Integrated Portable Biogas Systems for Managing Organic Waste

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Abstract: - Biogas is a renewable energy source which is commonly used for heating/cooking. A community's investment in biogas technology can simultaneously reduce dependence on non-renewable energy sources as well as providing cost effective technologies for recycling wastes. Biogas technologies use anaerobic digesters to recycle organic wastes into biogas and fertilizers. Common waste materials include animal/human waste, plant material, and other organic wastes. Biogas technology can significantly help communities solve their economical, environmental, health and energy hardships, leading to a much better quality of life if the technology is utilized correctly.

Fixed biogas units require a lot of capitol investment, building time, and a long operational life to become profitable. Refugee and natural disaster communities lack the capital and expected lifetime to make fixed biogas systems viable. Viable technologies for waste management and fuel production are vital for the communities' survival. Portable biogas systems could be advantageous as they can be moved from location to location as required increasing operational lifetime, therefore profitability of each unit, while providing the necessary waste management and fuel for the stated communities. The biogas units could be run by Relief Organisations that are often tasked with developing the infrastructure for these communities. The biogas systems should be integrated into the feed deposit locations, i.e. sinks and toilets, to remove user handling of waste. In order to design portable systems, suitable construction material must be used and the systems size must be carefully designed.

A review of current biogas technologies and processes is offered in order to select a suitable technology that can be used for portable systems. Operational conditions and considerations are also offered for biogas reactor technologies, in particular for the selected technology.

Key Words: - Biogas, Organic Waste Management, Waste Recycling, Small Scale

1 Introduction

Biogas is a renewable energy source which is commonly used for heating/cooking and can be a source of income from an investment. Biogas is a mixture of Methane, Carbon dioxide, and Hydrogen Sulphide. A community's investment in biogas technology can simultaneously reduce dependence on non-renewable energy sources as well as provide cost effective technologies for recycling wastes. Common waste materials which biogas technologies treat include farm animal wastes, human waste, plant material, and other organic wastes. Anaerobic digesters are a key component of the technology and are used to recycle organic wastes into biogas and fertilizers, which requires a mixture of fermentative, acetogenic, and methanogenic bacteria in the digester. Ultimately the technology has been researched and developed extensively leading to many available small and large scale technologies; which have, in general, been implemented successfully worldwide to help solve some of the economical, health, environmental, and energy problems which are faced by communities, particularly those in developing countries, on a daily basis.

It has been reported that a rural family of 4 will roughly consume 0.57 cubic meters of biogas per day for heating/cooking (Edgar J. DaSilva etal, 1980). A study into the yield of biogas from the organic component of municipal waste showed that a tonne of waste will produce 180-220 cubic meters of biogas (H. Hartmann, B. Ahring etal 2005). From this data it is estimated that a family of 4 would need to recycle at least 2.6-3.2 kg of organic municipal waste per day, with similar recycle yields to those given by Harmann etal, in order to meet all of their energy requirements. It is plausible that the family could produce and recycle the required waste per day with biogas technology. This highlights the great potential of biogas technology in developing clean and sustainable households.

There are however many barriers which have limited the extent of implementation and success of biogas technologies. Biogas technology is currently underutilized due do a lack of social acceptance for reasons such as deficient investment incentive, difficulty in maintenance, operational issues, current cheaper fuel options, and user unwillingness of transporting unpleasant material to the biogas system (R. Rabezandrina etal, 1990). Some social acceptance issues could be managed by designing small scale, integrated, biogas technology that recycles organic wastes into biogas and fertilizer.

Integration of the technology ideally should be achieved by directly feeding the system from waste disposal locations, i.e. sinks and toilets. This integration is advantageous as it will remove the need for the user to personally transport the unpleasant material to the system, leading to increased social acceptance. This has been attempted before by certain groups with some degree of success. This paper is aimed towards selecting suitable anaerobic reactor technologies, selecting suitable operating conditions, and waste feeds so that recommendations can be made for the design of a cost effective, portable biogas unit; which mainly treats household wastes and animal wastes. This paper offers the need for portable biogas systems as well as offering a review of the processes involved in biogas production.

Project Objectives:
1. To review current biogas technologies and processes to allow the selection of a suitable biogas technology which can be further developed to create an integrated portable biogas system.
2. To offer recommendations to develop and aid future work which can take the development of the integrated portable biogas unit further.

2 Potential Applications of Portable Biogas Systems

Portable biogas systems could be used to provide quick infrastructure for communities who are for example:

- Natural Disaster Communities
- Within Refugee camps
- In war zones.

These communities often lack any proper waste treatment methods and are often short on fuel for cooking and heating. Suitable waste management systems must be put into place quickly once these communities develop otherwise a health crisis will quickly follow due to poor sanitation. Biogas systems have been proven to help solve a lot of the waste and energy problems once they are installed. Fixed biogas systems require a lot of start-up capitol, sufficient time to install, and will need to run over a long time in order to be economically viable. Shorter term communities find fixed biogas units uneconomical which is a cause for biogas technology rejection. Portable biogas systems have the potential to be a good first step in developing infrastructure quickly which will allow these communities to control their waste and energy problems. Transportable biogas systems could be installed at a location where they are needed on a temporary basis, when there is no longer a need for the portable biogas system; it can be transported and used/stored elsewhere. This could reduce capitol loss for the technology's use for short time bases as a system can be re-used later. Re-using the technology will increase the units operational life leading to greater economic viability. Portable biogas systems will be of interest to World Relief Organisations who often support these communities by running and organising their infrastructure.

3 Literature Review

3.1 Biogas Reactions

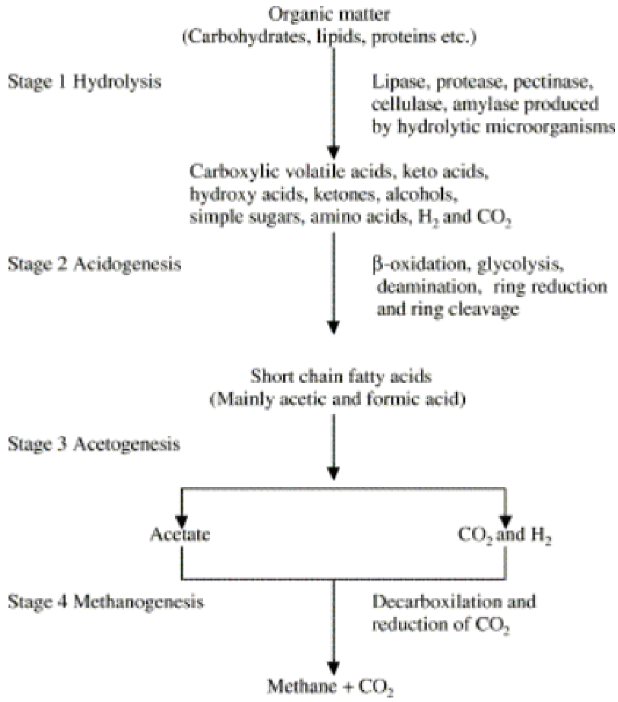

Figure 1 – Urmila Balasubramaniyam et al, 2008. 4 step production process for Biogas for a range of organic materials.

Figure 1 shows the 4 steps which process organic waste into biogas using anaerobic digestion. Initially the waste is hydrolyzed using Fermentative bacteria, followed by Acidification using Acetogenic bacteria, followed by the production of acetate, CO_2, and H_2 during the acetogenic phase, and finally biogas is produced during Methanization using Methanogenic bacteria. Table 3
Table 4 - J. L. Walsh et al, 1989. This figure illustrates the properties of Methane and Carbon Dioxide which make up approximately 99% of biogas. Using this data the properties of Biogas can be calculated using the mass fraction of the gases in the Biogas mixture., in the appendix, illustrates some of the main reactions associated with biogas production from plant material.

The reaction rates will be dependant on several factors, most notably the concentrations of the reactants, concentrations of the bacteria, and the physical properties of the process fluid. During the process Volatile Fatty Acids (VFAs) are produced which can disturb subsequent reactions if allowed to accumulate. Accumulation of VFAs can lead to reactor failure.

3.1.1 Biogas Physical Properties

Biogas is a roughly made up of 55-70% Methane, 35-45% Carbon Dioxide, and trace quantities of Ammonia and Hydrogen Sulphide (Sherif F. Ali, Mohamed G, Hassan, 2010). Table 4, in the appendix, gives the physical properties of Methane and Carbon Dioxide under a certain temperature and pressure.

3.2 Anaerobic Digester Technology

There are many anaerobic digester technologies which previously have been designed, tested, and implemented. The current technologies have been critically analysed to discover which of the technologies could be used to design a portable biogas system. The investigated technologies are:

- CSTR – Continuous Stirred Tank Reactors
- UASB – Upflow Anaerobic Sludge Blanket Reactors
- AFR - Anaerobic Filter Reactors
- AAFEB - Anaerobic Attached Film Expanded Bed Reactors
- AFB - Anaerobic Fluidized Bed Reactors

Operational pathways and processes were investigated to select possible advantages and disadvantages for the technologies. Table 5, in the appendix, shows typical data on a selection of anaerobic digester reactors.

3.2.1 CSTR

Continuous Stirred Tank Reactors are often designed with the assumption of perfect mixing. Perfect mixing is unusually achieved in real reactors; under normal operational conditions however a good degree of mixing is obtained. This mixing effectively gives the reactants and products a uniform concentration in the process fluid. The compositions of the streams exiting the reactant are the same as those compositions in the reactor. Advantages of mixing in anaerobic digesters are a reduction in reactor dead space, reduction in accumulated acids, uniform nutrient concentrations, and the maintenance of uniform conditions (A Keshtkar et al, 2001). These aspects lead to greater reactor stability as the bacteria is kept under optimum conditions leading to less likelihood of nutrient or reactant shortages. Also CSTRs require no start up period which is very advantageous to portable systems. A disadvantage of the technology is bacteria structure breakdown, leading to reduced efficiencies, can occur if the mixing is too vigorous. The level of mixing will therefore have to be less for anaerobic digester CSTRs when compared with other reaction processes which use CSTR technology.

Overall the technology requires slightly larger reactor volumes to achieve the same conversion when compared with other reactor technologies. This is due to the fact that the concentrations of reactant are diluted with the products throughout the reactor volume. Portable biogas systems will require minimum reactor volumes in order to increase portability which is one reason why the technology has been deemed inappropriate. Another reason for rejection is that stable bacteria conditions are required, therefore turbulence in the system has to be minimized which is impossible for CSTRs as mixing is required.

3.2.2 UASB

The Upflow Anaerobic Sludge Blanket technology is a vertical column reactor which requires a liquid feed injected into the bottom of the reactor. The process fluid is pushed up the reactor and subsequently drawn out of the reactor at the top of the liquid level. The produced biogas is removed and collected from above the liquid level where it naturally separates from the process fluid. The bacterium in this system fixes itself to solid particles such as sand, gravel, and activated carbon which are purposefully added by the operator. The low hydraulic loading rates and height of the reactor allows high levels of bacterium complex retention by gravitational settling (Medhat M. A. Saleh et al, 2004). Retaining bacterium complexes saves on capital requirements. The following figure a diagram of a general UASB technology

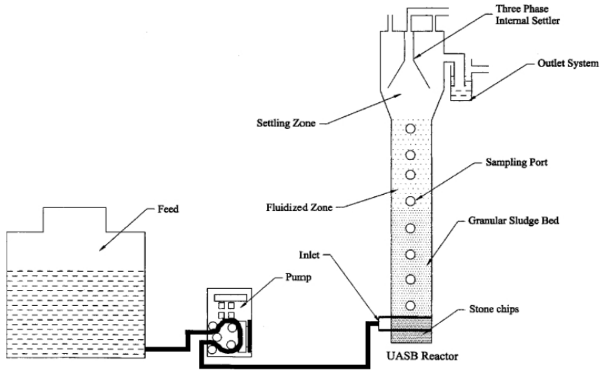

Figure 2 - Medhat M. A. Saleh et al, 2004. A simplified diagram of a typical UASB reactor.

Advantages of this reactor:

- No required internal reactor parts which increases the yield per reactor volume ratio
- High bacteria complex retention
- Can treat high settleable solid feeds
- Can treat high organic loading rates

Disadvantages of this reactor:

- Long start up period is required
- Large quantities of startup material are required.

Overall this reactor is highly suitable for portable biogas systems. Its major drawback is the long start up period however suitable methods for reducing this start up period have been investigated.

It is also possible to use a down flow of process fluid through this reactor technology provided a floatable packing material is used. The choice of upflow or down flow is dependant on the packing material used.

3.2.3 AFR

Anaerobic Filter Reactors are made up of a tank filled with plastic media which allows bacteria fixing which develops into a thin film referred to as bio-film. The inlet fluid passes through the bio-film which acts as a filter as the organic component is trapped and subsequently digested into biogas. This technology is said to allow the system to effectively treat wastes with highly variable inlet conditions as the organic component is filtered out of the process fluid. (D. Defour et al, 1994). Other advantages include the ability to build vertical reactor columns leading to a reduction in required construction space. Due to the high cost of the packing material, it is said the reactor is most suitable for small designs which reduce the required packing material. Another drawback of the technology is that the packing material is prone to clogging so it is important to consider the nature of the feed when designing. This reactor technology is suitable for portable biogas systems; however the drawback for this system is that it is highly susceptible to clogging which will increase the need for technical operators.

3.2.4 AAFEB

Anaerobic Attached Film Expanded Bed Reactors consist of a column packed with a suitable support media which expands upwards with the upward flow through the reactor (Michael S. Switzenbaum et al, 1982). Bacteria within the reactor are fixed on the support media which is similar to previous reactors discussed. This ensures a high mass transfer area which leads to high reaction rates. The AAFEIB has been shown to effectively treat dilute wastes at low retention times within the psycophillic temperature band (4-20^{0}C) (Michael S. Switzenbaum et al, 1980). Bacteria within the reactor are fixed on media similar to previous reactors discussed. The following figure shows a schematic diagram of a typical AAFEB reactor.

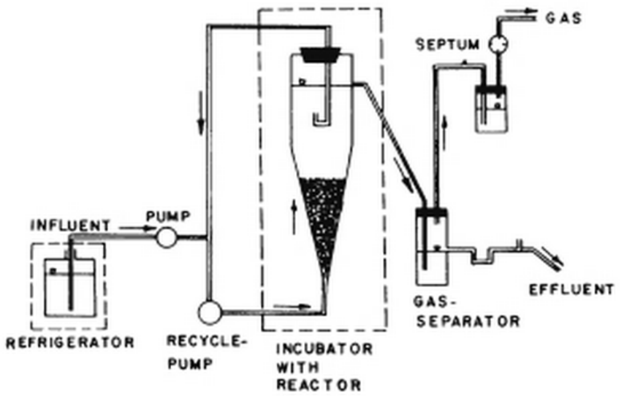

Figure 3 – Gosse Schraa et al, 1984. A simplified diagram of a typical AAFEB system.

Advantages of the AAFEB:

- Functions effectively at low temperatures leading to lower heating requirements.
- High surface area of bacteria due to packing material
- No internal parts leading to good volume to yield ratio

Disadvantages of the AAFEB

- Packing material can lead to clogging problems

3.2.5 AFB

Anaerobic Fluidized Bed Reactors use a designed upwards flow rate to counteract downward forces exerted on particles in the reactor to keep suitable media fixed with bacteria suspended. The operation of AFBs is similar to AAFEB however the fluidized bed does not expand in the same way due to the simpler design of the AFB.

3.2.6 Batch Reactors

Essentially batch reactors are a similar concept to landfill treatment for the recycling of organic wastes into biogas. However batch reactors offer key advantages over landfill leading to an average yield of 50-100 times greater for batch reactors. These batch reactors, such as lagoons, are typically run at higher temperatures than the temperatures landfills are subjected to leading to faster biogas production. Another advantage is that batch reactors are often mixed which disperses the nutrients, VFAs, improves contact between bacteria and reactants, and re-circulates the leachate which all lead to improve yields.

3.3 Useful Bacteria

The production of biogas from organic waste requires a mixture of bacteria which are defined in functional groups. The biogas process would fail if any one of the functional groups is missing. The first group is the fermentative bacteria. The bacteria for this process exist naturally which is evident from the fact that the functional groups work in symbiosis with each other. The second group is the acetogenic bacteria which create acids which the third bacterial require to produce biogas. This is evidence of the symbiotic relationship as the second bacteria group actually creates the necessary chemical compounds and reaction conditions which favor the third bacterial group.

3.4 Controlling Properties

3.4.1 Temperature

Anaerobic digesters are designed to perform in one of three temperature bands. These bands are named psycophillic (4-20^{0}C), mesophillic (20-40^{0}C), and thermophillic (40-60^{0}C). Bacteria activity is greatly influenced by temperature. Typically anaerobic digesters are run in the mesophillic or thermophillic bands, optimum temperature within the mesophillic band is at 35-37^{0}C which favours the methane producing methanogenic bacteria. A noticeable reduction in bacteria activity has been reported to occur at 40^{0}C due to a lack of any bacteria preference to this temperature, to high for mesophillic bacteria and too low for thermophillic bacteria (Luke Jenangi). Yields are found to be greater in the thermophillic band up to a point; however the increased yield is offset by the increased heating requirements so it is not usually desirable. There is also a higher risk of failure of the reactor at higher temperature therefore it is at the user's discretion which temperature band is used.

3.4.2 pH

The anaerobic digester processes generate volatile fatty acids (VFA) which can have a serious impact on the stability and yield of the system if they are allowed to accumulate. Ideally the process fluid should be mixed in order to reduce VFA accumulation in isolated areas. Mixing alone will not control the pH as required, therefore it is suggested to use alternate control methods such as the addition of sodium bicarbonate in order to gently control the pH. The quantities of chemicals which must be added should be designed for each specific system. Acetogenic bacteria favour acidic conditions whereas the methanogenic bacteria favour neutral conditions, approximately 6.8-7.2. Most reactors are designed to perform with neutral pH favouring the methanogenic bacteria as the levels of VFA in the system can be controlled by the methanogenic bacteria.

3.4.3 Nutrients

Anaerobic digesters use bacteria and organic processes to generate biogas which requires the correct nutrients in the correct concentrations to function properly. Typical micronutrients which are required are in the table below

Table 1 - Medhat M. A. Saleh et al, 2004. A list of the main micronutrients required for anaerobic digestion processes.

Micronutrients :		
Nitrogen	Phosphorus	Sulphur
Magnesium	Iron	Nickel
Manganese	Copper	Potassium
Cobalt	Calcium	Zinc

Without the nutrients the bacteria will not grow and function effectively leading to poor yield of biogas or failure of the system. Some of the nutrients are contained in significant concentrations in the bacteria itself, particularly iron, nickel, and cobalt. Other nutrients are contained in the feed to the reactors. However the concentrations of nutrients will be dependant on the particular type of feed in question. It may be necessary to supplement the process fluid of the reactor with nutrients pre-treatment. The required quantities can be known by considering the feed. It is however suggested that the optimum nutrient concentrations are double the minimum concentrations. The optimum C:N:P ratio is 100:2.5:0.5.

3.4.4 Organic Loading Rates

Different reactor technologies are capable or processing different organic rates. An increased organic loading rate increases the COD of the process fluid. It is important for the final effluent to have a COD value within acceptable discharge limits. Higher organic loading rates will reduce the amount of COD that is removed per pass within the reactor therefore the feed inlet must be carefully controlled. It is recommended that a buffer tank is used to store process fluid pre-treatment in order to keep steady inlet conditions.

3.5 Typical Feed Compositions

Anaerobic digesters are very versatile as they can process many different forms of organic waste. Common properties of the waste are water content, chemical oxygen demand (COD), solid percentage, chemical concentrations, and organic component. These factors most notably affect which reactor technologies can be used as well as required retention time. A list of typical organic waste generators is written below.

- Animal Manure – Cow, Chicken, Swine, ect
- Human Waste – Urine and Faecal Matter
- Household Waste – Food Wastes
- Plant Material – Olive Oil

The solid content for the feed should be in the 0-20% bracket in order to use anaerobic digesters effectively. Addition of water and use of mixing pre-treatment is suggested.

If a mixed stream of urine and faecal matter from human waste is required to be treated, it is important to reduce the levels of ammonia contained in the urine. The reason for this is explained later in section 4.1 Chemical Concentrations Limit.

3.6 Typical Yield

A tubular plastic $4m^3$ biogas which runs off of 1 part excreta from 1-2 cows, 4 people, or 5-8 pigs which is mixed with 2 parts water can produce 1m3 of biogas daily which is more than enough for 4 people's daily heating and cooking requirements (Source: SURUDE Foundation for Sustainable Rural Development NGO, Tanzania) This biogas system is run as a household system so it is assumed that it is run within the mesophillic temperature band.

4. Reactor and Operating Conditions Selection

As the aim of the Portable Biogas system will be to treat household waste and animal waste, it can be assumed that there will be a relatively high solid percentage in the feed. The high solid content will cause blockages so it is important to select reactors which are not prone to clogging problems. This initial constraint selects CSTR reactors and UASB reactors as the most viable. The UASB was deemed more appropriate for several reasons. The first of which is it is more capable at treating high solid content and high COD demand streams. Less retention time is required to treat the process fluid. Overall the system requires less volume to treat the same quantity of material. The drawback of selecting this reactor technology is that less mixing will occur which reduces the efficiency of the reactor. However as long as a suitable length to width reactor ratio is chosen when the reactors are designed, a decent level of mixing could be achieved. Wider UASB reactors promote better mixing due to convection currents being formed within the reactor therefore better mixing is obtained which leads to less radial change.

Pre-treatment feed control will be paramount to allow correct operation and good yield for this reactor. Most notably the influent to the reactor must have a suitable solid fraction; this is around 10-12% for the UASB. There must enough water available in order to control this property to ensure correct reactor operation. There are other considerations to consider when operating and starting up the reactor which are explained in the following sections.

Retention times for the treatment of the influent are highly dependant on the nature of the feed. However for cattle manure the retention time has been quoted to be around 2-8 weeks for a mesophillic digester. This retention time will be similar to other feed types, however above and below the 2-8 weeks is possible. Operating the reactor within the thermophillic temperature band can reduce the required retention time to less than 2 weeks in some cases.

4.1 Chemical Concentrations Limit

With all processes there are factors which can inhibit the process mechanics, so much so that the yield can be reduced so that the system becomes uneconomical. With biogas processes, Carbon and Nitrogen are a requirement to facilitate the necessary reactions. Optimum operational C:N ratio should lie within 8-20 depending on the conditions of a particular case. However if the concentration of Nitrogen, usually contained in ammonia, is too great, it can have an inhibitory effect. The limits for Nitrogen have been quoted to approximately be 1700 mg ammonium-nitrogen per litre of substrate (GTZ project Information and Advisory Service on Appropriate Technology). Noticeable biogas inhibition occurs at Nitrogen concentration values above this limit. It is found that the amount of free nitrogen increases with temperature which is an important factor to take into account when selecting operational temperature. Given enough time biogas bacteria are capable of some degree of adaption to this inhibitory effect.

Other substances which may affect biogas bacteria activity include an overabundance of heavy metals, presence of antibiotics which would destroy present bacteria, and other chemicals which may have been added to the feed such as bleaches and detergents. ***Table 2*** shows some quoted values for upper limits of these substances.

Table 2 - GTZ project Information and Advisory Service on Appropriate Technology. This table shows the limiting maximum concentrations for chemicals which will inhibit anaerobic digestion processes if they are exceeded.

Substance	Concentration (mg/l)
Copper	10-250
Calcium	8000
Sodium	8000
Magnesium	3000
Nickel	100-1000
Zinc	350-1000
Chromium	200-2000
Sulfide (as Sulfur)	200
Cyanide	2

4.2 Start-up Concicerations

A draw back of the UASB is that a long start-up period is required to get the reactor functioning properly. This time has been quoted to be 4-16 days. This obviously affects portable biogas systems as the waste will build up during the start-up, therefore the storage facilities will need to be sufficiently large. It is possible to store bacteria under cold conditions in order to maintain the quantity and quality of bacteria for longer time periods. Bacteria can be collected and stored from operable biogas systems, and transported with the portable biogas system. This will lead to improved start-up procedures and subsequently shorter start-up times.

4.3 Gas Storage Devices

Biogas is similar to any other gas production industry; there is an inherent danger with storing gases under pressure, particularly flammable gases such as methane. The method of gas collection and storage device is a fundamental aspect of a complete biogas unit. As a general rule however, there is a greater risk of gas release and subsequent problems for processes at higher temperature. The development of any biogas system must include safety considerations and which must include routine gas leakage tests. A few gas storage devices are written below:

- Floating Drum
- Expanding Gas balloon
- Water sealed gas holder
- Gas cylinders and Tanks under high pressure

The expanding gas balloon gradually increases in size as it fills with gas which serves two purposes, most notably it allows gas storage, and secondly it allows simple readings of stored gas quantities which can be done by inspection.

It is also possible to link the gas line from the biogas systems into main gas lines; however the gas from the biogas system must be filtered to remove impurities such as hydrogen sulphide and carbon dioxide. This is an important step for the commercialization of biogas and has previously been made possible by earlier researchers. Currently there are biogas systems which create and purify biogas using integrated purification units. These however have the largest success in economically developed countries and have yet to be implemented effectively in developing countries. This is party due to available useful infrastructure capital in developed countries.

5 Causes of Social Rejection and Possible Solutions

A major issue which reduces the extent of biogas technology utilization and success is funding. Biogas systems are expensive and many people lack the necessary start-up funds. The reasons for biogas success stories can often be lead back to heavy government involvement. These governing bodies, such as those in China and India particularly, subsidise communities with part of the necessary start-up funds

There is also a noticeable extent of social revulsion in using biogas recycled from organic wastes, particularly due to religious reasons. In order to improve biogas utilization, it is vitally important to change cultural viewpoints on the biogas to improve social acceptance. This is a very difficult task which can be met by educating communities about the cleanliness and advantages offered by biogas.

Other biogas system failures can be linked to community's lack of interest in continuing the operation of the systems as well as from direct difficulties in operating the devices. To improve on the operating difficulties, the communities must be trained effectively. There have been a lot of documented cases where there was digester failure due to underfeeding the system. This underfeeding could be caused by there simply not being enough feed generated for the digester, or that the communities did not collect the feed in the required quantities. This suggests that the size of the reactors should be more carefully designed for the particular users, and that the feed should be integrated into the device to remove the need for users to collect the feed.

6. Findings and Considerations

Use of UASB reactor technology has been deemed appropriate for the development of small scale integrated portable biogas units. The advantageous offered by the portable system include increased operational life with regards to shorter term fixed biogas units, which increases the economic viability of the units. There is a great need for waste management and fuel generation technologies in struggling short term communities such as those in refugee camps. Biogas technology are a good solution to both of these needs, however further development of the systems is necessary in order to allow its use. This development should include optimizing the size and dimensions of a UASB reactor in order to reduce the volume as much as possible to increase portability. The development should also include optimizing the construction material in order to increase portability.

It is possible to achieve good yields from the mesophillic temperature band which should be used as it is safer. However the thermophillic temperature band is found to reduce the average required process fluid retention time which subsequently reduces the required reactor volume. The use of the thermophillic band therefore will increase portability of the device which is why it should be considered when designing portable biogas systems.

In order to improve operation with regards to solving underfeeding problems, the systems feed collection should be integrated into the biogas system so that user handling of waste is removed. This will also help to manage cultural acceptance of the technology leading to improved biogas utilization.

The typical yield from a $4m^3$ tubular reactor, which most likely is run within the mesophillic band produced 1m3 of biogas from the waste of 4 people. It seems that 1m3 of reactor is required for every person who uses the reactor. Large reactors would be unsuitable for transport. Use of the thermophillic temperature band will reduce the required reactor volume therefore it may be most appropriate for using portable biogas systems.

6.1 Operational Considerations

- Water or liquids such as urine should be mixed with the feed in order to optimize the solid content of the feed to the optimal level, approximately 10-12% for UASB.
- Nutrients must be added in excess in order to ensure stable bacteria activity; however concentrations must not be over certain values otherwise process inhibition may occur.
- Operate within the mesophillic band for safety, and within the thermophillic band to reduce required reactor volume.
- Aim to use buffer tanks which are mixed in order to stabilize the feed.
- A decent level of mixing is required in the reactor to promote substrate mixing and to prevent accumulation of VFAs within the reactors.

7. Conclusions

Future work should be conducted in order to further refine the UASB reactor so that it can be utilized for integrated portable biogas units. Future work should include:

- Conducting experiments on small scale UASB
- Mathematical modelling of UASB using experimental data as a basis to allow scalability

and optimization of the reactor technology

- Selection of suitable construction material
- Economical study on the optimized technology to check its financial viability.

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7. Appendix

Table 3 - (Rene Rabeandrina, 1990). This figure illustrates the key chemical reactions associated with biogas production from plant material.

Phases	Substrates	Reactions	Products
	Cellulose	$nC_6H_{10}O_5 + nH_20 \rightarrow$	$n(C_6H_{12}O_6)$
Hydrolyse	↓		(Glucose)
	Glucose	$C_6H_{12}O_6 \rightarrow$	$CH_3CHOH\ COOH$
Acidification	↓		(Lactic Acid)
	Fatty Acids		$CH_3CH_2CH_2\ COOH$
	+		(Butyric Acid)
	Alcohols		$C_2H_5OH + CO_2$
Methanization	↓		(Ethanol)
	Biogas	$4H_2 + CO_3 \rightarrow$	$CH_4 + 2H_2O$
		$C_2H_5OH + CO_2 \rightarrow$	$CH_3COOH + CH_4$
		$CH_3COOH \rightarrow$	$CO_2 + CH_4$

Table 4 - J. L. Walsh et al, 1989. This figure illustrates the properties of Methane and Carbon Dioxide which make up approximately 99% of biogas. Using this data the properties of Biogas can be calculated using the mass fraction of the

Physical Constant	Methane (CH_4)[a]	Carbon Dioxide (CO_2)[a]
Specific gravity, air=1 [b]	0.554	1.52
Specific Volume	1.51 m^3/kg	0.55 m^3/kg
Heat Capacity, Cp @ 101 kPa	2261 J/(kg K)	858 J/(kg K)
Ratio Cp/Cv	1.307	1.303
Limit of Inflammability	5-15 % by volume	-
Stoichiometry in Air	0.0947 by volume	-
	0.0581 in mass	-

a = Properties of pure gases given at 25^{o}C atmospheric pressure

b = Air at 101 kPa, 15.6^{o}C

gases in the Biogas mixture.

Table 5 - Medhat M. A. Saleh et al, 2004. This figure illustrates key properties of a selection of reactor technologies. HRT stands for Hydraulic Retention Time and COD stands for Chemical Oxygen Demand

Anaerobic Reactor Type	Start Up Period (days)	Channelling Effect	Effluent Recycle	Gas Solid Separation Device	Carrier Packing	Typical Loading Rates (kg COD/m3/day)	HRT (days)
CSTR	-	Not Present	NR	NR	NR	0.25-3	10 – 60
UASB	4 - 16	Low	NR	E	NR	10 - 30	0.5 – 7
Anaerobic Filter	3 - 4	High	NR	B	R	1 - 4	0.5 – 12
AAFEB	3 - 4	Less	R	NR	R	1 - 50	0.2 – 5
AFB	3 - 4	Not Present	R	B	R	1 - 100	0.2 - 5
Key:	NR - Not Required	R - Required	E- Essential	B - Beneficial			