Potentiality of Biogas and the Role of Subsrates in Biogas Formation Potential

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Abstract

Biogas infrastructure development, particularly in countries such as Vietnam, has the potential to provide great benefits to people living agrarian lifestyles in rural areas. Decentralized wastewater treatment facilities that utilize anaerobic technologies to digest organic waste for the purpose of collecting methane provide a number of benefits to centralized use as well. In both cases, users benefit from the production of methane gas, wastewater treatment, nutrient recycling, and organic fertilizers. In the case of decentralized use, as is most prevalent in Vietnam, integrated farming methods, such as the VACB model, allow farmers to reap the benefits of a wide array of economic, environmental, social and health factors that are not as easily recognized with larger, centralized treatment facilities.

While biogas systems in Vietnam have the potential to provide such benefits, the dissemination of knowledge concerning the process and construction is largely stifled by a lack of resources; both on governmental and individual levels. Other limitations include the low socio-economic component of rural Vietnamese populations who, despite being the ones that could most greatly benefit from biogas implementation, are the ones that can least afford it. The proceeding experiment was prefaced with such discussions in order to give insight into the purpose and implications of the study.

While this issue is ongoing, so too is the issue of research and development of the biogas production process. This paper looks specifically at the role of substrate addition in biogas formation potential. As Uri Marchaim of the Galilee Technological Centre asserts, "…the technology of anaerobic digestion has not yet realized its full potential for energy production" (Marchaim, 1992). Thus, the importance of studying the biogas process to better understand the importance of suspended materials and added substrates becomes a central concern in the effort to expand the technology and apply it on a larger scale. Experiments were conducted with organic market waste that was added to a series of biodigesters in order to measure the varying gas outputs in both quality and quantity. The purpose of this study was to draw conclusions about the potential of substrate loading on biogas formation potential, utilizing human waste. Sampling was done at dorm B23 of the Cantho University campus with hopes that conclusions may also be drawn as to how the involved parties may enhance the gas yield of the 500L digester.

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"You should never think something is impossible. When you first came to Vietnam, you thought you could never cross the street; you think it is impossible. But you can cross the street. Never think that something is impossible...If you do not try to cross the street, you will stay in the same place forever"

- Tran Xuan Thao, Director of the Fulbright Program in Vietnam

1. Introduction

Further biogas development in Vietnam is both a sensible & plausible goal for sustainable development. In order for biogas to be implemented on a larger scale, however, there must be a greater understanding of the costs and benefits of infrastructure development and the science of the process as well. As Uri Marchaim of the Galilee Technological Centre asserts, "…the technology of anaerobic digestion has not yet realized its full potential for energy production" (Marchaim, 1992). Such potential has caught the attention of the scientific community in Vietnam, as well as educational facilities such as Cantho University (CTU). The expansion of technological resources and the opening of the door to international collaboration have, in recent years, bolstered research development of biogas in Vietnam. At CTU, for example, several projects are being conducted at the School of Technology concerning water resource management and decentralized water treatment. The Sansed Project, which is supported by Bonn University of Germany, is a de-centralized water treatment project that has been ongoing since 2003 and conducts research on biogas as a component of the project. Some of the specific research being conducted is on the effects of substrates on biogas yield and composition. This is an important avenue of research because it helps shed light on possible benefits of adding organic bi-products, most of which are considered waste as well, to the biogas production process. Such research, however, does little on it's own to provide insight into the biogas debate and the potentiality of biogas utilization in

Vietnam. A critical understanding of the basics of biogas and potential for, as well as implications for development have to be realized before conclusions can be drawn about the costs and benefits of substrate loading in the production of biogas.

2. The Science of Biogas

2.1 Key Terms & Processes

In understanding the intricacies of the biogas debate, it is important to first define standard key terms. For the purposes of this paper, definitions of key biogas terms and the specific guidelines by which the batch experiments were constructed come from the handbook, “Fermentation of organic materials: Characterization of the substrate, sampling collection of material data, fermentation tests”. The purpose of this manual, published in 2006, is to set up standardized guidelines for conducting fermentation tests in order to avoid inaccurate information due to varying test conditions, methods and procedures. The manual first defines biogas as: “the gaseous product of fermentation which consists primarily of methane and carbon dioxide and which can also contain, depending on the substrate, ammonia, hydrogen sulfide, water vapor and other gaseous or evaporable components” (Verein Deutscher Ingenieure, 2006). What is not explicitly, but implicitly understood in this definition is that the biogas referred to here is produced by anaerobic, not aerobic decomposition. Anaerobic treatment is defined as: “a biotechnological process with the exclusion of oxygen whose objective is to degrade organic matter while extracting biogas” (Verein Deutscher Ingenieure, 2006). Such biotechnological processes will be expanded upon in further sections.

While the specific anaerobic processes that decompose waste in the biodigester are indeed complicated, the basic concept of harnessing biogas is rather simple. Organic waste from either a human or animal source is fed into an anaerobic digester (without air) where it is decomposed by groups of micro-organisms which produce methane, or biogas, and then is discharged as pathogenically-treated-waste. The gas that is produced, however, also has a plethora of other elements suspended in it. Levels of hydrogen sulfide are often present, although small, as well as water vapor, carbon dioxide, etc. Depending on the type of digester, methods of mixing must be employed to ensure that all of the waste is anaerobically digested and the maximum amount of biogas per unit waste is harvested.

2.2 Metabolic Groups

The history of biogas research can be categorized by a long periods of time that have been punctuated by various groundbreaking discoveries. One such discovery was made in the 1890's when Omelianski reported that by isolating the processes of biogas production, it could be demonstrated that the fermentation of organic material required the functions of different groups of bacteria. Contributions made by later researchers (Bryant et al., 1967) expanded on this idea and asserted that "the complete oxidation of a simple compound such as ethanol to carbon dioxide and methane would require contributions, combination and coordinated metabolism of different kinds of…anaerobic bacteria species" (Marchaim, 1981). It is understood that there are at least 4 such metabolic groups that function together in anaerobic digestion (Imhoff 1938). These are clearly illustrated in table 2.1.

Metabolic Groups	**Characteristics**
1. Hydrolytic/fermenting	Converts complex organic molecules (i.e.- lipids & proteins)
2. Hydrogen-producing acetogenic	Converts products of group 1 (organic acids larger than acetic acid & neutral compounds larger than methanol (i.e.- ethanol)
3. Homo-acetanogenic	Convert multi- or mono-carbon compounds to acetic acid
4. Methanogenic	Convert H2/CO2, monocarbon compounds & acetate into methane

Table 2.1, Metabolic groups (Marchaim, 1992)

2.3 Environmental Conditions

Certain environmental conditions in the reactor are of central importance to the microbial processes that decompose the waste and produce biogas. “Environmental factors which influence biological reactions, such as pH, temperature, nutrients and inhibitor concentrations, are amenable to external control in the anaerobic digestion process.” (Marchaim, 1992). Indeed, depending on the conditions, these factors must sometimes be controlled to regulate nominal conditions for biogas production within a reactor. Such factors are also crucial in analyzing and discussing further test results of batch experiments (see section 5.4).

Temperature is something that can alter the rate of digestion in both positive and negative ways. In terms of the external environment, the tropical environments prevalent throughout Vietnam, which are characterized by higher average temperatures and humidity levels, are more ideal for the production of biogas (Nguyen et al., 1996). This doesn’t exclude reactors in tropical environments from problems arising from temperature however: while metabolic growth rates of bacteria tend to increase with temperature, they still must remain between the tolerance temperatures of the micro-organisms in the reactor (Marchaim, 1992). Depending on the type of digestion, these temperatures vary. Under mesophilic digestion for instance, temperatures must hover around 35° C, while thermophilic digestion requires an average temperature of 55° C. The most important difference to note between these two kinds of digestion is that thermophilic reactors process waste much quicker than mesophilic reactors and thus require ½ the volume to produce the same amount of biogas (Marchaim, 1983). Thus the importance of monitoring reactor temperatures to ensure that test results are representative and that gas production is nominal, are of the utmost importance.

Another equally important condition is the pH of the reactor. The pH levels in a reactor are influenced by the amount of dissolved fatty acids and acetates in the effluent which are steadily increasing over time as. Despite this buildup, the digester has what is called a “buffer capacity”, which is quantified by the amount of strong acids that need to be added to the system in order to lower pH. This buffer capacity can be increased by the addition of particular proteins and bicarbonates, which help keep the pH level of the digester as neutral as possible by producing strong bases such as ammonia (Marchaim, 1992). This is critical to ensure a high methane composition in the biogas, as it is the methanogenic bacteria that are the most sensitive to changes in pH. If pH does start to decrease and begins to inhibit gas production there are 2 operational methods that can be undertaken to combat these effects: 1) stop the feed and allow methanogenic bacteria until populations recover and can raise pH to at least 6.8, or 2) add chemicals to normalize pH and increase buffer capacity (Marchaim, 1992).

Finally, the relative abundance or lack of certain nutrients, as well as inhibitors, within a reactor play significant roles in the quantity and rate of gas produced. “Anaerobic bacteria appear to have relatively simple nutrient requirements, which include nitrogen, phosphorous, magnesium, sodium, manganese, calcium, and cobalt” (Speece & McCarty 1964; Marchaim, 1992). Outside of an organic energy source, there are typically no problems in finding these elements; if anything there may be an overabundance in the reactor.

3. Costs & Benefits of Biogas

The process of biogas production has many positive effects. What was once conceived as a means to produce energy via biomass conservation, has developed into a multi-functional system with a wide array of meaningful applications. In a time when the global community is facing increasing pressures due to environmental change, resource scarcity, and a rapidly increasing human population, developing such new, innovative ideas in terms of energy use, nutrient recycling and waste disposal are of growing concern. Looking at biogas infrastructure development from a cost-benefit perspective is difficult to do, however, as there are many social benefits that are not easily quantified in economic terms. Much as this is the case with environmental valuation, however, it is clear that the benefits of biogas go above and beyond the simple production of gas. Conversely, the costs of implementation are generally defined more clearly. The reason for this is that there are no substantial issues concerning social costs and the financial costs of development rarely transcend the bounds of initial material investment. This may not come as a surprise when one considers that biogas production is sustained by the use of waste; the productive use of which society has few qualms with. The reason for low financial inputs in the form of maintenance costs on the other hand, can be attributed to the gravity-flow sewage treatment process that requires neither energy or daily management (GTZ, 1996). It is important to realize also that developing a biodigester for either decentralized or privatized use is in fact an investment; the monetary benefits of which will compound over time. The multi-faceted production cycle of biogas offers answers to a plethora of problems concerning sustainability. Through decentralized application, it is also important to note that people can incorporate such concepts of sustainability into their daily lifestyles and livelihoods as well.

When considering the costs and benefits of biogas development, it is critical to categorize the project. "In assessing the economic viability of biogas programs, it is useful to distinguish between four main areas of application: 1) individual household units; 2) community plants; 3) large scale commercial animal rearing operations, and 4) municipal/industrial projects" (Marchaim, 1992). The concept of feasibility is another important thing to consider when looking at costs and benefits and, according to Marchaim, can be divided into 2 categories: 1) a financial approach that involves the consideration of monetary benefits involving the sale or re-use of products, combined with the costs of constructing and maintaining the facility, and 2) a social assessment of all inputs and outputs, that consider intangibles such as reduced reliance on fossil fuels and reduced deforestation, to name a few.

3.1 VACB Model

In Vietnam, where biogas is largely utilized on a decentralized level, people often implement integrated systems to help fully recognize potential benefits. Primarily, this integrated system is known as the VACB model. This Vietnamese acronym stands for (V) garden, (A) animal farm, (C) fish pond, and (B) biogas.

This model provides a multitude of long term benefits that enhance the user's adaptability to external forces. It achieves this by offering a diversification of income sources which serves as a buffer to unpredictable market forces and environmental conditions. Money can also potentially be generated and/or saved from all of the components. Fish can be sold, orchard products can be sold, and pigs can be sold at market. In general, an efficient system will also decrease the cost of living by reducing the amount of money spent on fish food and fertilizers. The VACB model also indirectly combats the effects of deforestation and improves women's living conditions. All of these benefits will be more thoroughly discussed in the following sections.

3.2 Methane

According to Bac Hai, a farmer and veteran biogas user and developer in My Khan Village, using biogas as a fuel source for cooking can save a family roughly 200$/year (Bac Hai, 2007). Aside from this most apparent benefit of biogas installation, however, there are many other benefits that are not as easily quantified monetarily. For example, women who were once obligated to spend a great deal of time collecting scarce firewood to prepare the days meals, are given the opportunity to use their time more freely. It is widely understood that alleviating such domestic duties on women empowers them to lead more active roles in society by liberating them from the bonds of domestic servitude; something that is all too familiar in rural Vietnam.

Aside from this social benefit of gas production there are health benefits as well. Methane burns much cleaner than traditional fuels such as fire wood. While women are usually obligated to collect the wood, they must also use it to prepare meals in cramped, poorly ventilated kitchens. Airborne residues such as soot and ash from the burning firewood are things that, aside from being rather unpleasant, also contribute to acute respiratory diseases. Coupled with higher cooking temperatures and an adjustable flame that can be turned on at the flick of a switch, it is clear that such convenient innovations together with their social and health benefits are worth considering making the investment.

3.3 Nutrient Recycling

Nutrient recycling adds yet another dimension to the benefits of biogas. Where as there are economic and social benefits, so too are there environmental benefits to its production. "Burning non-commercial fuel sources, such as dung and agricultural residues, in countries where they are used as fuels instead of as fertilizer, leads to a severe ecological imbalance, since the nutrients, nitrogen, phosphorous, potassium, and micro-nutrients are essentially lost from the ecosystem." (Marchaim, 1992). The gas production process also allows the discharged effluent to be used in various applications, such as a food source for fish or environmentally friendly, productive organic fertilizers.

3.4 Organic Fertilizers

These organic fertilizers have several instrumental benefits for farmers. The first of which is the freeing of assets that were once used to purchase in-organic fertilizers. On top of alleviating a financial burden, using organic fertilizers also helps promote a more sustainable, environmentally conscious approach to increasing crop yield. Organic fertilizers are more natural, in the sense that they are products of natural enrichment and thus cause less serious problems associated with nutrient runoff into waterways. It has also been noted by farmers in China, that utilizing digested sludge as a fertilizer can lead to a 30% increase in crop yields over other fertilizers (Marchaim, 1992). One reason for this is that the nitrogen in the digested slurry can be more readily utilized by plants and that less nitrogen is lost than in storage or composting (Marchaim, 1992)

3.5 Waste Water Treatment

Problems concerning inefficient wastewater treatment procedures as well as untreated wastewater are not inherently issues of developed or developing countries. Depending on the circumstances, there remain serious questions to be answered as to who must take responsibility for wastewater treatment, how they must do so in accordance with standards of efficiency and practicality, and why this must be realized as a common initiative of the country/locality in question. In respect to decentralized wastewater treatment in Vietnam, however, people often have no options other than to use drainage canals as their primary sources of water; particularly in the dry season. As most humans living along the river also use this as a means to a bathroom, such water resources that are used for cooking, cleaning, and drinking are not sanitary to say the least. If biogas systems can pathogenically treat this waste and rid it of 90%+ bacteria such as fecal coliform, one could expect to see drastic increases in human health as well.

4. Biogas Potential & Limitations

4.1 Potentiality & Utilization

When analyzing biogas development potential in Vietnam, important population demographics must be considered. Perhaps the most important of these is the fact that more than 70% of the Vietnamese population lives in the countryside (Man, T.D, et al., 2006). In a developing country, such as Vietnam, it is also important to recognize that such a highly agrarian societal structure primarily lends itself to the decentralized utilization of biogas. One of the main reasons for this is that unless there is a community regulated biogas system, one house will not produce enough waste for the investment in a decentralized biodigester to be worthwhile. However in Vietnam, where 99% of livestock farms belong to individual households with 5-20 heads, there remains a great potential for biogas production. As of 2006, there were an estimated 40,000 family-size Biodigesters (1-50 cubic meters) installed in Vietnam (Man, T.D, et al., 2006). Table 4.1.2 illustrates this biomass potential in Vietnam.

Biomass Potential in Vietnam (feedstocks for biogas production)	**Millions tons/year**
Pig dung	25.7
Cattle dung	20.2
Buffalo dung	16.0
Municipal waste	6.4

Table 4.1, Biomass Potentiality, Utilization & Status Development, 2005 (Man, T.D, et al., 2006)

In terms of Centralized use, as table 4.1.2 illustrates, there is a great deal of potential for the utilization of waste in urban centers as well. While private companies and municipalities in Vietnam are slow to adopt biogas systems, it may be seen by smaller enterprises as a viable means to recover costs. In other words, although larger companies may have a comparatively low incentive to install systems due to larger revenue and overall size, smaller companies may find that the investment will save them a larger percentage of their costs over time and will be more amiable to implementing the technology (DEWATS, 2007). Looking at the big picture, however, it seems that future development of biogas in Vietnam should be focused on rural, decentralized applications. This is a positive realization because it is through decentralized biogas systems, utilized through integrated farming systems such as the VACB model, that the full benefits of this sustainable practice are realized. Instead of simply providing the benefits of waste water treatment and gas production, as are the primary benefits to centralized users, such systems that are utilized in rural communities can take advantage of other benefits such as organic fertilizer and fish feed. This is also important because unlike people in urban centers, people in the countryside do not typically have a lot of options to improve their lives in such a variety of ways.

	Hanoi	**Ho Chi Minh City**
Total urban waste volume, mill. tons/yr.	.95	1.9
Fuel waste portion, %	18	18
Theoretical potential, mill. tons/yr.	.17	0.34
Collected waste rate, %	70	70
Total collected waste volume, mill. tons/yr.	.66	1.33
Waste portion for fuel, %	50	50
Feasible potential for fuel, mill. tons/yr.	0.054	0.11

Table 4.1.2, Urban Waste Source, 2002 (Man, T.D, et al., 2006)

4.2 Limitations

Factors inhibiting the proliferation of anaerobic digesters for the production of biogas come from several different perspectives. Particular economic and political limitations to privatized or centralized development include: 1) despite low investment, operating and foreign exchange costs, the required investments in capital are still lacking; 2) financial institutions lack awareness of the technological potential and are thus more tentative about offering credit facilities; 3) fossil fuels provide equally economically viable sources of energy; 4) small number of plants means that economies of scale cannot yet be realized; 5) public contractors often dominate the municipal sector (cost-effective solutions are not always favored by decision makers); 6) anaerobic technologies decrease the "financial volume" of individual projects (i.e.- reduced costs→reduced revenue), and 7) the speed of decision making often lags behind technological development and understanding of the process (GTZ, 1996). While the extent to which these problems vary between localities is great, they still provide a fundamental picture of potential economic limitations for centralized implementation

Biogas development on a decentralized level, which may often be subject to such limitations as well, is usually impeded by the individuals lack of financial capital and the lack of know-how that is required to install and maintain a biogas system (particularly

VACB models). In regards to initial capital investment, there are organizations and NGO's such as Heifer International who provide assistance to farmers in the form of microcredits, however there is still a large number of individual households who could potentially benefit from VACB implementation that are not helped due to lack of available resources (NGO, governmental, etc) (Heifer International, 2007). While the material investment to construct a polyethylene biodigester is estimated to be in the neighborhood of 60-70$, this does not include the costs of procuring livestock, paying for livestock feed or purchasing fish food, all of which are necessary components of the VACB model (Bac Hai, 2007). Even with these obstacles, sometimes the biggest challenge is getting the farmer to sign onto the idea that biogas would be in his best interest. Sometimes households are tentative to adopt such a system simply because they know little about it, or they are hesitant to deviate from a system that, to them, seems to work just fine.

5. Experiment

Julia Nuber, a Research Assistant of the Sansed Project, has been conducting experiments with biogas at CTU since 2003. Amongst other things, she has recently dedicated her focus to studying the effects of substrates on biogas production. Over the last several weeks, she has been monitoring 45 batch experiments containing various combinations of substrates in order to distinguish between varying gas outputs and composition of each of the 15 replications. In accordance with the "Handbook on Organic Fermentation" that stipulates that sampling must be conducted with the assistance of professionals or people with corresponding practical experience, I worked alongside her to develop my own experiment and assist with hers as well. The proceeding sections document the standardized language and procedures of the experiment set forth by the "Handbook on Organic Fermentation" and document the test results and discussion as well.

5.1 Characterization of Substrates

The distinction between solid and liquid substrates is perhaps the most obvious categorization of the substrate. It is also an important one, as liquid substrates are often used in co-fermentation tests to enhance biogas yield. Above and beyond this, however, how are these substances defined? Other criteria are derived from biotechnological suitability, the preparatory work required and from the suitability of the substrate for fermentation (Gesellschaft, 2006). More specifically, categorization includes things such as consistency of the substrate, composition and homogeneity. These characteristics are succinctly abbreviated in table 5.1.

Characterization	**Qualities**	**Importance**
Consistency	- Liquid or pourable - Paste like to spadeable - Solid	* Helps determine technical effort required for sampling, substrate preparation, storage, and suitability of fermentation procedure
Composition	*Basic Parameters* - Chemical oxygen demand, water content, dry matter Total Solids content & organic dry matter *Secondary Parameters* - Fats, proteins, carbohydrates, lignin *Tertiary Parameters* - Carbon, Nitrogen, Sulfur, Phosphorous, Magnesium, Potassium	* Statements can be made regarding essential fermentability of a substrate, inhibitory influences and biogas yield (i.e.- possible product inhibition due to ammonia or hydrogen sulfide) * Help to characterize and classify the fermentation products as fertilizers

Interferents	- Heavy materials (i.e.- sand, metal, bones) - Light materials (i.e.- plastics, wood) Note: generally, things that interfere with the process, technology, or product quality	* Type and amount in the substrate are basic factors in selecting a fermentation procedure and preparation method * Occur predominantly in mixtures of solids
Pollutants	*Inhibits Process* - Disinfectants - Biocides - Antibiotics *Impairs Products* - Heavy metals - Organic pollutants	* The heavy metal content in fermentation products will be significant if the fermentation products are to be used for things such as fertilizers * Regulation of this can be categorized in legal terms
Hygiene	* Hygiene concerns arise from substrate use such as animal-by-products from slaughterhouses and food waste from restaurants or markets because they may contain pathogens, such as viruses or parasites	* Considered in sampling methodology, sample transportation, sample preparation and fermentation tests * Alert to special precautions to prevent transmission or dispersal of pathogens Note: the fermentation process (particularly thermophilic fermentation at 55° C) will considerably reduce pathogens in the substrate
Fermentability	- Alcohols or glycerin - Fermentable substrates following preparation and homogenization - Substrates that are potentially fermentable (i.e.- diluted/mixed with other substrates)	* Gives further information on consistency and composition of the substrate which facilitates a better understanding of fermentation conditions, sampling and results
Biogas Yield & Quality	* The quantity of biogas, measured under standard conditions, generated with each kilogram of substrate fresh mass * Depends on the quantity of organic compounds within the substrate (i.e.- fats, proteins, carbohydrates) that are biologically degradable under anaerobic conditions	* Helps identify issues with high pH, carbon dioxide, or hydrogen sulfide dissolved in the fermentation medium * Helps account for distorted volumes of gas due to water vapor in the biogas Note: noxious gases often originate from protein breakdown

Legal Classification	*Basic legal considerations to:* - Waste/waste-water - Farmyard manure - Renewable raw materials	* Waste is subject to waste legislation which sets requirements relating to the fermentation technology, involved organizations, and the monitoring of the quality of products and their utilization.
Homogeneity	*Liquids* - Generally homogeneous due to ease of uniform mixing *Solids* - Uniform material composition - Homogenous grain size distribution - Near-absence of interferents Note: Solids are typically not homogenous and must thus be prepared accordingly	* Perpetuates uniformity in sampling and test conditions * Gives insight into costs of preparation procedures (i.e.- labor, energy, and monetary) Note: The process of homogenization of samples is crucial in acquiring representative data

Table 5.1, Criteria for substrate characterization (derived from the handbook on "Fermentation of organic materials, 2006)

5.2 Methodology

The most important function of consistent methodology when conducting batch experiments is to ensure that homogeneity of samples in accordance with the stipulations of the handbook so results of fermentation tests can be considered representative. It is also said that the "objective of the fermentation tests…must be to carry out continuous investigations, to obtain reliable long-timebase data about the gas yield and the material composition of the gas, and to build up the most comprehensive picture possible regarding the degradation of the organic material, the course of fermentation, and any problems in the degradation process" (Verein Deutscher Ingenieure, 2006). Thus it is important to plan the experiment while answering questions regarding:

- Objective of and reason for research

    - Objective: to gain a working knowledge of the role of organic market waste/substrates on the potential gas yield in order to explore possibilities of substrate addition to local biogas plants to increase gas yield and to promote nutrient recycling (re-using market waste)
- Origin of the material
    - Organic human waste will be taken from the septic tank at dorm B23 on the CTU campus
    - Discarded organic market waste will be used from local market vendors
- Material spectrum expected
    - Dry floating layer of solid waste will be taken from septic tank
    - Liquid inocculum will be taken from septic tank
    - Market waste will be a collection of cabbages and lettuce
- Fluctuations in the distribution of the stock of the material
    - Aside from the inocculum, the distribution of the other organic materials will have to be taken into account during sample preparation to ensure homogeneity (market waste is a heterogeneous mixture and so too is the organic human waste)
- Parameters to be defined
    - IMPORTANT: experiments will only be dealing with human waste
    - Samples are taken from small biogas plant
- Occupational safety measures
    - Take appropriate measures to ensure that health and safety risks are minimized

5.2.1 Sampling

Preliminary aspects of the sampling related to "scope" and "performance" are defined by the handbook for the "Fermentation of Organic Materials; Sampling, Collection of Data & Fermentation Tests" include:

- Examination of the consistency/homogeneity of the basic quantity
    - Feces and market waste will need to be prepared in accordance with homogeneous standards.
    - Mixing techniques and random sampling should be employed
- Determine the volume/the mass
    - Organic dry matter content of inocculum, market waste and organic waste must be calculated prior to sampling
    - Water must be removed from samples for 12 hours @ 55 deg. C→ measure cups before and after to calculate mass lost→ cooked again @ 550 deg. C to reduce material to ash (inorganic matter)→ calculate percentage mass lost and infer % of fresh sample that is actual organic matter (calculate organic dry matter content—oDM)
    - Found that
        - oDM market waste: 20 grams = 381.43 grams fresh matter
        - oDM human waste: 30 grams = 196.30 grams fresh matter
        - *Note: calculations of these quantities is exhibited in Appendix A*
- Definition of basic quantity to be evaluated
    - Replications 1-3: total 0 grams oDM/reactor

    - Replications 4-6: total 50 grams oDM/reactor
    - Replications 7-9: total 40 grams oDM/reactor
    - Replications 10-12: total 30 grams oDM/reactor
- Definition of the number of samples & sub samples
    - 12 total batch experiments
    - 4 different experiments with 3 replications each
        - (3)2L Inocculum
        - (3)2L Inocculum + 30 g oDM
        - (3)2L Inocculum + 30 g oDM + 10 g oDM (Market Waste)
        - (3)2L Inocculum + 30 g oDM + 20 g oDM (Market Waste)
- Sampling procedure
    - Septic tank was opened and material was extracted over a period of 20 minutes
    - Protective gear was worn
- Sampling methods (i.e.- systematic, random)
    - Measures were taken to help ensure random selection of material
- Sampling equipment
    - Pump and manual tools
- Reduction to laboratory sample
    - Completed at the rabbit farm with help from Trung
    - Samples were weighed as accurately as possible on site and were sealed shut immediately after all appropriate substrates had been added

- Basic instrument with would not have contaminated or degraded the samples were used to transfer the material from vessel to vessel

- Conservation
    - Samples to be kept in cool place, out of immediate sunlight
    - Samples should be utilized as soon as possible after extraction to ensure that no degradation of material occurs over time
- Packing/transporting
    - Carry to rabbit farm in clean, plastic containers to await batch experiment preparation

Other Considerations

- Take necessary personal protective measures to minimalize health risks
- Use clean sampling equipment that is made from materials that will limit the external influence on the fermentation medium
- Make sure to label and document experiments properly: waterproof labels with type of sample, date and location of sampling and name of sampler
- In extracting liquids, it is necessary to mix it to ensure homogeneity
- Likewise, when sampling and preparing the batches it is important to ensure that the parameters to be investigated have a homogeneous distribution
- Samples should be properly preserved until commencement of fermentation testing

<u>5.2.2 Batch Experiments</u>

What do they provide information on?

- Fundamental evaluation of the biogas yield and the anaerobic biological degradability of a material
- Qualitative appraisal of the speed of anaerobic degradation of the material
- Qualitative evaluation of the inhibitory effect of the material in the specific range of concentrations

Setup

- 12 air tight reactors will be labeled accordingly
- 12 empty biogas bags will be prepared to be attached after material has been added
- Fresh substrates will be weighed by scale, onsite, to ensure that the correct amount of organic dry matter will be present in each experiment
    - oDM market waste: 10grams = 190.71 grams fresh matter

    - oDM market waste: 20 grams = 381.43 grams fresh matter
    - oDM human waste: 30 grams = 196.30 grams fresh matter
- Reactors will we shaken to facilitate the digestion process and to dissolve suspended gases in the mixture and then they will be left at the rabbit farm, in an enclose room, without any temperature regulation to be monitored daily
- Mixing is done once a day to encourage "degassing of the biogas which forms and to prevent the formation of dry and inactive layers of flotate" (Verein Deutscher Ingenieure, 2006).

Collection of Data

- Data will not necessarily be collected everyday
- Bags that are full enough for measurement (> 1L) must be removed and replaced with new, empty bags ASAP to limit the amount of oxygen that diffuses into the reactor and the amount of methane that will diffuse out of it.
- Bags will be measured in the 4th floor lab at the School of Technology between the hours of 9am-12pm to ensure that results are collected at standard intervals
- Since the volume of gas varies with changes in humidity and pressure, the gas has to first be cooled before measurement to remove water vapor
- Machine that measures composition must be calibrated before each use and requires at least 1L of gas to accurately calculate composition
- CH4 (methane), CO2 (carbon dioxide), H2S (hydrogen sulfide), and O2 (oxygen) levels were the gases measured. All of these were in % composition with the exception of H2S which is measured in parts per million.

- Pressure is also recorded before each session in order to later convert the measurements to STP (Standard Temperature and Pressure)
- Bags of each replication will be measured together to ensure similar conditions at time of measurement
- Result will be recorded on spreadsheet
- Results will then be entered into excel spreadsheet to calculate quantity of gas, rate of production, and to compile a graphical representation of biogas production cycle
- At the end of the experiment, bags will all be measured and final data will be entered into the computer to be assessed and discussed
- Note: in the case of this experiment, sufficient time to complete the anaerobic digestion process was not available. Ongoing measurements are being conducted by qualified CTU staff.
- The below picture illustrates the red cooling tank (far left), the gas composition reader (middle), and the devise which measures volume (far right).

5.3 Results

The data collected over the first 18 days of the experiment exhibit trends that give some insight into the role of substrates in biogas formation potential. The results of gas quality and quantity of batches 4-12 are illustrated in figures 5.31-5.33. Batch numbers 1-3 containing the inocculum, were used more as a control than as an actual gas monitoring experiment. The fermenters produced an insignificantly small amount of gas, if any, and there is thus no graph illustrating quantity or composition of them.

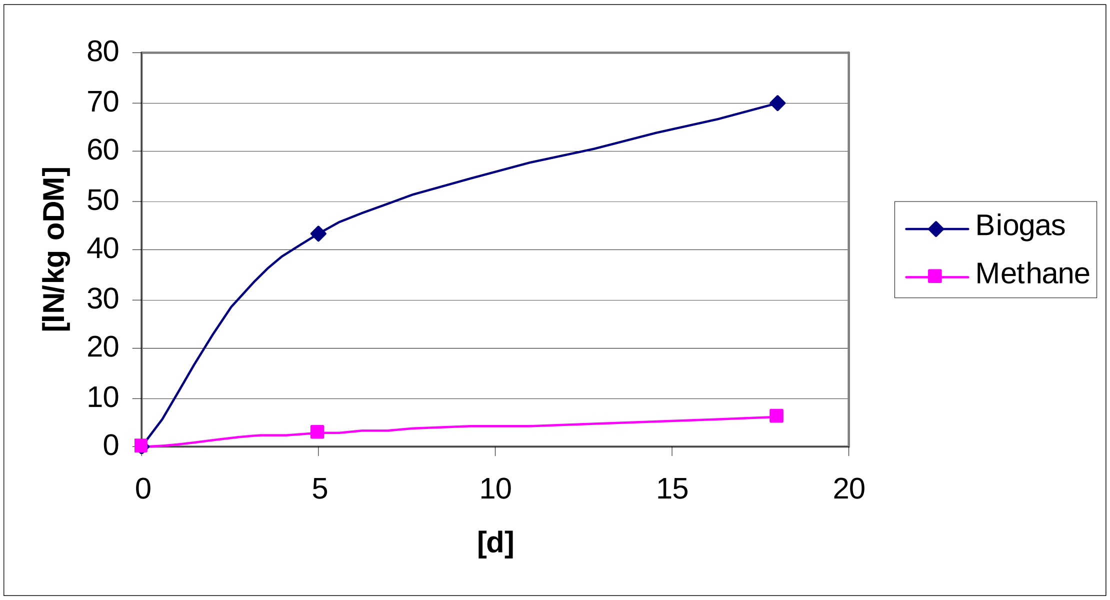

Fig. 5.31, Batches 4-6: 2L inocculum + 30g oDM (waste) + 20g oDM (market waste)

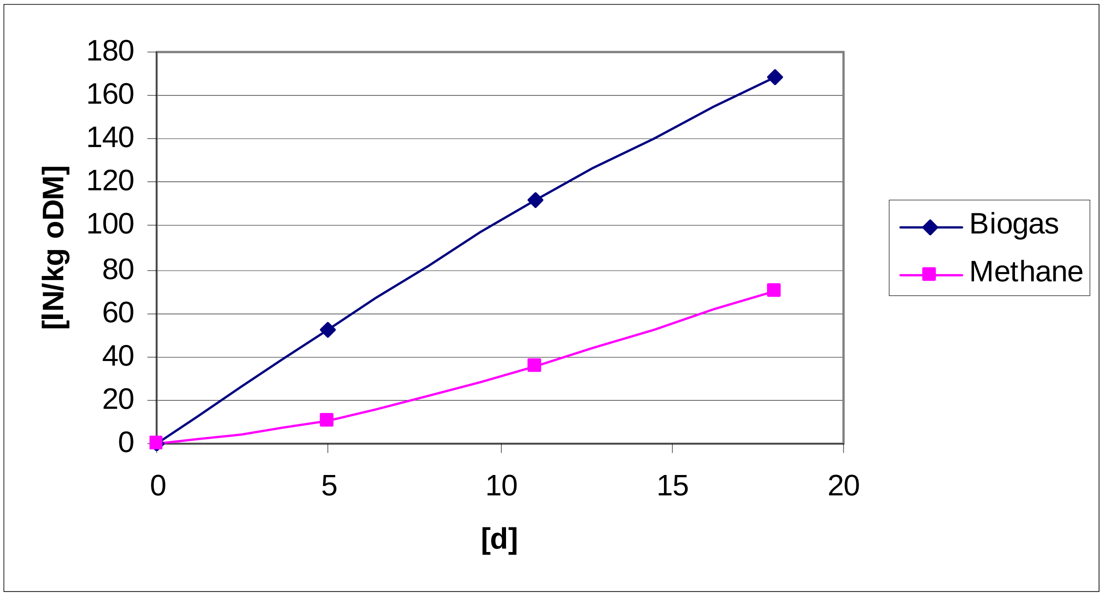

Fig. 5.32, Batches 7-9: 2L inocculum + 30g oDM (waste) + 10g oDM (market waste)

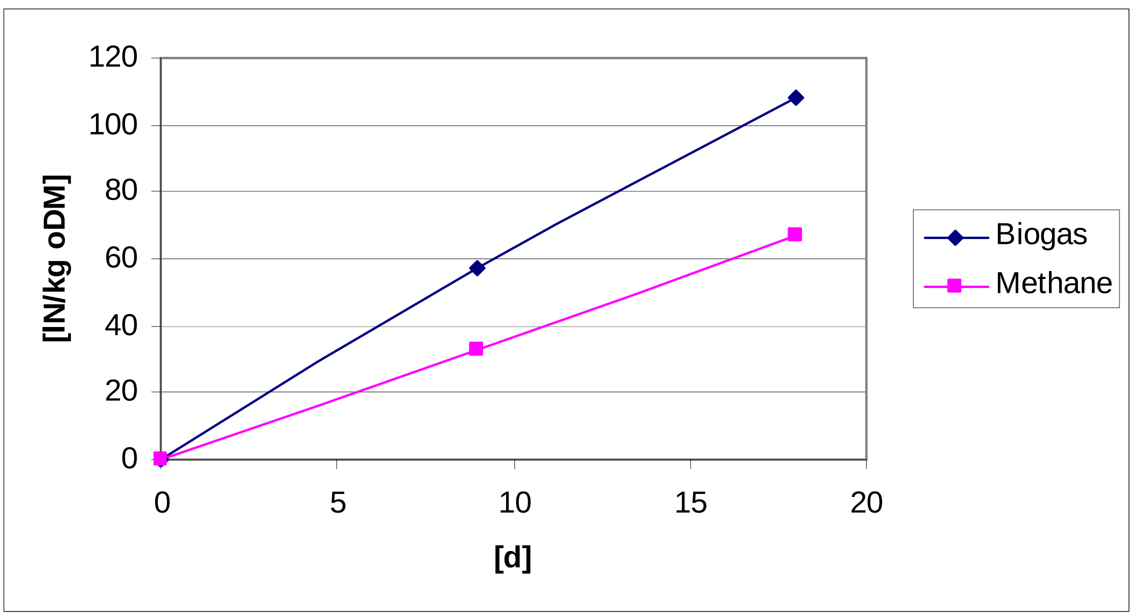

Figure 5.33, Batches 9-12: 2L inocculum + 30g oDM (waste)

5.4 Discussion

It is important to note that due to time constraints, the experiment was not completed in its entirety. As the batch experiments were setup on Saturday, May 5th and the process of anaerobic digestion takes roughly 30 days to complete, the final results of gas quantity, gas quality and the pH of the reactors could not be determined for the purposes of this paper.

Although the test is not yet fully complete, some basic observations can be discussed in terms of the quality and quantity of gas produced thus far. In short, the expectations prior to the experiment was that an increase in organic dry matter, whether it be market waste or human waste, would increase the biogas yield for a replication. Typically, the higher the amount of organic material within a digester means that there is more "food" for anaerobic bacteria and thus, under the right environmental conditions, can produce more gas than they would otherwise.

So what went wrong then? It seems that when considering the circumstances, something went awry in the environmental conditions of the reactor that led to, in the case of the 20 gram oDM market waste replications, a drastically low level of methane production and an increase level of carbon dioxide production. Although the pH of the reactor could not be measure and titration tests could not be conducted at the close of my stay, certain trends point to possible problems with pH level and/or some incongruity or in-homogeneity of the original samples.

As all of the batches were stored in the same place, they were all subject to the same external environments (mainly temperature) and they were not exposed to any light or internal exposure to inhibitors. It is possible that the higher load of organic waste caused the fermentating and acetogenic bacteria to produce a great amount of acetate and other fatty acids too quickly and that the process could not be sustained because the methanogenic bacteria, who require the greatest amount of time to synthesize acetate for their metabolism, couldn't use it as fast as it was being created. This increase in pH would account for the high amount of carbon dioxide present in the 20 gram samples, however there is really no way of knowing, as the pH could not have been measured prior to this report.

Other explanations may involve the opposite explanation; that there was too much ammonia being produced by the first 3 metabolic groups and there was thus a very high pH in the reactor. This would also be antagonistic to methanogenic growth/digestion as they are the most sensitive of the bacteria's to environmental changes. Since it was human waste that was being utilized, this may seem to be more likely than a buildup in acetate or strong acids because human waste is typically very high in nitrogen. Nitrogen present in the digester serves 2 important functions: 1) it facilitates the synthesis of amino acids, nucleic acids and proteins, and 2) it is converted to *ammonia* which, as a strong base, is important in keeping the pH of the reactor above a nominal 6.8 for methanogenic bacteria (Marchaim, 1992).

In light of the fact that human waste is much higher in nitrogen than cattle or pig dung, this excess buildup of nitrogen may be the main source of the problem in these digesters. What may also play a role is the fact that the fermentation of animal waste, such as cow manure, is much faster acting due to an already high presence of bacteria in the dung (ruminant); maybe adding any excess organic waste to human waste is more difficult to sustain due to the lack of initial presence of bacterial colonies. Whatever the reason for the low levels of methane in the 20 gram oDM sample, it is unclear whether or not these problems were caused by pH, temperature, or the presence of pollutants or inhibitors due to the inability to test for such things at the current time.

As for the 10 grams oDM market waste replications and the inocculum + 30 grams oDM (human waste), it would also be improper to draw any serious conclusions about the processes either, as they both behaved similarly despite the varying total oDM content and composition.

6. Conclusion

The remainder of this project will be seen through by qualified CTU students conducting similar research. The bags will continue to be monitored for both quantity and quality over the next couple of weeks to be evaluated at a future point in time. Such experiments are critical and effective in helping to better understand the biotechnological process of the biogas formation cycle and are thus important avenues of research in a place such as Vietnam, where the vast majority of the population lead agrarian lifestyles and who are developing an increasing demand for modern amenities and the basic right to clean water resources and a sustainable future. The application of these technologies depends on such studies to provide a clearer view of what it will take to develop these technologies for the benefit of the Vietnamese people and also to help shed more light on the plethora of benefits it provides on economic, social and environmental levels.

References

Bac Hai (2006). Environmental Field Studies Seminar. My Kahn Village, Vietnam.

Bryant, M.P., Wolin, E.A Wolin, M.J and Wolfe R.S (1967) Arch.

DEWATS (2007) Decentralized Wastewater Treatment Seminar, School of Technology, Cantho University, Vietnam.

GTZ-Deutsche Gesselschaft fuer Technische Zusammenarbeit (1996). Proceedings of the Regional Seminar of South-East Asia on "Anaerobic Technology for Wate and Wastewater Management and its Economic, Social, and Ecological Impacts", Ho Chi Minh City, Vietnam.

Heifer Inernational (2007) Environmental Field Studies Seminar. Cantho, Vietnam.

Imhoff, K. (1938) In: (L. Pearse, ed.) Modern Sewage Disposal, Lancaster Press, Lancaster, Penn., p. 47.

Man, T.D., Hien, L.T. (2006) "Biomass Potentiality, Utilization and Status Development of Bio-fuel in Vietnam". Institute of Biotechnology, Vietnamese Academy of Science and Technology, Vietnam.

Marchaim, U., and Criden, J. (1981) In: (D. L. Wise, ed.) Fuel gas production from biomass, Vol. 1, CRS press, Boca Raton, FL., pp. 95-120.

Marchaim, U. (1983) Acetic to propionic acid ration as a control device for anaerobic digestion processes. A report to Battelle, Columbus, OH.

Marchaim, Uri. (1992) Biogas processes for sustainable development. MIGAL Galilee Technological Centre, Kiryat Shmona, Israel.

Nguyen, N.S, Nguyen V.T, Do, N.Q, Lam, M.T, Do Hong, L.C. (1996) Application of anaerobic process for waste treatement, Environmental protection in Vietnam. Ho Chi Minh City, Vietnam.

Speece, R.E. and McCarty, P.L. (1964) Advances in Water Poll. Res. 2, Pergamon Press, London, p. 305.

Verein Deutscher Ingenieure (VDI) (2006). Fermentation of organic materials: Characterization of substrate, sampling, collection of material data, fermentation tests. VDI- Handbuch Energietecknik.

Appendix A

	Gefäß [g]	Schale+Einwaage [g]	Einwaage[g]	Gefäß+Rückstand [g]	Rückstand [g]	TS [%]	TS [%]
Biowaste	79.053	114.996	35.943	81.68	2.627	7.31	**6.36**
	50.768	92.548	41.78	53.031	2.263	5.42	
Inocculum	49.341	131.241	81.9	49.488	0.147	0.18	**0.18**
	72.971	137.783	64.812	73.092	0.121	0.19	
Human waste	47.165	102.063	54.898	56.267	9.102	16.58	**16.54**
	51.164	105.243	54.079	60.082	8.918	16.49	

* 1st cook @ 55 deg. C→ elimate water content

	Gefäß [g]	Schale+ Einwaage [g]	Einwaage [g]	Gefäß+Rückstand [g]	Rückstand [g]	GV [g]	GV [%]	GV [%]
Biowaste	79.053	81.68	2.627	79.442	0.389	2.238	85.19	**82.41**
	50.768	53.031	2.263	51.229	0.461	1.802	79.63	
Inocculum	49.341	49.488	0.147	49.408	0.067	0.08	54.42	**55.31**
	72.971	73.092	0.121	73.024	0.053	0.068	56.20	
Human waste	47.165	56.267	9.102	47.822	0.657	8.445	92.78	**92.43**
	51.164	60.082	8.918	51.871	0.707	8.211	92.07	

* 2nd cook at 550 deg. C→ elimate organic matter content

	TS [%]	GV [%]	oTS [%]	oTS[g]	FM [g]
Biowaste	6.36	82.4	5.24	20	381
Inocculum	6.36	82.4	5.24	10	191
Human Waste	16.54	92.4	15.28	30	196
	0.18	55.3	0.10		

* Weighted sample calculations