of liquid) and the flame will still not burn properly you must have nitrogen or some other gas present.

To measure pressure in a digester simply put a clear plastic tube into a container of water (a glass container is easiest) and connect the tube to the digester gas line. The digester pressure will push down the water surface in the tube and the difference between inside and outside levels is known as "water gauge". If the pressure is too great gas will bubble out the bottom of the tube. You can also make a "manometer" by bending a plastic tube into a U and putting water in – when one end is connected to the gas line and the other is open to atmosphere (you may need to restrict this to a small hole so the levels settle quickly) you can measure the difference in water heights.

Gas Storage

The digester itself provides the simplest gas storage, but supply pressure will fall as gas is used. You may need some weights to place on the digester to develop more pressure, but be careful of puncturing the digester body. If the use is a fair way from the digester better burner performance may be obtained by having a separate Gas storage near the use point. This can be either a flexible, gas tight bag or a floating drum type storage. With the second storage it is a good idea to allow low pressure collection of the gas (to minimise the possibility of gas leaks) and to use weight to increase pressure during burner operation, but you need the "back flow preventer" to make best use of this.

The storage should be sized to hold one day's use of gas if possible, which should be as closely matched as possible to digester gas production. If production does exceed use then any excess gas needs to be flared, as the methane in biogas is about 23 times worse as a greenhouse gas than carbon dioxide produced during combustion.

Burners

Satisfactory burner operation is obtained when the flame is large enough to heat the item fairly quickly but is stable – in other words the flame "attaches" to the burner.

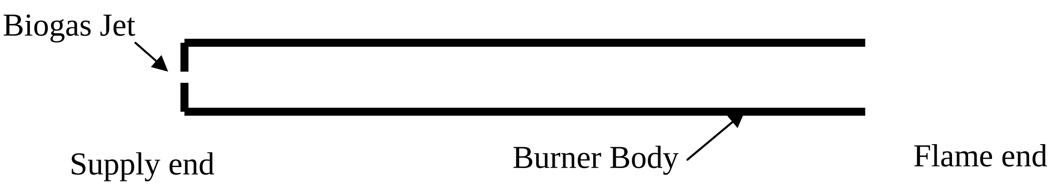

Figure 8 Simple Diffusion Burner

Flame size is set by the combination of gas jet size and operating pressure, which set the gas flow rate. At low operating pressures a larger jet is required to give reasonable gas flow. For a given jet size, as pressure is increased the gas flow rate increases and so does the flame vigour – until the flame "blows out". If the operating pressure is causing "blow out" the actual burner opening needs to be bigger for the same jet size, as this will reduce the gas exit velocity so the flame will stay attached. Of course if you use a larger jet, allowing more gas flow, you may need a larger burner opening as well and the mixer length must be enough to allow the velocity to drop off.

For the scientifically minded combustion of biogas is basically the combination of a methane molecule (which has one carbon and four hydrogen atoms) with two oxygen molecules (each with two oxygen atoms) to form a carbon dioxide molecule and two water molecules (ignoring all the trace gases). This can be written as

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

A simple “diffusion” type burner will work satisfactorily provided the gas velocity is not too high. This is achieved by restricting the biogas flow rate through a small opening and letting the gas exit through a larger diameter metal (or ceramic) tube. I have found that a 1/16” jet and a 7/16” body work quite well, so 1/8” and 7/8”, 3/16”and 1¼”, ¼”and 1¾”, 5/16” and 2¼” and 3/8” and 2 ½” combinations should all work just as well at 2 cm water gauge. The “Areas of Circles” Tables below are meant to make this sort of calculation easier.

Commercial burners are “premixed” type and will work very well with biogas provided the gas jet is sized for the lower supply pressure. See Appendix 2 for Burner Design.

Fault Finding

Possible faults will be minimised by careful construction initially and regular checking as part of a routine – you are dealing with a living system that does need some care and attention, just like plants and animals.

As with all fault finding try the easy things first and try to work by elimination.

If there is a loss of pressure check that there is water in any water traps and that all hoses are connected and outlet taps are off. Then look for damage to the digester and gas holder (if separate). Use soapy water to check for possible gas leaks. If there are no obvious leaks isolate the digester (if you do not use a backflow preventer) – if the digester inflates over the next few days there is a leak in the gasholder section, if not you need to look at the digester system.

If no leaks are present think about how much gas has been used and what has been put into the digester – possibly do a check on gas quality.

Poor burner operation may be caused by low supply pressure or poor gas quality.

Low pressure may result from insufficient weight on the gas storage or damaged/blocked supply lines. If the supply line has not been installed properly on a grade with a drain at the lowest point water may have collected and be restricting gas flow.

Areas of Circles

Table 4 Areas of Circles (metric)

Diameter	(mm)	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20	22	24	26	28	30	35	40	45	50	55	60
	1/16"	0.6	1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.7	6.3	6.9	7.6	8.8	10.1	11.3	12.6	13.9	15.1	16.4	17.6	18.9	22.0	25.2	28.3	31.5	34.6	37.8
(mm)	Area	0.8	3.1	7.1	12.6	19.6	28.3	38.5	50.3	63.6	78.5	95.0	113.1	153.9	201.1	254.5	314.2	380.1	452.4	530.9	615.8	706.9	962.1	1256.6	1590.4	1963.5	2375.8	2827.4
															Number of holes													
1	0.8	1.0	4.0	9.0	16.0	25.0	36.0	49.0	64.0	81.0	100.0	121.0	144.0	196.0	256.0	324.0	400.0	484.0	576.0	676.0	784.0	900.0	1225.0	1600.0	2025.0	2500.0	3025.0	3600.0
2	3.1		1.0	2.3	4.0	6.3	9.0	12.3	16.0	20.3	25.0	30.3	36.0	49.0	64.0	81.0	100.0	121.0	144.0	169.0	196.0	225.0	306.3	400.0	506.3	625.0	756.3	900.0
3	7.1			1.0	1.8	2.8	4.0	5.4	7.1	9.0	11.1	13.4	16.0	21.8	28.4	36.0	44.4	53.8	64.0	75.1	87.1	100.0	136.1	177.8	225.0	277.8	336.1	400.0
4	12.6				1.0	1.6	2.3	3.1	4.0	5.1	6.3	7.6	9.0	12.3	16.0	20.3	25.0	30.3	36.0	42.3	49.0	56.3	76.6	100.0	126.6	156.3	189.1	225.0
5	19.6					1.0	1.4	2.0	2.6	3.2	4.0	4.8	5.8	7.8	10.2	13.0	16.0	19.4	23.0	27.0	31.4	36.0	49.0	64.0	81.0	100.0	121.0	144.0
6	28.3						1.0	1.4	1.8	2.3	2.8	3.4	4.0	5.4	7.1	9.0	11.1	13.4	16.0	18.8	21.8	25.0	34.0	44.4	56.3	69.4	84.0	100.0
7	38.5							1.0	1.3	1.7	2.0	2.5	2.9	4.0	5.2	6.6	8.2	9.9	11.8	13.8	16.0	18.4	25.0	32.7	41.3	51.0	61.7	73.5
8	50.3								1.0	1.3	1.6	1.9	2.3	3.1	4.0	5.1	6.3	7.6	9.0	10.6	12.3	14.1	19.1	25.0	31.6	39.1	47.3	56.3
9	63.6									1.0	1.2	1.5	1.8	2.4	3.2	4.0	4.9	6.0	7.1	8.3	9.7	11.1	15.1	19.8	25.0	30.9	37.3	44.4
10	78.5										1.0	1.2	1.4	2.0	2.6	3.2	4.0	4.8	5.8	6.8	7.8	9.0	12.3	16.0	20.3	25.0	30.3	36.0
11	95.0											1.0	1.2	1.6	2.1	2.7	3.3	4.0	4.8	5.6	6.5	7.4	10.1	13.2	16.7	20.7	25.0	29.8
12	113.1												1.0	1.4	1.8	2.3	2.8	3.4	4.0	4.7	5.4	6.3	8.5	11.1	14.1	17.4	21.0	25.0
14	153.9													1.0	1.3	1.7	2.0	2.5	2.9	3.4	4.0	4.6	6.3	8.2	10.3	12.6	15.4	18.4
16	201.1														1.0	1.3	1.6	1.9	2.3	2.6	3.1	3.5	4.8	6.3	7.9	9.8	11.8	14.1
18	254.5															1.0	1.2	1.5	1.8	2.1	2.4	2.8	3.8	4.9	6.3	7.7	9.3	11.1
20	314.2																1.0	1.2	1.4	1.7	2.0	2.3	3.1	4.0	5.1	6.3	7.6	9.0
22	380.1																	1.0	1.2	1.4	1.6	1.9	2.5	3.3	4.2	5.2	6.3	7.4
24	452.4																		1.0	1.2	1.4	1.6	2.1	2.8	3.5	4.3	5.3	6.3
26	530.9																			1.0	1.2	1.3	1.8	2.4	3.0	3.7	4.5	5.3
28	615.8		Fractional inch		1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16		1.0	1.1	1.6	2.0	2.6	3.2	3.9	4.6
30	706.9		Decimal inch		0.0625	0.125	0.1875	0.25	0.3125	0.375	0.4375	0.5	0.5625	0.625	0.6875	0.75	0.8125	0.875	0.9375			1.0	1.4	1.8	2.3	2.8	3.4	4.0
35	962.1		Millimetres		1.59	3.18	4.76	6.35	7.94	9.53	11.11	12.70	14.29	15.88	17.46	19.05	20.64	22.23	23.81				1.0	1.3	1.7	2.0	2.5	2.9
40	1256.6																							1.0	1.3	1.6	1.9	2.3
45	1590.4																								1.0	1.2	1.5	1.8
50	1963.5																									1.0	1.2	1.4
55	2375.8																										1.0	1.2
60	2827.4																											1.0

Table 5 Areas of Circles (imperial)

Areas of Circles IMPERIAL

	Diameter	(inch)	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2
		(inch)	0.0625	0.125	0.1875	0.25	0.3125	0.375	0.4375	0.5	0.5625	0.625	0.6875	0.75	0.8125	0.875	0.9375	1	1.25	1.5	1.75	2	2.25	2.5
		(mm)	1.6	3.2	4.8	6.4	7.9	9.5	11.1	12.7	14.3	15.9	17.5	19.1	20.6	22.2	23.8	25.4	31.8	38.1	44.5	50.8	57.2	63.5
(inch)	(inch)	Area	0.003	0.012	0.028	0.049	0.077	0.110	0.150	0.196	0.249	0.307	0.371	0.442	0.518	0.601	0.690	0.785	1.227	1.767	2.405	3.142	3.976	4.909
													Number of holes											
1/16	0.0625	0.003	1.0	4.0	9.0	16.0	25.0	36.0	49.0	64.0	81.0	100.0	121.0	144.0	169.0	196.0	225.0	256.0	400.0	576.0	784.0	1024.0	1296.0	1600.0
1/8	0.125	0.012		1.0	2.3	4.0	6.3	9.0	12.3	16.0	20.3	25.0	30.3	36.0	42.3	49.0	56.3	64.0	100.0	144.0	196.0	256.0	324.0	400.0
3/16	0.1875	0.028			1.0	1.8	2.8	4.0	5.4	7.1	9.0	11.1	13.4	16.0	18.8	21.8	25.0	28.4	44.4	64.0	87.1	113.8	144.0	177.8
1/4	0.25	0.049				1.0	1.6	2.3	3.1	4.0	5.1	6.3	7.6	9.0	10.6	12.3	14.1	16.0	25.0	36.0	49.0	64.0	81.0	100.0
5/16	0.3125	0.077					1.0	1.4	2.0	2.6	3.2	4.0	4.8	5.8	6.8	7.8	9.0	10.2	16.0	23.0	31.4	41.0	51.8	64.0
3/8	0.375	0.110						1.0	1.4	1.8	2.3	2.8	3.4	4.0	4.7	5.4	6.3	7.1	11.1	16.0	21.8	28.4	36.0	44.4
7/16	0.4375	0.150							1.0	1.3	1.7	2.0	2.5	2.9	3.4	4.0	4.6	5.2	8.2	11.8	16.0	20.9	26.4	32.7
1/2	0.5	0.196								1.0	1.3	1.6	1.9	2.3	2.6	3.1	3.5	4.0	6.3	9.0	12.3	16.0	20.3	25.0
9/16	0.5625	0.249									1.0	1.2	1.5	1.8	2.1	2.4	2.8	3.2	4.9	7.1	9.7	12.6	16.0	19.8
5/8	0.625	0.307										1.0	1.2	1.4	1.7	2.0	2.3	2.6	4.0	5.8	7.8	10.2	13.0	16.0
11/16	0.6875	0.371											1.0	1.2	1.4	1.6	1.9	2.1	3.3	4.8	6.5	8.5	10.7	13.2
3/4	0.75	0.442												1.0	1.2	1.4	1.6	1.8	2.8	4.0	5.4	7.1	9.0	11.1
13/16	0.8125	0.518													1.0	1.2	1.3	1.5	2.4	3.4	4.6	6.1	7.7	9.5
7/8	0.875	0.601														1.0	1.1	1.3	2.0	2.9	4.0	5.2	6.6	8.2
15/16	0.9375	0.690															1.0	1.1	1.8	2.6	3.5	4.6	5.8	7.1
1	1	0.785																1.0	1.6	2.3	3.1	4.0	5.1	6.3
1 1/4	1.25	1.227																	1.0	1.4	2.0	2.6	3.2	4.0
1 1/2	1.5	1.767																		1.0	1.4	1.8	2.3	2.8
1 3/4	1.75	2.405																			1.0	1.3	1.7	2.0
2	2	3.142			Fractional Inch	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16		1.0	1.3	1.6
2 1/4	2.25	3.976			Decimal Inch	0.0625	0.125	0.1875	0.25	0.3125	0.375	0.4375	0.5	0.5625	0.625	0.6875	0.75	0.8125	0.875	0.9375			1.0	1.2
2 1/2	2.5	4.909			Millimetres	1.59	3.18	4.76	6.35	7.94	9.53	11.11	12.70	14.29	15.88	17.46	19.05	20.64	22.23	23.81				1.0

Further Information

Books

AUTHOR Meynell, P.J.
TITLE Methane: planning a digester
PUBLISHED Dorchester, UK, Prism press, 1982

AUTHOR Fry, L. John
TITLE Practical Building of Methane Power Plants for rural energy independence
PUBLISHED Andover (Staddlestones, Penton Mewsey, Andover, Hants. SP11 0RQ) : D.A. Knox, 1974.

AUTHOR Spargo, Raymond F.
TITLE Methane CH4, the replaceable energy
PUBLISHED Tomerong, N.S.W : Australian Methane Gas Research, 1979
also
TITLE Methane: the eternal flame

AUTHOR Hobson, P. N.and Andrew D. Wheatley
TITLE Anaerobic digestion : modern theory and practice
PUBLISHED London ; New York : Elsevier Applied Science, c1993

Author: Fulford, David
TITLE Running a biogas programme : a handbook
PUBLISHED Intermediate Technology Publications, 1988

Electronic Sources

http://www.adelaide.edu.au/biogas/
http://www.tve.org/ho/doc.cfm?aid=555
http://www.angelfire.com/mac/egmatthews/biogas/index.html (The actual site is good BUT you get "Popups" here!)
http://www.practicallygreen.com/

and MANY more!

References

Chen, Y. R. (1983). "Kinetic Analysis of Anaerobic Digestion of Pig Manure and its Design Implications." Agricultural Wastes **8**: 65-81.

Fulford, D. (1988). Running a Biogas Programme: A Handbook, Intermediate Technology Publications.

Appendix 1 – Notes from the First Course in Bamenda.

Making the Poly Digester!

Remember that the plastic film is fairly easy to puncture, so try to work on a smooth surface, be careful not to fold the plastic too much and don't put anything hard on the sheet.

Challenge – Gas outlet needs to be nearer the inlet!
Remedy – While working "inside" seal "outlet end" and inflate tube (using a "poly bag" to push air in through the inlet, an air compressor or a motorbike exhaust – but have a long hose so the exhaust can cool!), before putting in the gas outlet. Then we can get the orientation right and see where the folds are to make it easier to put in the outlet gas in one of the folds.

Challenge – Positioning the digester tube in the trench and digging the "gas outlet hole".
Now we can just lay the digester in the trench, after it is reinflated, to see where to put the "gas outlet hole". Use a flexible tube to close both ends of the "tee" and tape some plastic over the inlet to keep the air in (the "outlet" is still sealed).

Challenge – Filling the digester.
Remedy – Once the inflated digester is properly located in the trench <u>set up the outlet tube in its water container</u>. Put in about half the proposed operating volume of water through the outlet - it can be unsealed, but hold/tape the plastic around the hose to keep in the air pressure, excess air will bubble out the "safety valve.

Challenge – Setting the outlet level.
Remedy – When the digester is half full place the "outlet stick" so that it just touches the water surface and adjust the outlet level to 2-5 cm below the top of the gas outlet pipe

Challenge – Using the gas.
Remedy – A long pipe can be attached to the tee so gas can be used at a convenient location. If you have a long (10 m or more) gas line make a "storage bag" and put this near the kitchen with a "backflow preventer" between the digester and the storage bag.

Note:
It would be easier to use the same size plastic tube for both the inner and outer bag.

Feeding the Poly Digester!

Challenge – Getting the amount of manure right!
Remedy – Use the Biogas Tables to work out how much of each type of manure can be fed.

As this will take you some time I provide the following as a guide (you should check my computers calculations!).

Table 6 Feeding Recommendations

Waste Type	Recommended			
	Mass	RT	Dilution	Gas
Beef	1.7 kg (1/20)	53	1.5	90 l
Poultry	1 kg (8)	53	3	90 l
Pig	2 kg (1/3)	53	1	90 l
	Maximum			
Beef	2.6 kg	33	1.5	97
Poultry	1.7 kg	33	3	110
Pig	3.5 kg	33	1	140

Note : This table is based on a 200 litre digester at 15 °C.

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Appendix 2 – Burner Design

To design a burner you need to know the **output power** you want to develop and the **supply pressure** available. To help decide the power keep in mind that 1 kW will boil one litre of water in about 6 minutes (depending on starting temperature and altitude!). As a starting point for supply pressure poly bag digesters typically operate at 2-3 cm of water, but it is possible to have higher supply pressures if necessary. Larger jet size will compensate for low pressures and there will be less leakage problems, so why use high pressure anyway?

This design method and most of the assumptions are based on "Running a Biogas Programme: A handbook" by David Fulford, published by Intermediate Technology Publications, London, 1988.

Because nothing is 100% efficient you always need more gas power than the appliance will put out. Fulford uses a stove efficiency of 55%, but I estimate the setup I use is only about 30% efficient – I hope to have better data soon. It is always better to use a lower efficiency if you are not sure, as you can always reduce the supply pressure by closing the tap a bit and find uses for extra biogas but it may be difficult to develop more pressure or find more biogas if you estimate too high.

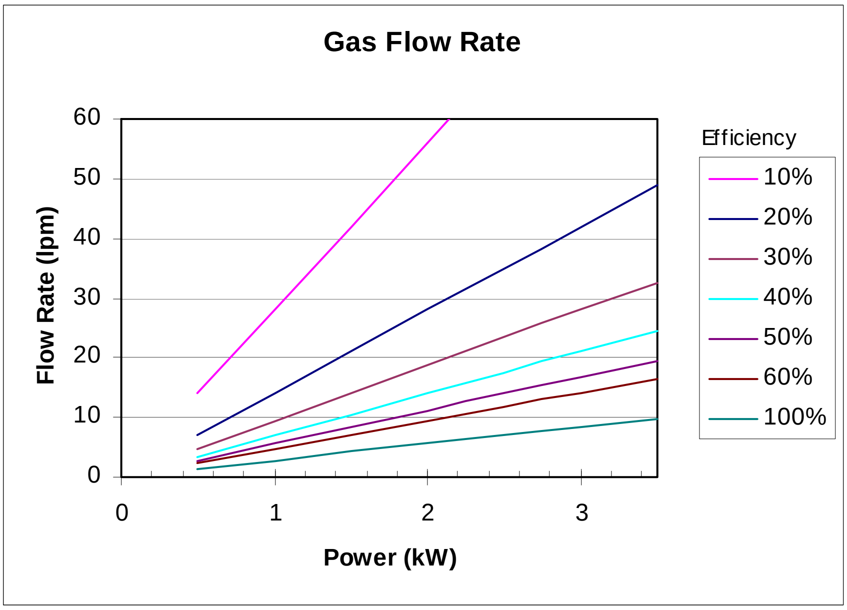
The equations used to set up the tables are :-

$H = 39000 * Cd * Ao * W * \sqrt{p}$ where H is the burner power (kW)
Cd is the Discharge Coefficient (= 0.73)
Ao is the Jet Area (m^2)
W is the Wobbe Number for Biogas (= 22.2 kJ/l)
and p is the Supply Pressure (mm WG)

and
Efficiency = Power Out / Power In * 100

Table 7 Gas Flow Rate Required (Litres per minute lpm)

Power Required (kW)	0.5	**1**	1.5	2	2.5	3	3.5
Efficiency \ (W)	500	1000	1500	2000	2500	3000	3500
10%	14.0	28.0	42.0	56.0	70.0	84.0	98.0
20%	7.0	14.0	21.0	28.0	35.0	42.0	49.0
30%	4.7	9.3	14.0	18.7	23.3	28.0	32.7
40%	3.5	7.0	10.5	14.0	17.5	21.0	24.5
50%	2.8	**5.6**	8.4	11.2	14.0	16.8	19.6
60%	2.3	4.7	7.0	9.3	11.7	14.0	16.3
70%	2.0	4.0	6.0	8.0	10.0	12.0	14.0
80%	1.8	3.5	5.3	7.0	8.8	10.5	12.3
90%	1.6	3.1	4.7	6.2	7.8	9.3	10.9
100%	1.4	2.8	4.2	5.6	7.0	8.4	9.8



Graph 1 Gas Flow Rate Required (Litres per minute lpm)

For example to get 1 kW out of a stove that is 50% efficient you need 5.6 lpm of biogas.

Once you know the Power and Pressure values the Table or Graph below are used to find the required jet size by finding the Operating Pressure ("WG or mm) in the appropriate column on the left of Table 2 and then following across that line until you get to the Flow Rate in the first part of the procedure. On the graph the jet size is found from the intersection of the Supply Pressure and the required Flow Rate.

The tables are based on the equation :-

$Ao = Q / (3.9 * Cd * \sqrt{(p/s)} * 60000$ where Ao is the Jet Area (m^2)
Q is the Biogas Flow Rate (lpm)
Cd is the Discharge Coefficient (= 0.73)
p is the Supply Pressure (mm WG)
and s is the Biogas SG (= 0.94)

and then
$d = \sqrt{(Ao * 4 / \pi)} * 1000$ where d is the Jet Diameter (mm)
and $\pi = 3.412$ or 22/7

Table 8 Jet Diameter (mm or ")

Burner Jet Calculation

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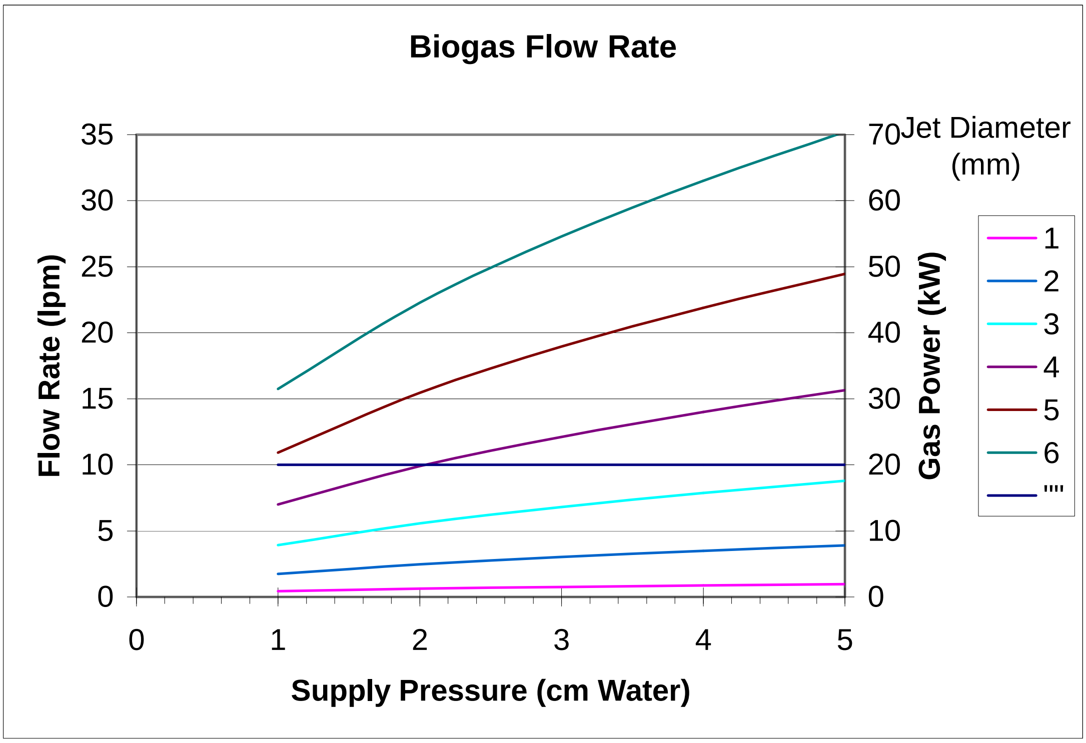
Gas Flow Rate (lpm) (for different jets and supply pressures)

	Dia. (“)			1/8"			1/4"
Pressure	Dia. (mm)	1	2	3	4	5	6
1/2"	1	0.4	1.8	3.9	7.0	10.9	15.8
	2	0.6	2.5	**5.6**	9.9	15.5	22.3
	3	0.8	3.0	6.8	12.1	18.9	27.3
	4	0.9	3.5	7.9	14.0	21.9	31.5
2"	5	1.0	3.9	8.8	15.7	24.5	35.2
	6	1.1	4.3	9.6	17.1	26.8	38.6
	7	1.2	4.6	10.4	18.5	28.9	41.7
	8	1.2	5.0	11.1	19.8	30.9	44.6
	9	1.3	5.3	11.8	21.0	32.8	47.3
4"	10	1.4	5.5	12.5	22.1	34.6	49.8
	11	1.5	**5.8**	13.1	23.2	36.3	52.2
	12	1.5	6.1	13.6	24.3	37.9	54.6
	13	1.6	6.3	14.2	25.2	39.4	56.8
	14	1.6	6.5	14.7	26.2	40.9	58.9
6"	15	1.7	6.8	15.3	27.1	42.4	61.0
	16	1.8	7.0	15.8	28.0	43.8	63.0
	17	1.8	7.2	16.2	28.9	45.1	65.0
	18	1.9	7.4	16.7	29.7	46.4	66.8
	19	1.9	7.6	17.2	30.5	47.7	68.7
8"	20	2.0	7.8	17.6	31.3	48.9	70.5
In. water	cm water						
	Area (m^2)	7.85E-07	3.14E-06	7.07E-06	1.26E-05	1.96E-05	2.83E-05



Graph 2 Jet Diameter (mm or ")

Continuing with the example of a 1 kW burner, if the supply pressure is 2 cm water gauge you need a 3 mm (1/8") jet or you can use a 2 mm jet at about 11 cm water.

For a simple diffusion burner with no primary air holes (See Figure 8) all you need to do now is find what burner area is needed to keep the gas velocity below 0.25 ms^{-1} so the flame will not blow out.

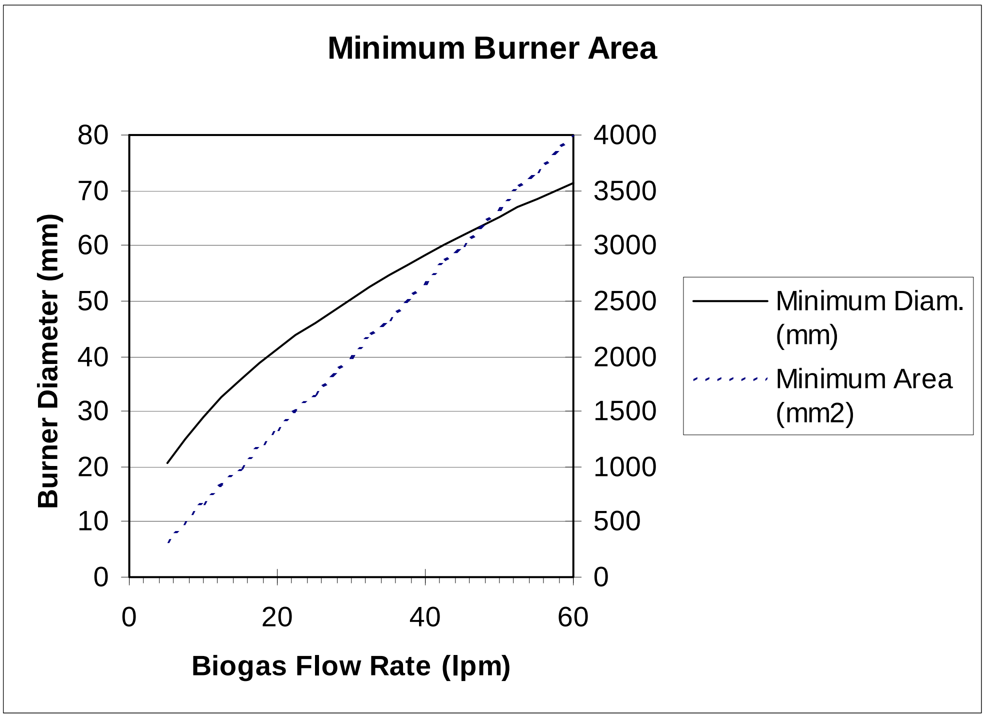
This is done using the equation :-

Ab = Q / v where Ab is the Minimum Burner Area (m^2)
Q is the Biogas Flow Rate (lpm)
and v is the Gas Velocity (= 0.25)

Table 9 Minimum Burner Diameter (mm)

Burner Area Required

Gas Flow Rate (lpm)	**5**	10	15	20	25	30	35	40	45	50	55	60
Minimum Area (mm^2)	333	667	1000	1333	1667	2000	2333	2667	3000	3333	3667	4000
Minimum Diam. (mm)	**20.6**	29.1	35.7	41.2	46.1	50.5	54.5	58.3	61.8	65.1	68.3	71.4



Graph 3 Minimum Burner Diameter (mm)

This means that our simple burner needs to be over about 21 mm diameter, so a 25 mm pipe should be adequate as a burner body. If a number of smaller flames are necessary, rather than a single larger flame, then "Areas of Circles" Tables can be used to find the number of holes of suitable diameter needed to give the necessary area. If you use 6 mm (1/4") diameter holes for the burner outlet you will have to have at least 14 holes to provide the approximately 452 mm^2 area needed.

For a better performing premixed burner primary air needs to be added to the biogas stream, through "primary air" holes. As a first estimate the burner area found above can be used as the "throat" area and the primary air area can be made equal to the throat area. The actual Burner Area is usually about ten percent bigger than the burner "throat" (body) area, because of the entrained air. The "Areas of Circles" Tables can again be used to find the number of holes required.

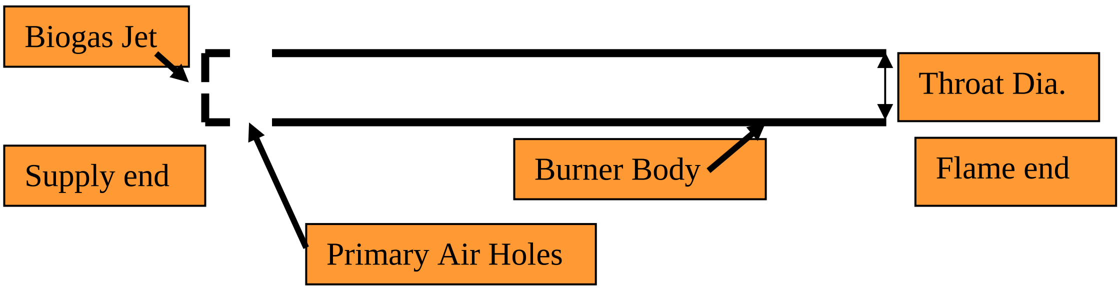


Figure 9 Premixed Burner

For the example burner the Throat and Primary Air become 22 mm diameter and if 6mm (1/4") diameter burner holes are used (as Fulford recommends, at 12 mm centres) then at least 21 are needed.