San Francisco Agricultural School

Biodigester Usage and Improvement

An Interactive Qualifying Project

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An Interactive Qualifying Project
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by
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Abstract

The San Francisco Agricultural School seeks self sufficiency and has biogas generation potential. This project sought the best use of the school's biogas. The team carried this out through interviews with key personnel, observations of relevant activities, and textbook calculations. Biogas should be directed to warm young piglets during cold periods. Construction and testing of the system should follow.

Acknowledgements

We would like to thank the professors and students at the San Francisco Agricultural School and Fundación Paraguaya for their help and friendship. Without the following individuals, our project would not have been possible.

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Executive Summary

Paraguay is a landlocked country in South America challenged by a high poverty rate, primarily in rural areas. To address this, Fundación Paraguaya utilizes several methods, notably, agricultural schools. The San Francisco Agricultural School was Fundación Paraguaya's first and relies on self-sufficiency for its operation. The school augments self-sufficiency through the generation of its own energy.

Biodigesters convert agricultural waste to biogas that can be used as energy. The school has two biodigesters. The biodigester in the Animal Production Center currently produces biogas but the biogas has not been utilized. Previous projects have created a manual for the operation of the biodigester and drafted a plan to direct the biogas to warm the piglets. However, other potential uses of the biogas have not been investigated.

Therefore, the team explored other potential applications of the unused biogas and designed optimizations for the biodigester. Interviews with staff identified four main applications. These were warming the suckling piglets, heating water for the slaughter of animals, heating water for the boys' dormitory, and supplying gas to burners in the kitchen.

The team familiarized themselves with the basics of biodigesters. Interviews with key personnel and observations determined the physical features of the biodigester, biodigester maintenance practices, and the specifics of the four applications. The team calculated the biogas demand and financial benefits of each application. Table (i) shows each application's monthly biogas demand, distance from the biodigester, and monthly earnings.

Application	Monthly Biogas Demand (m^3)	Distance from Biodigester (m)	Monthly Earnings (Guaranies)
Animal Slaughter	21	205	0
Supply Kitchen	391	218	6,061
Warming Piglets	651	68	210,000
Boys' Dorm	1038	192	0

Table (i): Summary of biogas application details

The San Francisco Agricultural School should direct biogas to warm the suckling piglets. The benefits are the proximity of the piglets to the gas source, financial gain, and improved working conditions of students tending to the piglets.

Several optimizations for the biodigester are also recommended. The longevity of the biodigester can be increased by the addition of a roof and by a filter made of a PVC tube and iron shavings. The productivity of the biodigester can be improved by the addition of a one to four percent incline in the base of the well and by a PVC or bamboo grid weighted with water bottles to increase pressure in the bags. Additionally, the school could use the digestate as fertilizer and construct another biodigester.

Authorship

Each group member contributed equally to all parts of the paper. Its writing, editing, and organization were products of team meetings. Team cohesion and general affability allowed the team to write this paper together, and not even sentences were finalized without every member having a hand in it.

Alicia Aquino

Alicia performed the technical research required for the understanding of biodigester operation. This researched was summarized and presented to the group. She additionally aided in all interviews, by taking down notes and asking pertinent follow-up questions. Alicia helped with the writing and editing of each section in the paper by ensuring that sentences were succinct and clear.

Gabriela de Peralta

Gabriela kept the team on task and focused on the goals of the project. She organized Gantt charts, schedules and meetings and maintained team productivity. Gabriela was also the co-lead on the project's calculations and presentation organization. She also ensured the organization of the paper fit with the requirements and was excellent at making concrete decisions to move the project forward.

Alexandra Rozen

Alexandra acted as the interview scheduler and staged questions before each interview. Alex would routinely draft large sections of the report, most notably the methodology, and would be open to feedback and corrections. She would always contribute feedback to others' writing. She also contributed greatly to the overall organization of the paper.

John Tofuri

John served as the primary interviewer and Spanish speaker of the project. He translated interview questions before meetings and presentations and drafted the executive summary in Spanish that was submitted to the San Francisco Agricultural School. John also improved the syntax of the paper by providing clear, professional ways to phrase sentences.

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1.0 Introduction

Paraguay is a developing country located in the center of South America. Of Paraguay's 6.7 million residents, thirty-five percent live below the poverty line (South America, 2016). The highest percentages of poverty are in rural areas of the country due to an inability to effectively use the land to make a profit (World Bank, 2014).

Fundación Paraguaya was founded to address poverty in Paraguay. The foundation utilizes several different methods to achieve this, notably, by enrolling students in agricultural schools. The San Francisco Agricultural School was Fundación Paraguaya's first of such schools. The purpose of the school is to teach business and agricultural skills to rural youth. These skills include hospitality, marketing, dairy processing, and organic farming. To achieve this purpose, the school relies on self sufficiency in its curriculum and operation. Self-sufficiency is crucial to the school because it must support 150 resident students and faculty members with minimal outside funding. The school achieves self-sufficiency in numerous ways, particularly through the generation of energy using biodigesters.

The San Francisco Agricultural School has two biodigesters. The first is located near the kitchen and supplies energy for cooking (Lazaro, et. al., 2015). The second, located near the cow pens, is operational, but is not directed to an application.

Ardini and Mackoul designed a plan and performed a cost analysis for directing this biogas to warm the piglets (2013). Lazaro, et al. created a manual for the operation of the biodigester and suggested design changes to improve biogas production (2015). However, these projects did not analyze other applications for the biogas.

This project identified potential uses of the biogas, analyzed the energy demand and additional costs and benefits, and recommended a plan for the best application. As a result of this project the school's biogas will be put to use, furthering the school's mission of self-sufficiency.

2.0 Background

In order to maximize self-sufficiency, the San Francisco Agricultural School must make the most of its available resources. A resource readily available at the school is manure. Typically manure is discarded as waste or used as fertilizer. However, it can also be used in the generation of biogas. Biogas is an alternative source of energy that is burned as fuel. Biodigesters produce biogas energy with minimal costs. The important considerations for a biodigester are the conditions it operates under, the transportation to its application, and the types of applications.

2.1 Biodigesters

Biodigesters convert manure and other organic waste into biogas for fuel. The digested waste can then be used as fertilizer, thereby mitigating the cost of solid waste disposal. Because the labor and material costs of simple biodigesters are low, people around the world use them as sources of energy.

The school uses a tubular balloon biodigester. This is a longitudinal system with a bag partially recessed into a trench constructed for the bag's size.

The energy production process of a biodigester has three main stages: 1) input of organic waste, 2) conversion of waste to methane, and 3) collection and transport of methane for energy use (see Figure 2.1-1).

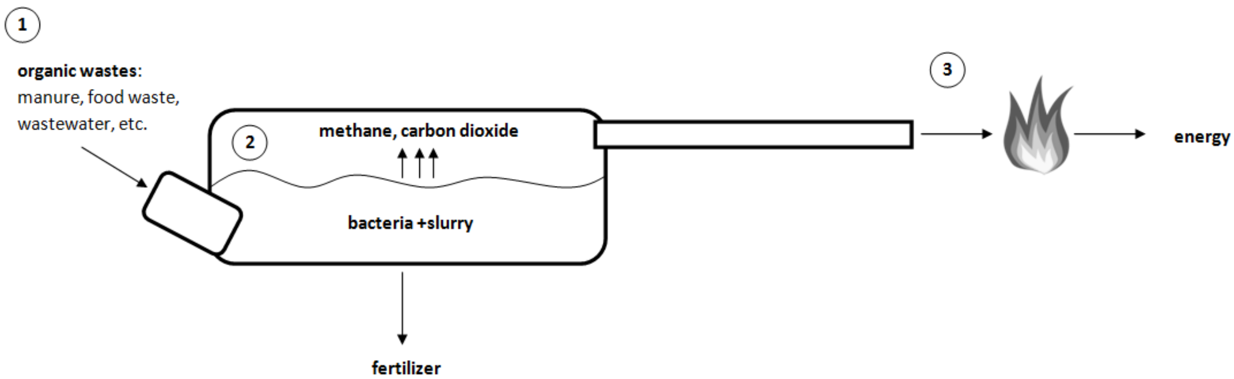

Figure 2.1-1: Diagram of stages in biodigester operation.

The feed of the biodigester is slurry, a mixture that consists of water and organic waste. Organic waste materials are byproducts of living organisms. Bacteria in the digester metabolize these materials and release methane. Organic waste materials that are more easily metabolized by bacteria yield greater amounts of methane. For example, cow manure is more easily digested than fiber-rich wastes such as wood and leaves (Lazaro et al., 2015). The school's current daily input is approximately 100 kilograms of cow manure.

The properties of the bag include its dimensions, material, and biology. Each bag at the school is a tube that, when fully inflated, extends ten meters in length and two meters in diameter. The bags are located in a well that is one meter deep so as to leave the top half of the bag exposed. The bags are made of 200-micrometer thick polyethylene. The biological properties of the bags are the same as other biodigesters when the primary fuel is cow manure. Inside the biodigester, organic waste is broken down by naturally occurring bacteria through anaerobic respiration. Methane gas is the end product of this process (Lazaro et al., 2015). The methane as well as other gases diffuse to the top of the biodigester where they can be directed through pipes to where energy is needed.

2.1.1 Biodigester Conditions

Although a biodigester is a simple apparatus, it requires certain conditions to ensure successful operation. These conditions are consistent temperatures and regular maintenance.

The ideal temperature range for methane production is twenty five to forty degrees Celsius. For comparison, the ambient temperature of Paraguay ranges between twenty and forty degrees Celsius. Higher digester temperatures increase the rate of methane production, resulting in higher methane yield. To increase the temperature of the digester, a greenhouse roof can be constructed (Solano, et al., 2010).

Regular maintenance is performed by students and staff of the school. Routine operations include the daily loading of the bag and the agitation of its contents. Each morning, students collect cow manure, mix it with water, and load the slurry into the biodigester. The contents of the bag are regularly agitated with a flexible pole to prevent build up of dried slurry. A one to four percent incline better facilitates the mixing and movement of slurry through the biodigester. This aids the egress of the digestate. Digestate then pools into the exit well from which it flows as an uncontained stream.

2.1.2 Energy Transportation

Three methods to deliver energy produced by biodigesters are direct transport of the biogas through rubber tubing, a methane storage system, and distributing hot water created by burning the gas.

Direct Transport.

To directly transport biogas, the physical properties of the tubing must be considered, pressure must be maintained, and corrosive components must be removed.

The physical properties of the tubing are the dimensions and material. The dimensions that affect gas flow are length and diameter. Greater length increases the volume of the system, thus decreasing the gas flow. Smaller diameters increase the friction of the gas through the pipes. High friction in the pipes decreases gas flow. Additionally, material considerations must be made, as some are more susceptible to corrosion than others. Metal and PVC are prone to corrosion, while rubber is not (J. Samaniego, pers. comm., March 29, 2016).

Pressure can be maintained by pressurizing the gas directly or by compressing the bags. Pressurizing can be achieved with pumps; however, this method is not economical for the school. Compression can be easily achieved by placing weights onto the bags. The concern here is that the weights neither tear nor puncture the bag.

Corrosion in the system can be mitigated by filtration. Filtration can be achieved by the addition of iron shavings or steel wool into the pipe (J. Samaniego, pers. comm., March 29, 2016) (Ardini and Mackoul, 2013). Iron chemically reacts with corrosive sulfur compounds to produce non-corrosive materials.

Storage Systems.

Methane can be stored in either transportable or non-transportable containers. Transportable containers include inner tubes, balloons, or pressurized tanks (Lazaro, et al., 2015). Non transportable containers are gas reservoirs that are typically constructed near the use of the gas. The same material considerations for tubing apply to biogas storage.

Hot Water.

The heat generated by burned methane can be delivered as hot water. The efficiency of heat transfer in the system must be considered. Efficiencies are well documented in the literature. The delivery of hot water over a distance results in a heat loss, and therefore it is almost always more efficient to transport gas than to transport hot water (see Appendix A5).

2.1.3 Biogas Applications

Biogas can be used to fuel a burner for space and water heating and for cooking. The school is considering all of these uses, specifically, warming piglets with biogas heaters, heating water for showers in the boys' dormitory or to aid the plucking of chickens, and to fuel the kitchen burners.

The school's current method of warming suckling piglets is unreliable. Fires are lit next to the farrowing pens to warm the piglets. The fires are tended by students from the school who stay in the barn overnight. Despite these good intentions, fires will often go out. This is a problem because piglets require an ambient temperature of thirty to thirty five degrees Celsius in the first three weeks of life. If temperatures drop below this, the piglets chill, develop diarrhea, and die within two to three days (L. Saucedo, pers. comm., March 17, 2016).

Supplemental heating is needed year-round. During the winter months, heating is required throughout the day. In early spring and late autumn, fourteen hours of supplemental heat are needed. Even in the summer, piglets must be heated for four to nine hours (L. Saucedo, pers. comm., March 17, 2016).

Currently, the boys' dormitory does not have a regular source of hot water. Among other things, this means that cold showers are normal and pose a health hazard on cold winter days (V. Borges, pers. comm., April 5, 2016). With as many as three showers per day per student at five liters a shower, the need for a gas fired boiler for the boys' dormitory is evident.

Hot water is required for plucking chickens. Typically, the water is heated between sixty and eighty degrees Celsius (L. Saucedo, pers, comm. April 5, 2016). Once the water is at temperature, the chicken is fully submerged for thirty to forty-five seconds (Rady, 2013). The school typically plucks chickens ten times a month and uses fifty liters of water per operation. Wood is the current fuel, but its availability is rapidly decreasing on campus.

The primary fuel for the kitchen is electricity. This was augmented by methane produced by a small biodigester. This biodigester no longer operates and appears beyond repair. If gas from the new, larger biodigester was available, the kitchen could resume using this source of fuel.

3.0 Methodology

The methodology section identifies the ways that information was gathered and calculations were made to assess the best use of the biogas. Observations and interviews determined the way in which the school's biodigester is maintained, the key physical features of biogas production,, and the possible uses for the gas.

Observations of the maintenance of the bag were conducted on April 6th and 7th, 2016. The focus of these observations was to identify how students load the biodigester and recorded any additional maintenance. Students were observed in the morning between 6:30 and 7:00 AM and their activities were manually recorded.

Another observation, the measurement of distances between the biodigester and four prospective areas of applications, was conducted on April 8th, 2016. The results of this observation were recorded manually.

Finally, observations were conducted on March 29th, 2016 at the Taiwanese University of Asuncion. The team studied the university's biodigesters and observed a working biodigester system in which the gas was directed to heat piglets. The results of this observation were recorded manually and photographically.

In addition to observations, interviews were conducted at the school with staff and other IQP teams. Each interview was recorded and then reviewed by the team for content and accuracy. Director of the *Centro de producción animal* (animal production center) was interviewed frequently. These interviews were conducted on March 17th, 21st, and April 6th. The interviews gathered more information about the logistics of the biodigester and the warming of piglets, and the feasibility of directing biogas to the piglets. The final interview sought a critique of the teams work to date. These interviews are documented in Appendix C.

Interviews provided by Director of Escuela Agricola Luis Cateura also critiqued and advised the progress of the project. These interviews were conducted on April 4th and 20th of 2016. Feedback was recorded manually and is shown in Appendix C.

Finally, an interview with the Director of General Services, Virgilio Borges, was conducted on April 5th, 2016. This interview identified logistics of the different possible applications of biogas at the school. This interview was manually recorded and can be found in Appendix C.

Along with interviews and observations, there were calculations. These calculations determined the biogas demand of each application, the additional volume of biogas needed to fill different lengths of pipes, and the financial benefits of each application. The principles and formulas for calculations were standard textbook operations.

3.1 Ethics

The project encountered two ethical concerns: how to conduct qualitative research and how to do business abroad. In regards to qualitative research, the team always sought permission to record what was said. When doing business abroad, the team promoted the view that everyone involved was a partner in the effort to determine the best use of biogas. The team worked collaboratively with the teachers, students and staff at the San Francisco Agricultural School to accomplish the project.

4.0 Results and Discussion

The results and discussion section examines requirements for each of the four uses of biogas that were identified by school personnel. These are warming piglets, heating water for showers or slaughtering animals, or cooking. Each section analyzes the negatives and positives of each application based on biogas demand, financial considerations, and human factors.

4.1 Warming Piglets

The biogas can be used to warm piglets at the school. There are negatives and positives to this application. The negatives are that piglets require the second highest amount of biogas relative to the other applications and that the system is the most difficult to install. The positives are the proximity of piglets to the biodigester, the financial opportunity when piglet mortality is reduced, and the amount of labor and resources required is reduced by using biogas.

Negatives.

The biogas demand for the piglets was calculated using the hourly demand of a Puxin biogas heater. This heater requires 0.3 cubic meters of gas per hour (Puxin Biogas, n.d.). Based on information provided by director Saucedo, it was assumed that in the winter, the piglets need to be heated for between fourteen and twenty-four hours per day. In the summer, only four to nine hours of heat are required. In total, Paraguay’s winter requires approximately four to seven cubic meters of gas per day per heater and the summer requires approximately one to three cubic meters of gas per day per heater. These results are summarized in Figure 4.1-2.

The system to heat the piglets has requirements that make it difficult to install. The first is a one inch rubber hose that must be strung above ground, utilizing the buildings and additional poles as support. Second, the hose must be attached to heaters in series using a T-joint. The heaters must hang above the farrowing crate and include valves to control the flow of biogas. This system is modeled after the team's study of the Taiwan Technical Mission at Universidad Nacional de Asunción. In terms of materials, all necessary components are compiled in Figure 4.1-3. This is the most complicated system of the four possible applications, however the system has benefits as well.

Positives.

The piglets are located closest of the four applications at sixty-eight meters. Over this distance, pressure loss due to friction was determined to be negligible (see Appendix B1). The volume of gas needed to fill the pipe distance is a larger concern. Before the gas can be burned for use, an extra 0.0314 cubic meters of gas is required. This calculation is shown in Appendix A5.

Warming the piglets also provides the greatest monetary gain for the school. Each piglet costs 130 thousand Guaranies to be raised and can be sold for 200 thousand Guaranies. This results in a profit of seventy thousand Guaranies per piglet. Typically, one to two piglets die per litter (Luis Saucedo, pers. comm., March 21, 2016). Assuming there are three litters per month and one piglet is saved per litter with the biogas heaters, the school could earn 210 thousand Guaranies each month by implementing this system.

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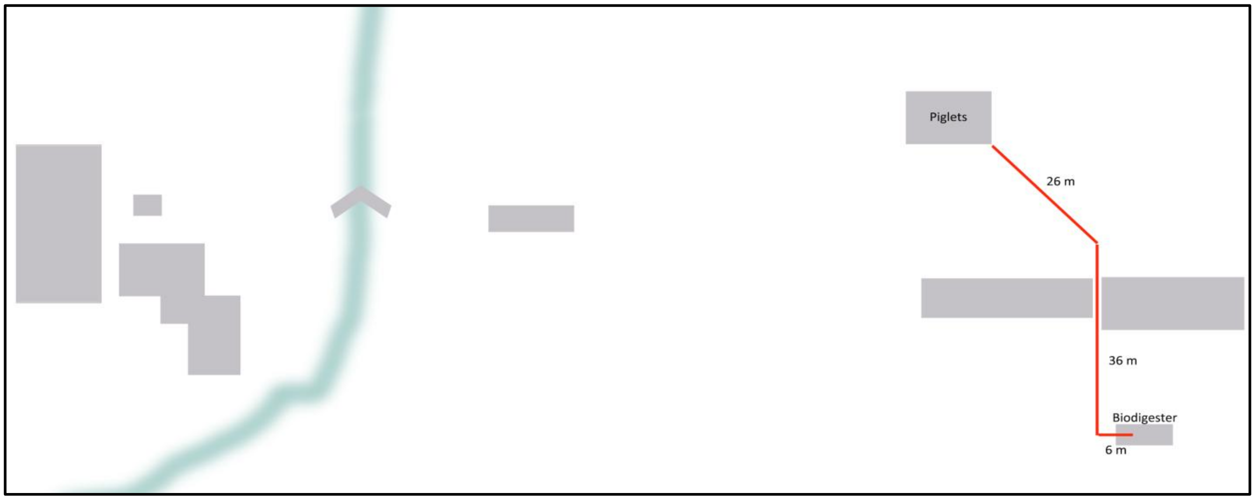

Figure 4.1-1: Piping Route to Piglets

Warming Piglets	One Heater (0.3 m^3/hr)			
	Winter (Long)	Winter (Short)	Summer (Long)	Summer (Short)
Hours of heating	24	14	9	4
Biogas Needed (m^3)	7.2	4.2	2.7	1.2
Pipe Volume (m^3)	0.0			
Total Biogas (m^3)	7.2	4.2	2.7	1.2

Table 4.1-1: Seasonal Biogas Demand Summary Table

1	68 meters (minimum length) of 1” diameter rubber tubing
2	3 biogas heating lamps
3	Hydrogen Sulfide filter
4	3 PVC elbow joints (1 for each biodigester, 1 to angle down from roof of farrowing pen)
5	4 PVC T-joints (1 to connect the biodigesters, 1 for each heating lamp)
6	6 globe valves (1 for each biodigester, 1 before the filter, 1 for each heating lamp)
7	One 4 meter pole

Table 4.1-2: Suggested Materials List

4.2 Heating Water for the Boys' Dormitory

The biogas can be used to heat showers in the boys' dormitory. Heating this water has negatives and positives. The negatives are that this application has no monetary benefits for the school, requires the most amount of biogas, and is the second farthest location from the biodigester. On the other hand, the health of the boys can be improved.

Negatives.

This system has high upfront costs and no return on investment. The school would be required to purchase all the components of the system and would not be able to generate any profit. There is no monetary benefits from installing hot water in the boys' dormitory. A list of the components for the installation of this system can be found in Figure 4.2-3.

Additionally, the biogas demand for this application is highest. This conclusion follows from an investigation of two heating systems: tankless water heaters and natural gas fire tube boiler tank. The tankless water heater can service one shower stall at a time and consumes three cubic meters of biogas per hour. To make this estimate, a maximum use scenario was assumed. Shower stalls would be used constantly during the break periods of the day. One and one-half hours during the morning, two hours during the afternoon, and almost five hours at night. To meet this demand, the tankless water heater requires 24.75 cubic meters of biogas per day.

Alternatively, the school could use a natural gas fire tube boiler tank. The hourly biogas consumption of an appropriately sized boiler is 4.18 cubic meters (Boiler Types and Selection, n.d.). Under the same assumptions for operation as the tankless heater, the demand for the entire boys' dormitory would be 34.485 cubic meters of biogas per day. Either of these options still has the greatest biogas demand of all applications.

Lastly, the boys dormitory is 192 meters from the biodigester. This increases the daily biogas demand by 0.097 cubic meters of gas to fill the pipes. These calculations can be found in Appendix A5.

Positives

Hot showers will improve the boys' health. Cold water in cold weather challenges anyone's physiology and sickness can result. This does not consider the issue of student morale.

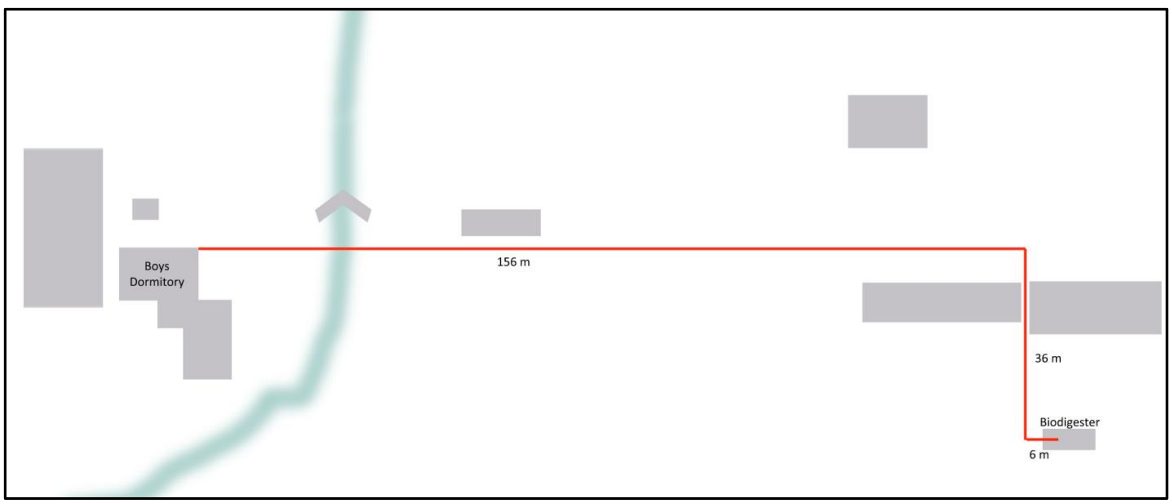

Figure 4.2-1: Piping Route to Boys' Dormitory

Boys' Dorm		Boiler Tank (4.18 m^3/hr)	One Tankless Boiler (3 m^3/hr)
Morning	Hours	1.5	
	Biogas Used	6.3	4.5
Afternoon	Hours	2	
	Biogas Used	8.4	6
Night	Hours	4.8	
	Biogas Used	19.9	14.3
Pipe Volume (m^3)		0.1	
Total Biogas (m^3)		34.6	24.8

Table 4.2-1: Daily Biogas Demand Summary Table

1	198 meters (minimum length) of 1" diameter rubber tubing
2	a) 14 or fewer biogas tankless water heaters (1 for each shower head) b) 1 Natural Gas Fire tube Boiler
3	Hydrogen Sulfide filter
4	2 PVC elbow joints (1 for each biodigester)
5	a) 15 PVC T-joints (1 to connect the biodigesters, 1 for each shower head) b) 1 PVC T-joint (1 to connect the biodigesters)
6	4 globe valves (1 for each biodigester, 1 before the filter, 1 before series of heaters or before boiler)

Table 4.2-2: Suggested Materials List

4.3 Heating Water for Animal Slaughter

The school can use the biogas to heat water for the slaughter of animals. This application has negatives and positives. The negative is that it has no monetary benefit for the school because no-cost firewood is currently used for fuel. The positive is that it uses the least amount of biogas and can be combined with other applications.

Negatives.

The negative of this system is that it incurs costs without subsequent profits. The school would need to invest in a heating tank, connecting hose, and related materials (Figure 4.3-3). Firewood, the current fuel, has no cost.

Positives.

The demand for gas to slaughter animals differs for chickens and pigs. Four hours of chicken slaughter requires 2.13 cubic meters of gas. Forty-five minutes of piglet slaughter requires 0.63 cubic meters of biogas. In addition, both slaughterings require 0.104 cubic meters to fill the pipe volume. For detailed calculations, see Appendices A2 and A5.

Since the gas demand is low relative to the other three applications, animal slaughter can be thought of in tandem with another application. For example, a hot water boiler could be installed to service both the boys' dormitory and the slaughterings. The biogas could also be directed to burners for both the kitchen and the slaughterings. This is feasible since the slaughterings take place near the boys' dormitory and the kitchen.

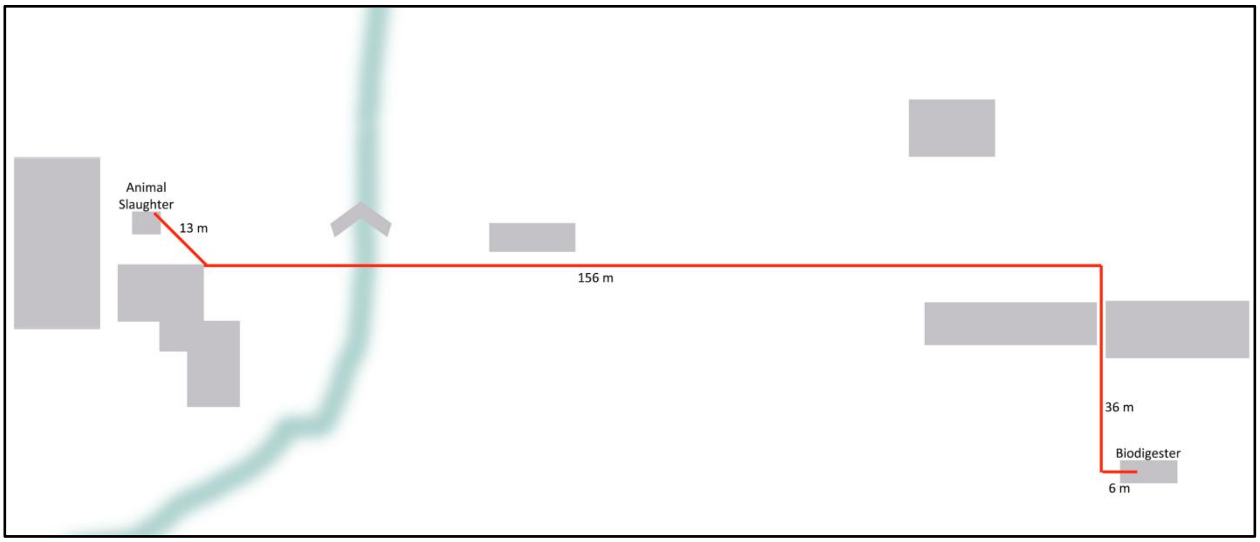

Figure 4.3-1: Piping Route to Animal Slaughter

Animal Slaughter	Stovetop Burner (0.45 m^3/hr)		Boiler Tank (4.18 m^3/hr)	
	Chickens	Pigs	Chickens	Pigs
Water needed @ 80 °C (L)	50	30	50	30
Time (hr)	4.5	1.2	4.5	1.2
Biogas Used (m^3)	2.0	0.5	18.8	4.9
Pipe Volume (m^3)	0.1			
Total Biogas (m^3)	2.1	0.6	18.9	5.0

Table 4.3-1: “Per Event” Biogas Demand Summary Table

1	211 meters (minimum length) of 1” diameter rubber tubing
2	1 biogas burner
3	Hydrogen Sulfide filter
4	2 PVC elbow joints (1 for each biodigester)
5	1 PVC T-joint (to connect the biodigesters)
6	4 globe valves (1 for each biodigester, 1 before the filter, 1 for the burner)

Table 4.3-2: Suggested Materials List

4.4 Supplementing the Kitchen

The fourth application is the school kitchen. The implementation of biogas in the kitchen has negatives as well as positives. Negatively, the kitchen is the farthest from the biodigester, and use of gas there requires new equipment. However, changing the kitchen to biogas would positively impact its energy costs.

Negatives.

The kitchen has the highest additional biogas demand due to distance. It is located 218 meters from the biodigester. This adds 0.11 cubic meters of biogas to the daily demand (see Appendix A5). Moreover, the school would need to purchase additional biogas stove tops depending on the amount of biogas directed to the kitchen. This presents a potentially large upfront cost to the school. A list of suggested materials can be found below in Figure 4.4-3.

Positives.

Conversely, operating costs for the stoves in the kitchen could be virtually eliminated. Each electric burner that a biogás burner replaces saves the school 1,500 Guaranies per month in electricity. .

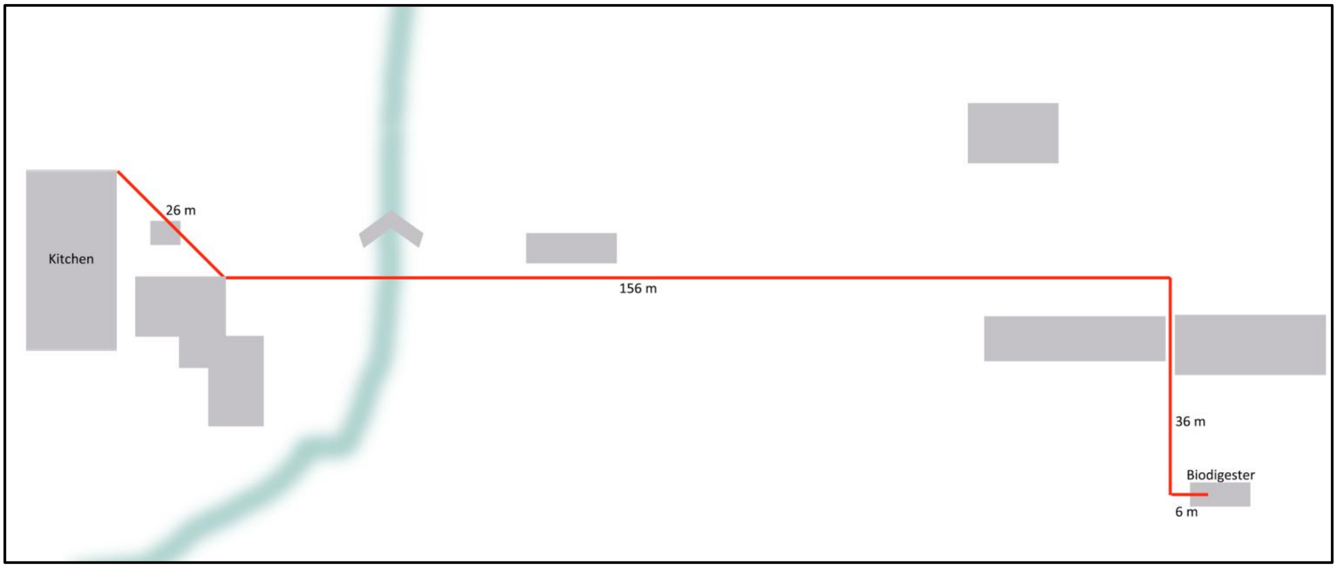

Figure 4.4-1: Piping Route to Kitchen

Supply Kitchen	Single Burner (0.45 m^2/hr)			
	Desayuno	Almuerzo	Cena	Tortillas
Cook Time (hr)	1	2	2	2
Biogas Used (m^3)	0.5	0.9	0.9	0.9
Pipe Volume (m^3)	0.1			
Total Biogas without Tortillas (m^3)	2.4			
Total Biogas with Tortillas (m^3)	3.3			

Table 4.4-1. Daily Biogas Demand Summary Table

1	224 meters (minimum length) of 1" diameter rubber tubing
2	1-4 biogas burner(s)
3	Hydrogen Sulfide filter
4	3-6 PVC elbow joints (1 for each biodigester, 1 for each burner)
5	2 PVC T-joints (1 to connect the biodigesters, 1 for the burners)
6	4 globe valves (1 for each biodigester, 1 before the filter, 1 before burners)

Table 4.4-2: Suggested Materials List

4.5 Additional Findings

Following the analysis of the four applications, there were other considerations. These include improvements to the longevity and productivity of the biodigester and other findings. To improve the longevity, the design and addition of a filter and a shift to alternative bag materials were investigated. To improve productivity, the addition of a retention pool and the design of a compression system were studied. Finally, the installation of hydronic heating, an additional biodigester, and the use of human waste were considered.

Filter.

A hydrogen sulfide filter is crucial to the longevity of the biogas system. The filter and its importance is discussed by Ardini and Mackoul (2013). Hydrogen sulfide corrodes any plastic or metal it contacts, and its effects were observed at the Taiwan Technical Mission.

A hydrogen sulfide filter can be made with a PVC tube containing iron. Iron reacts with hydrogen sulfide to create non corrosive materials (Serfass, n.d.). Two low-cost sources of iron are steel wool and leftover iron shavings. This type of filter requires replacement every six months. Commercial filters need less frequent replacement but cost more.

Alternative Bag Material.

The lifespan of the biodigester can be increased through the use of thicker and more durable bags. Red Mud PVC bags are made of recycled PVC compounds and red mud, a waste byproduct of the aluminum production industry. The strengthened, highly elastic plastic results in greater resistance to acid and corrosion damages. Additionally, Red Mud bags perform better than polyethylene bags at absorbing and storing ambient heat. Red Mud PVC bags can last up to twenty years (Hao, 1979).

Retention Pool.

A retention pool improves the productivity of the biodigester. After a maturation period of thirty days, dangerous pathogens in the digestate are eliminated and the output becomes a safe form of fertilizer (United States Department of Agriculture, 1995). Currently, no retention pool exists to collect the output of the CPA biodigester.

Compression System.

Maintaining constant pressure in the bag increases the productivity of the biodigester by increasing gas flowrate. There are two options to accomplish this: a methane collection reservoir system and direct bag compression. A collection system installed conveniently near the point of use can be compressed during operation. Due to the corrosive nature of biogas even with filtering, a collection system would not be feasible. Direct compression of the bags can be done most efficiently with a weighted grid. This grid can be constructed with any smooth, yet rigid, material like PVC piping or bamboo. A lightweight platform or net should be attached across the top of the grid to hold weights such as water bottles. All parts should be secured with blunt and non-abrasive items to avoid puncturing or tearing the bag. Figure 4.5-1 shows an example of a weighting system.

Figure 4.5-1: Bamboo grid with water bottle weights

Hydronic Floor Heating System.

A hydronic floor heating system in the farrowing crates was considered. Options for a hydronic system involve embedding a metal plate or a series of tubes within the concrete of the creep area. These systems must be professionally installed and retrofitting is often costly and limited to certain spaces. In the long term, this system is cost-effective, however, the feasibility of hydronic heating requires further investigation (Radiant Floor Heating Cost, n.d.).

Additional Biodigester.

There is enough animal manure to meet the daily input needs of the two current biodigesters and a third biodigester. The school has about sixty cows. On average, each cow produces thirty six kilograms of manure per day, which results in a total of four thousand kilograms per day. This satisfies the daily feed of 100 kilograms per biodigester bag.

Human Waste.

Human waste was explored as a potential biomass source. However, the school already produces enough agricultural waste to supply the biodigesters and composts human waste (R. Burns, pers. comm., April 26, 2016). Additionally, human waste does not produce as much methane as animal waste. Therefore this option was not explored further.

5.0 Recommendations

This section outlines the recommendations. These include the best use of the school's biogas, ways to improve the longevity and productivity of the biodigester, and additional recommendations for the school.

The biogas at the San Francisco Agricultural School should be directed to warming the suckling piglets. The benefits are the proximity of the piglets to the gas source, reduced financial loss, and improved working conditions of tending the piglets. A suggested design for the transport of biogas to the farrowing barn is shown in Figure 5.0-1. A design for the warming system inside the barn is shown in Figure 5.0-2.

The longevity of the biodigester can be increased by the addition of a roof and by a filter made of a PVC tube and iron shavings. The productivity of the biodigester can be improved by the addition of a one to four percent incline in the base of the well, a PVC or bamboo grid weighted with water bottles to increase pressure in the bags, and a retention pool.

Additionally, the school could construct another biodigester. An additional biodigester would allow the school to use biogas for more applications, further increasing self-sustainability.

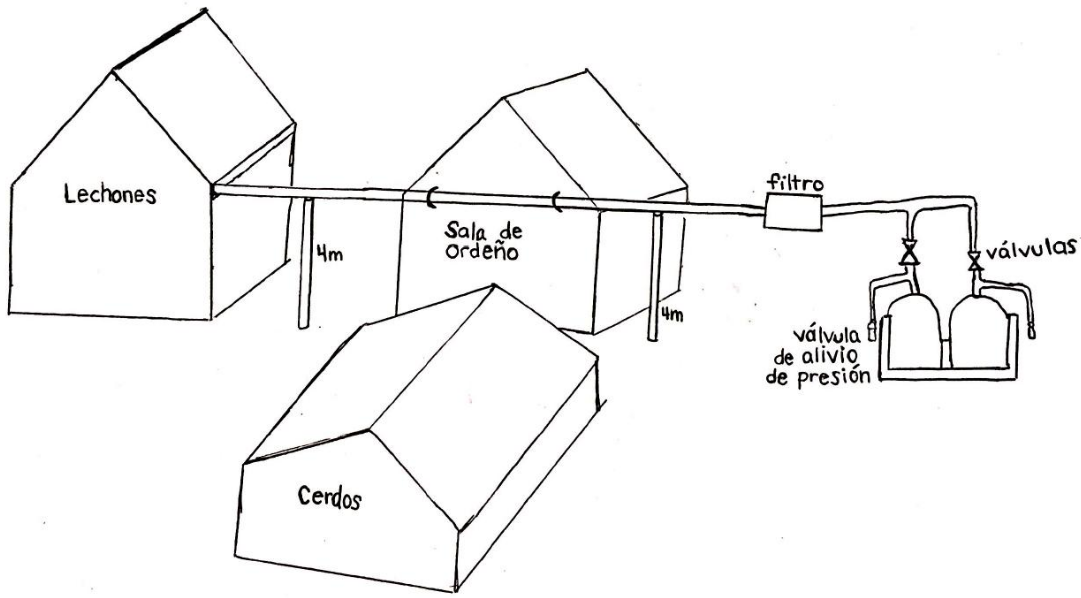

Figure 5.0-1: Plan to direct biogas to piglets

Figure 5.0-2: Interior Plan for Piglets

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Appendices

A: Energy Calculations

A1: Warming the piglets

<u>Information gathered on site:</u>

Temperature Piglets Need (C)	Area needed to heat (m^3)	Jaula Dimensions (m)
35	1.155	1.6 x 2.1
Creep Area (m)		
0.5 x 0.55		

Winter	Average (°C)	Temperature increase required, ΔT (°C)
Lowest temperature	12	23
Highest temperature	22	13

Summer	Average (°C)	Temperature increase required, ΔT (°C)
Lowest temperature	23	12
Highest temperature	34	1

Biogas Demand (m^3) = Biogas Heater (m^3/hr) * Time (hr)

Single Heater Demand	Winter Long (hr)	Summer Long (hr)	Winter Short (hr)	Summer Short (hr)	Single Burner Demand (m^3/hr)
	24	14	9	4	0.35
Biogas Needed Per day (m^3)	7.2	2.7	4.2	1.2	

A2: Heating Water for Animal Slaughter

Biogas Needed per Day (m^3) = Biogas Heater (m^3/hr) * Time (hr)

Single Heater Demand	Hot Water (L)	Temperature (C)	Time (hr)	Biogas Needed per Day (m^3)	Single Burner Demand (m^3/hr)
Chickens	50	80	4.5	2.025	0.45
Pigs	30	80	1.17	0.5265	

$Q = m_w c \Delta T$
$m_g = Q/E$
$t = m_g/\rho_b/D$

Heat, Q	Mass of Gas needed, m_g	Time, t
10465000 J	322.1578431 g	0.5216455247 h
10465 kJ	0.3221578431 kg	31.29873148 min

*additional 30 minutes added to each application to bring water to temperature

A3: Heating Water for the Boys' Dormitory

Biogas Needed per Day (m^3) = Biogas Heater (m^3/hr) * Time (hr)

	Morning Time (hr)	Afternoon Time (hr)	Night Time (hr)	Tankless Heater Demand (m^3/hr)	Boiler Demand (m^3/hr)
	1.5	2.0	4.75	3	4.18
					TOTAL
Tankless Biogas Needed per Day (m^3)	4.5	6.0	14.25		24.75
Boiler Needed Per Day(m^3)	6.27	8.36	19.86		34.49

A4: Supplementing the Kitchen

Methane Required per meal (g) = # of Burners(Single Burner Demand * X Cook Time)

Where X = meal or dish

TOTAL is the sum of the Methane Required per meal per day

Single (1) Burner	Desayuno Cook Time (hr)	Almuerzo Cook Time (hr)	Cena Cook Time (hr)	Tortilla Cook Time (hr)	Single Burner Demand (m^3/hr)
	1	2	1	2	0.45
					TOTAL
Biogas Needed Per Meal (m^3)	0.45	0.9	0.45	0	1.8
Biogas Needed on tortilla day (m^3)	0.45	0.9	0.45	0.9	2.7

Double (2) Burners	Desayuno Cook Time (hr)	Almuerzo Cook Time (hr)	Cena Cook Time (hr)	Tortilla Cook Time (hr)	Single Burner Demand (m^3/hr)
	1	2	1	2	0.45
					TOTAL
Biogas Needed Per Meal (m^3)	0.9	1.8	0.9	0	3.6
Biogas Needed on tortilla day (m^3)	0.9	1.8	0.9	1.8	5.4

Triple (3) Burners	Desayuno Cook Time (hr)	Almuerzo Cook Time (hr)	Cena Cook Time (hr)	Tortilla Cook Time (hr)	Single Burner Demand (m^3/hr)
	1	2	1	2	0.45
					TOTAL
Biogas Needed Per Meal (m^3)	1.35	2.7	1.35	0	5.4
Biogas Needed on tortilla day (m^3)	1.35	2.7	1.35	2.7	8.1

Quadruple (4) Burners	Desayuno Cook Time (hr)	Almuerzo Cook Time (hr)	Cena Cook Time (hr)	Tortilla Cook Time (hr)	Single Burner Demand (m^3/hr)
	1	2	1	2	0.45
					TOTAL
Biogas Needed Per Meal (m^3)	1.8	3.6	1.8	0	7.2
Biogas Needed on tortilla day (m^3)	1.8	3.6	1.8	3.6	10.8

A5: Additional Biogas per Length of Pipe

Application	Pipe Diameter, D (m)	Pipe Length, L (m)	Total Pipe Volume, V (m^3)
Piglets	0.0254	62	0.0314
Boys Dorm	0.0254	192	0.0973
Kitchen	0.0254	218	0.111
Animal Slaughter	0.0254	205	0.104

$V = (\pi D^2/4)*L$

B: Loss Calculations

B1: Pressure Drop Calculations

To calculate pressure loss this project used the Renouard equation, shown below. This equation is used for compressible natural gas flow.

$$p_1^2 - p_2^2 = 46742 * S_g * L * q_h^{1.82} * D^{-4.82}$$
$$S_g = \rho_{NG}/\rho_{AIR}$$

Where p_1 is absolute pressure in [bar], p_2 is absolute pressure out [bar], S_g is relative density [-], L is pipe length [km], q_h is volumetric flow rate [m^3/h] at standard conditions, D is pipe diameter [mm], ρ_{NG} is density of natural gas [kg/m^3] at standard conditions, ρ_{AIR} is density of air [kg/m^3] at standard conditions.

Knowns:

Parameter	Value	Source	Notes
p_2	1.02925 bar	PUXIN biogas heaters from Alibaba	Rated gas pressure: 1600 Pa + atmospheric pressure
ρ_{NG}	1.3724 kg/m^3	Engineering Toolbox	NTP, See calculation below
ρ_{AIR}	1.205 kg/m^3	Engineering Toolbox	NTP
q_h	0.3 m^3/h	PUXIN biogas heaters from Alibaba	Given gas consumption rate
S_g	1.139	Pipeflowcalculations.com Compressible gas flow	$S_g = \rho_{NG}/\rho_{AIR}$
D	25.4 mm	Professor Saucedo	He specified that he wanted 1 in hose for biogas transport

NTP - normal temperature pressure (20 ^oC, 1 atm)

ρ_{NG} calculation

Biodigester filled with 40% CH_4 and 60% CO_2

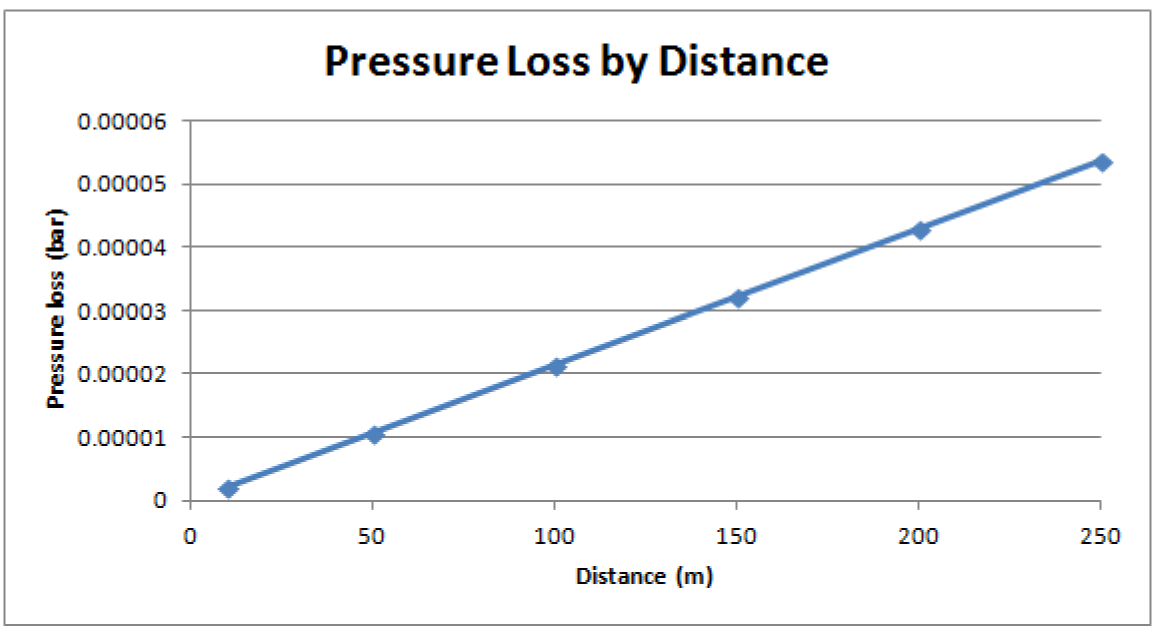
ρ_{CH4} = 0.668 kg/m^3 at NTP ρ_{CO2} = 1.842 kg/m^3 NTP

ρ_{NG} = 0.4(0.668 kg/m^3) + 0.6(1.842 kg/m^3) = 1.3724 kg/m^3

<u>Graph Pressure Loss vs Distance:</u>

$p_1 = sqrt(46742 * S_g * L * q_h^{1.82} * D^{-4.82} + p_2^2)$

L (km)	p_1 (bar)	L (m)	p_1 - p_2 (bar)
0.01	1.0292521	10	2.14876E-06
0.05	1.0292607	50	1.07438E-05
0.1	1.0292715	100	2.14874E-05
0.15	1.0292822	150	3.22309E-05
0.2	1.029293	200	4.29744E-05
0.25	1.0293037	250	5.37177E-05



B2: Heat loss calculations

Symbol	Parameter	Value	Symbol	Parameter	Value
q_{conv}	Convection heat rate	---	A_s	Surface area	
$\dot{m}$	Mass flow rate	0.083 kg/s	ΔT_{lm}	Log mean temperature	See below
C_p	Specific heat	See below	Re	Reynolds number	See below
T_o	Outlet temperature	See below	ρ_{H2O}	Density of water	965.3 kg/m^3
T_i	Inlet temperature	370 K	v	velocity	0.041 m/s
D	Diameter	0.0254 m	Nu_D	Nusselt number	See below
μ	Dynamic viscosity	0.798 Ns/m^2	k	Thermal conductivity	See below

Energy balance equation:
$q_{conv} = \dot{m}C_p(T_o - T_{,i})$

Rate equation:
$q_{conv} = \hbar A_s \Delta T_{lm}$

Log mean temperature difference equation:
$\Delta T_{lm} = (\Delta T_o - \Delta T_i)/\ln(\Delta T_o / \Delta T_i)$

Combined energy balance and rate equations:
$\hbar = [\dot{m}C_p/A_s]*[(T_o - T_{,i})/\Delta T_{lm}]$
$\hbar = [\dot{m}C_p/\pi*D*L]*[(T_o - T_{,i})/\Delta T_{lm}]$

Reynold number equation:
$Re = \rho vD/\mu$

$Re = \rho vD/\mu = (965.3\ kg/m^3)*(0.041\ m/s)*(0.0254\ m)/(0.798\ Ns/m^2)$

$Re = 1210 \rightarrow$ laminar flow for fluid through pipe

Convection correlation for laminar, fully developed flow with uniform surface temperature, T_s:
$Nu_D = 3.66$

Nusselt number equation:
$Nu_D = ħ*D/k$
$ħ = Nu_D*k/D$

Combined equation with Nusselt number equation:
$Nu_D*k/D = [\dot{m}C_p/\pi*D*L]*[(T_o - T_{,i})/\Delta T_{lm}]$
$Nu_D*k = [\dot{m}C_p/\pi*L]*[(T_o - T_{,i})/\Delta T_{lm}]$

Temperature (K)	Specific Heat (J/kgK)	Thermal Conductivity (W/mK)
275	4211	0.574
280	4198	0.582
285	4289	0.59
290	4184	0.598
295	4181	0.606
300	4179	0.613
305	4178	0.62
310	4178	0.628
315	4179	0.634
320	4180	0.64
325	4182	0.645
330	4184	0.65
335	4186	0.656
340	4188	0.66
345	4191	0.664
350	4195	0.668
355	4199	0.671
360	4203	0.674
365	4209	0.677
370	4214	0.679
375	4217	0.68

Taken from Bergman, T. L., Incropera, F. P., & Lavine, A. S. (2011). Fundamentals of heat and mass transfer (7th ed.). John Wiley & Sons.

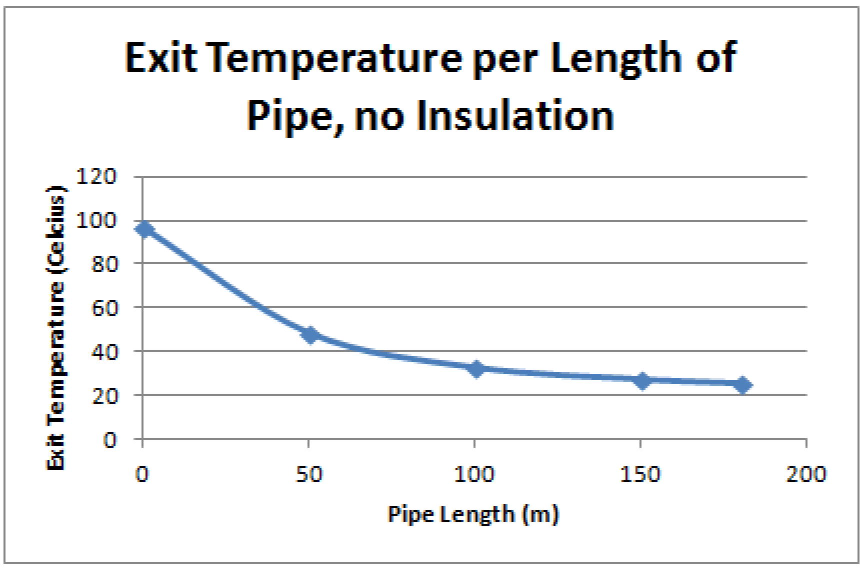
Temperature (K)	Specific Heat (J/kgK)	Thermal Conductivity (W/mK)	pi*L*k*Nu/ (m(dot)*C)	(To-Ti)	(Ts-To)-(Ts-Ti)	ln((Ts-To)/(Ts-Ti))	Tlm	(To-Ti)/Tlm
275.00	4211.00	0.57	0.94	-48.00	48.00	-1.10	-43.69	1.10
280.00	4198.00	0.58	0.96					
285.00	4289.00	0.59	0.95					
290.00	4184.00	0.60	0.99					
295.00	4181.00	0.61	1.00		Length	T avg	T out	T out (Celcius)
300.00	4179.00	0.61	1.01		0.00		370.00	97.00
305.00	4178.00	0.62	1.02		50.00	346.00	322.00	49.00
310.00	4178.00	0.63	1.04		100.00	338.10	306.20	33.20
315.00	4179.00	0.63	1.05		150.00	335.40	300.80	27.80
320.00	4180.00	0.64	1.06		180.00	334.48	298.95	25.95
325.00	4182.00	0.65	1.06		200.00		298.00	25.00
330.00	4184.00	0.65	1.07					
335.00	4186.00	0.66	1.08					
340.00	4188.00	0.66	1.09					
345.00	4191.00	0.66	1.09					
350.00	4195.00	0.67	1.10					
355.00	4199.00	0.67	1.10					
360.00	4203.00	0.67	1.11					
365.00	4209.00	0.68	1.11					
370.00	4214.00	0.68	1.11					
375.00	4217.00	0.68	1.11					

Length:	50		Inlet Temp:	370
Surface Temp:	298		Outlet Temp:	322
Nu:	3.66		Avg Temp:	346
Mass flow:	0.08333333333			
Pi:	3.141592654			

Method:

1. Choose length
2. Guess outlet temperature
3. Check whether pi*L*k*Nu/(m(dot)*C) column matches (To-Ti)/Tlm column at the correct average temperature row
4. Change outlet temperature guess and check again until column values match

Length	T avg	T out	T out (Celcius)
0		370	97
50	346	322	49
100	338.1	306.2	33.2
150	335.4	300.8	27.8
180	334.475	298.95	25.95
200		298	25



C: Interview Questions

All interview questions were asked in Spanish while responses were recorded in English.

Interview with Luis Saucedo March 17th, 2016
Head of Self-Sufficiency and Animal Production Center of the San Francisco Agricultural School

1. What type of heater do you want to use to heat the piglets?
(1.) Qué tipo de calentador quiere usar para calentar los lechones?
The Taiwan technical mission uses a system to heat the pigs and also gives away biogas to surrounding indigenous community. They are 25cm in diameter and they sell one like it in San Lorenzo, Asunción.

2. How many litters of pigs are there at one time?
(2.) Cuántas camadas tiene a un vez?
There are five at the same time in different cages, we try to space it out. The school weans at 28 days and is in the business of selling suckling pigs.
The piglets need to be kept at 35°C for the first three weeks (0-22 days), April to November are the coldest months. When pigs get cold they die of diarrhea within days. 250-300 piglets are born per year. Depending on the age of sow, they can have 4-18 piglets. If they have 18, 11 or 12 survive. A sow only has 12 teats. On average, 1 or 2 piglets are lost per sow.
Camadas = litter of pigs
escamoteadores = maternity pig pen

2. Can you show us how you heat the pigs with the firewood?
(2.) Puede nos muestra cómo calentar los lechones con lena?
They must keep it as far as possible from the back or dirty area of the sow. A fire serves the two cages at time. They would be happy with 3 heaters. During hot weather no more than 1 cubic meter of firewood and during the cold 2 cubic meters are used.
I would also really like to use the water for the slaughter of the animals. The pro is that it would be close to the biodigester, and would be the most efficient uses A suggestio could be to use solar panels to heat water and biogas to top it off.

Interview with Luis Saucedo March 21tst, 2016
Head of Self-Sufficiency and Animal Production Center of the San Francisco Agricultural School

1. How is the gas pumped to the kitchen?
(1.) Cómo impulsa el gas para la cocina?
No pump, just uses the pressure in the bag and use a rubber/plastic hose for these biodigesters.

2. How much wood do you go through per night (max and min)
(2.) Cuantas leñas se usa cada noche?
They use about ½ cubic meter per camada per night.

3. Is wood still donated to the school?
(3.) Todavía recibe donaciones de madera?
No, they get it from the farm, but it is a hassle.

4. Address and phone number of the taiwanese school
(4.) Tiene la locación de la programa Taiwanés?
Were going on the 29th of March and will talk to Dorothy about it.

5. Do you have a budget for this project?
(5.) Tiene un presupuesto por el proyecto?
Have one by Wednesday, but as low as possible.

Interview with Dr. Jose Samaniego March 29th, 2016
Boss of the farm at the Taiwanese Mission, UNA

Dr. Jose Samaniego: Jefe de la granja. Dirección: Ruta Mariscal Estigarribia Km. 10,5
Teléfono Dr. Samaniego: 0971959089 (local) +595 971959089 (internacional)
dsamaniego616@gmail.com
Sección de Comercialización e Industrialización Porana
Facultad de ciencias Veterinarias- Universidad Nacional de Asunción (UNA)

Questions and answers are paraphrased and do not represent word-for-word interview transcription

1. How often do you have to change the PVC pipes? (They do not have a filter for H_2S)
PVC pipes corrode and must be changed every 5 to 6 years.

2. Does the biodigester have an incline?
There is a 3 to 4% incline in the biodigester wells.

3. So you don't have to agitate the slurry?
No.

4. Is it dangerous to light a fire to heat the piglets right after using the biogas heaters?
No.

5. Where did you buy your biogas heaters?
They were imported from Brazil.

6. We have read that having heaters on the piglets causes them to move close to and away from the heater constantly, tiring them out and causing health problems. Have you found this to be an issue?
We use our heaters for one to two hours only during critical cold. We use electric heaters otherwise.

7. Do you have a biogas storage system?
No, the gas is corrosive and explosive.

8. How thick is the biodigester bag?
100 um thickness of the outer bag.

9. Do you always have to use the pump in your system?
We use the pump only during the winter. Otherwise the pressure is sufficient.

Interview with Luis Saucedo April 4th, 2016 (Summary)
Head of Self-Sufficiency and Animal Production Center of the San Francisco Agricultural School

1. Present project progress
The plan to supply biogas to heat the piglets is good, but they want an analysis of each of the possibilities of where to direct the biogas and for us to recommend the best use of the gas. The four possible options are the warming of the piglets, heating of water for the slaughtering of animals or the showers in the boys' dormitory, or to suppliment the cooking in the kitchen.

Interview with Virgilio Borges April 5th, 2016
Head of Rural Construction of the San Francisco Agricultural School

1. How did you prevent the bags from moving on top of each other during inflation?
(1.) Cómo se evita las bolsas se pone en la parte superior de uno a otro durante la inflación?
It is no longer a problem and does not need to be worried about.

2. Can we observe the next time maintenance is performed on the bag?
(2.) Podemos estar presentes a la próxima vez de mantenimiento de biodigestores?
Yes, the next time is tomorrow at 6 AM, and again at 1 PM.

3. Do you know the quantity of water that the boys' dormitory uses?
(3.) Conoce usted la cantidad de agua que usa el dormitorio de los varones?
The boys use 5 liters of hot water per person and mostly during the night, we would need to heat 600 liters of water per day.

4. Do you know of a heater that uses biogas?
(4.) Conoce usted un calentador que usa biogás?
Yes, they can be found in Asuncion at Mercado 4, at a store called Patterosi.

5. Do you know the quantity of water needed for the slaughter of animals?
(5.) Conoce usted la cantidad del agua que usa por la faena de los animales?
For the slaughtering of chickens, 50 continuous liters are needed at 80 degrees celsius for four hours. For the pigs, 30 continuous liters are needed at 80 degrees celsius for 40 minutes.

6. How do you currently heat the water for the slaughtering of animals?
(6.) Cómo calienta el agua por la faena de los animales ahora?
With wood fires.

7. How frequently are animals slaughtered?
(7.) Con qué frecuencia se faena los animales?
Fifty chickens are slaughtered at once, ten times per month.

Interview with Luis Saucedo April 6th, 2016
Head of Self-Sufficiency and Animal Production Center of the San Francisco Agricultural School

1. What pressure do the piglet heaters need to operate?
(1.) Qué presión necesitan los calentadores?
I don't know, this information isn't provided with the heaters.

2. How many hours do the piglets need to be warmed in the summer? And in the winter?
(2.) Cuántas horas necesita calentar los lechones en el verano? Y en el invierno?
During the summer, four to nine hours of warming are needed in the summer and fourteen to twenty four hours of heating are needed in the winter.

Interview with Tiana Vasquez April 7th, 2016
IQP 2016 Kitchen team

1. How many hours are the burners in the kitchen used?
At least one burner is used at all times that cooking is taking place, there are currently 8 electric burners in total. Breakfast is cooked for one hour from 6:30-7:30 AM, lunch and dinner are cooked for two hours at 10:00-12:00 PM and 6:30-8:30 PM, and twice a week tortillas are made for two hours.

Interview with Luis Cateura April 20th, 2016
Head Director of the San Francisco Agricultural School

1. How much does one piglet cost and how much does it sell for on average?
(1.) Cuanta cuesta un lechón de media?
Each pig can return 70 mil Guarani in profit. Piglets are born twice a year with eight piglets per litter, the first litter sold usually pays for all of the food for the year, so the second litter of piglets is all profit. Losing a few piglets is not the worst because the school just won't make as much money, but if we lose a significant amount of piglets the school loses money.

2. How much does it cost to use the burners in the kitchen?
(2.) *Cuanta cuesta para usar un quemador en la cocina?*
The burners use electricity, and I can give you a summary of electricity use to calculate this value.

Interview with Rebecca Burns April 26th, 2016
IQP 2016 Septic System team

1. Is it feasible to use human waste from the septic system as input for the biodigester?
The school plans to use the human waste for composting, so it won't be available to use for the biodigester.

D: Observations

D1: 3/29/16 Taiwanese Mission Biodigester Photographs

Biodigesters

Farrowing Crates

D2: 4/07/16 Biodigester Morning Loading Notes

Five students arrived at the biodigester just after 6 AM. There were three girls and two boys. Three girls filled two containers with water using a hose located at the exit of the biodigesters. The two boys carried two buckets and one hoe to the animal pen just outside the piglet nursing enclosure. We had observed cows being herded out of this animal pen earlier this morning before 6 am. One girl wearing a dark shirt sat at the entrance of the biodigester and played music on her phone. The other two girls, one wearing a green shirt and the other with a light red shirt carried different sized containers from the exit side to the entrance side of the biodigester. A strong smell of manure was noted at this point. A white dog hobbles over to the biodigester area.

The two boys return, each carrying one bucket of manure. One of the buckets of manure is added to a larger cylindrical container. This container is then filled with water until three fourths full. The girl with the dark shirt mixes the slurry with a long rectangular wooden stick and then adds the mixture to the biodigester closest to us. The second bucket of manure is added to the same cylindrical container and filled to the three fourths level with water again. This slurry was mixed by the girl in the dark shirt and added to the biodigester closest to us again.

The boys left again carrying the two buckets now empty of manure. The girl wearing the light red shirt and the girl wearing the green shirt had been filling the different sized containers with water ever since they were emptied. The boys return with their buckets. The buckets are the same type and size. The bucket carried by the boy wearing a green shirt is filled to the top. The bucket carried by the boy wearing a jersey is not filled completely. It is filled to the bottom of the ripples at the top of the bucket. The slurry is prepared the same as previously. Both batches are added to the biodigester further from us. The boys leave again each carrying an empty bucket. We wait. A crane squawks overhead.

The boy in the green shirt returns first with a bucket full of manure. He empties it into the cylindrical container and the girls add water and stir. The boy in the jersey arrives a little after the boy in the green shirt. Again his bucket is not filled to the brim, but it is filled to the same level as it was previously. The two batches of slurry are prepared again, one after the other. The first batch is added to the biodigester closest to us. The second batch is added to the biodigester furthest from us. The boy in the green shirt runs a hose into the exit of the front biodigester. The girl in the black shirt rinses her hands in a container of water. The boy in the jersey rinses his feet using the hose. The five students leave the area.

A total of three batches of slurry were added to each biodigester. Canals are not used to load the biodigesters.

E: Information from the National University of Asunción

E1: Information about Process and Operation

Page 1

Proceso del Proyecto de Biogás

Gather Separate solids organic fertilizer
recolectar→separar→solido→abono orgánico

↓

liquids anaerobic aerobic biological
Liquido → anaeróbico → aeróbico →biológico

↓↑ ↓

silt fish farming
Limo piscicultura

↓↓ ↓

dry off irrigation
Secar riego de cultivos

Design of the project and capacity of the process:
Diseño del proyecto y capacidad de procesamiento:

It is calculated that the farm produces 7,129 kg of manure per day
For each kilo of manure you need 5 liters of water
for cleaning / waste water, to give a total of 42,774 m³.

Se calcula que la granja produce por día 7,129 kg de estiércol; por cada kilo de estiércol se necesita 5 litros de agua para su limpieza, el desecho de aguas negras da un total de 42,774 M³.

Page 2

BOD → amount of dissolved oxygen needed by aerobic organisms to break down organic material in water

SS → suspended solids, measure of water quality

Process - lists materials needed for each process

Proceso del Proyecto de la Planta de Biogás:

Separate

(1) Separar: 1 separador, capacidad 20-40 ton/hrs.

Puede quitar BOD > 25% · SS > 40% · sólido > 65%.
↳ Biochemical Oxygen demand

Process fertilizer

(2) procesar abono orgánico: 1 bodega y 1 invernadero.
cellar greenhouse

El sólido requiere 30 días para madurar, para su posterior utilización. La granja posee una capacidad de producir por día 1,500 kg de abono.
The solid requires 30 day to mature for later utilization. The farm has a capacity to produce per day 1500 kg of fertilizer

Anaerobic

(3) anaeróbico: 9 piletas, con una capacidad de 66.24M³ total 596.16M3. Se procesa en 15 días, su efectividad es menor a 85% de BOD y SS.
9 pools with a capacity of 66.24 M³ totaling 596.16 m³. It is processed in 15 days, your effectiveness is less than 85% of BOD and SS

Aerobic

(4) aeróbico: canal aerógeno 124.20 Mts y 1 estanque de 1,066M³. Se procesa en 25 días. Su efectividad es menor a 90% de BOD y SS.

Pond of decantation ↳ separation of mixtures

(5) estanque de decantación: 1 estanque de 776M³. Queda el agua en el por 20 días.

Biological

(6) biológico: 2 estanques de 2,090M³ y 776M³. El agua queda en ellos por 60 días, se siembra camalote. Total de aguas negras procesadas en 120 días.

Fish farming

(7) piscicultura: 3 estanques, utilizando el remanente líquido de los estanques anteriores.

Organic fertilizer

(8) abono orgánico para de cultivos: maíz, frutas, etc.

The farm has the capacity to raise 1,675 pigs and in agreement of this, in a year can produce 2,602.09 tonnes of manure

La granja tiene la capacidad de criar 1,675 cabezas de cerdo, de acuerdo a eso, en un año puede producir 2,602.09 toneladas de estiércol.

Each ton of manure can produce 0.4 m³ of biogas in a year, a total production of 1,040,836 m³ of biogas

Cada tonelada de estiércol puede producir 0.4 M³ de biogás y en un año una producción total de 1, 040,836M³ de biogás.

Page 3

La planta de biogás puede producir energía para la fábrica de alimentos, matadero y calefactor para cerditos. Se calcula para el galpón de maternidad la necesidad de utilizar 68 lámparas, e inicio 56 lámparas de 250W; cada día consume energía eléctrica: 744, Kwh por día; aproximadamente la granja utiliza lámparas como calefactor durante 100 días en un año. En dicho periodo, el consumo total es de 74,400KWh., y el precio por cada KWh es de Gs.485, total costo en un año Gs.36,084,000 en dólares aproximadamente US$ 9,02（1US$ = Gs.4,000）. → 5500 GS

Gastos del Proyecto: Construcción US$71,560. Maquinarias US$5,000. Capa de goma US$9,000 total US$85,560; se recuperan los costos aproximadamente en 9.5 años.

food factory

slaughter

heater

Biogas can be used for food factory, saughter, and heaters

Need lamps

Consumes energy

Costs of machinery, rubber piping

E2: Information about Biodigester System

Page 1

CENTRO DE CRIA DE CERDOS EXPERIMENTACION Y PRODUCCION

BIODIGESTOR

Un biodigestor es un sistema artificial que aprovecha la digestión anaeróbica (en ausencia de oxigeno) de las bacterias que ya habitan en el estiércol, para transformar éste en biogás y fertilizante.

El biogás es un gas combustible que se genera en medios naturales o en dispositivos específicos, por las reacciones de la biodegradación de la materia orgánica mediante la acción de microorganismos y otros factores, en ausencia de oxígeno (esto es, en un ambiente anaeróbico). Este gas se ha venido llamando *gas de los pantanos*, puesto que en ellos se produce una biodegradación de residuos vegetales semejante a la descrita.

El biogás por descomposición anaeróbica

La producción de biogás por descomposición anaeróbica es un modo considerado útil para tratar residuos biodegradables ya que produce un combustible de valor además de generar un efluente que puede aplicarse como acondicionador de suelo o abono.

A. El resultado es una mezcla constituida por metano (CH_4) en una proporción que oscila entre un 60% a un 80% y dióxido de carbono 20-40% (CO_2), conteniendo pequeñas proporciones de otros gases como hidrógeno (H_2), nitrógeno 2-3% (N_2), oxígeno (O_2) y sulfuro de hidrógeno 0,5-2% (H_2S).

Este gas se puede utilizar para producir energía eléctrica mediante turbinas o plantas generadoras a gas, en hornos, estufas, secadores, calderas, u otros sistemas de combustión a gas, debidamente adaptados para tal efecto.

B. Sin embargo para ser dirigido a estos fines es preciso depurarlo, esto es, retirar las porciones de CO_2 principalmente, ya que supone entre 20 y 40% de gas sin posibilidad de generar calor, a más de las trazas de N_2, O_2 y H_2S; esto con el fin de volverlo mas puro y por lo tanto con mayores rindes del metano CH_4.

Adaptación de los biodigestores

Los biodigestores deben ser diseñados de acuerdo a su finalidad, a la disposición de la materia prima y tipo de la misma, y a la temperatura a la que van a trabajar. Puede ser diseñado para eliminar todo el estiércol producido en una granja de cerdos por ejemplo, o bien como herramientas de saneamiento básico en un colegio. El fertilizante líquido obtenido es muy preciado, y un biodigestor diseñado para tal fin ha permitir que la materia prima esté mayor tiempo en el interior de la cámara hermética (con el fin de maximizar la fermentación y disminuir los niveles de acides del residuo liquido) así como reducir la mezcla con agua a 1:3.

C.

Page 2

D. La temperatura ambiente en que va a trabajar el biodigestor indica el tiempo de retención necesario para que las bacterias puedan digerir la materia. En ambientes de 30 °C se requieren unos 10 días.

Funcionamiento de un Biodigestor

1. Separar la parte solida más gruesa, para el efecto se dispone de un separador con capacidad de procesar de 20 a 40 ton/hr. Puede reducir aproximadamente un 25% de DBO, 40% DE SST y más del 65% de los sólidos presentes en el caldo.
2. Trampa para sólidos: se decanta el líquido para retener mayor cantidad de sólidos (la presente explotación no tiene como fin la producción efectiva de biogás, fue concebido con un fin académico y demostrativo)
3. Fermentación anaeróbica: donde es producido el biogás, para el efecto se dispone de nueve piletas con cierre hermético, con una capacidad de 66.24 m3 cada uno (596.16 m3 en total).
4. Canal aeróbico: 124.20 mts. de longitud y un estanque de 1.066 m3, su efectividad reduce hasta en un 90% la DBO y SST.
5. Estanque de decantación: con capacidad para 1350 m3, se mantiene el caldo en el mismo por un periodo de 20 días.
6. Estanque biológico de decantación: dos estanques de 776 m3 y 2090 m3 respectivamente. El liquido queda en ellos por 60 días.

El paso de la mezcla por el biodigestor dependerá de la constancia con la que sea ingresada la mezcla a la misma, y esta a su vez estará condicionada por la producción de efluentes en los galpones.

E. Desde el ingreso al biodigestor hasta el último tratamiento se supone un periodo de 120 días en promedio.

Se calcula que la granja puede producir por día 7129 kg de estiércol (con capacidad de carga a pleno, es decir, 1675 cerdos); por cada kilo gramo de estiércol se precisan 5 litros de agua para su limpieza, el desecho de aguas negras da un total de 42.774 m3.

Cada tonelada de mezcla puede producir 0.4 m3 de biogás y en un año una producción total de 1040836 m3 de biogás.

Actualmente se utiliza la producción de biogás para la calefacción de los galpones donde se disponen de lechones, susceptibles al frio (maternidad e inicio), y además se ofrece a modo de gratuidad a familias colindantes con el Centro de Cría de Cerdos.

Se calcula para el galpón de maternidad la necesidad de utilizar 68 lámparas de 250 watt (744 kw/día, durante 100 días al año). En dicho periodo el consumo es de 74400 kw, significando esto un gasto anual de Gs 36084000, aproximadamente US$ 9021, dólar a Gs 4000 (Gs 485 cada kw/h).

El costo total del proyecto fue de US$ 85860, la recuperación del capital invertido se daría en 9.5 años.

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Este cálculo se realiza en el caso de que el único producto utilizado sea el biogás en bruto para calefacción; sin embargo un biodigestor puede ofrecer más utilidades: el gas puede ser utilizado en la generación de energía eléctrica a través de generadores a gas, el biol (abono liquido extraído luego de la fermentación) puede ser aplicado en la fertirrigación de cultivos, así mismo el remanente solido puede ser dirigido a los cultivos intensivos para mejorar las características físicas y químicas del suelo.

En un primer momento el biodigestor fue concebido para la generación única de gas y este utilizado en forma domestica y sin tratamiento, hoy por hoy un biodigestor ofrece grandes ventajas para quienes proyecten desarrollarlo.

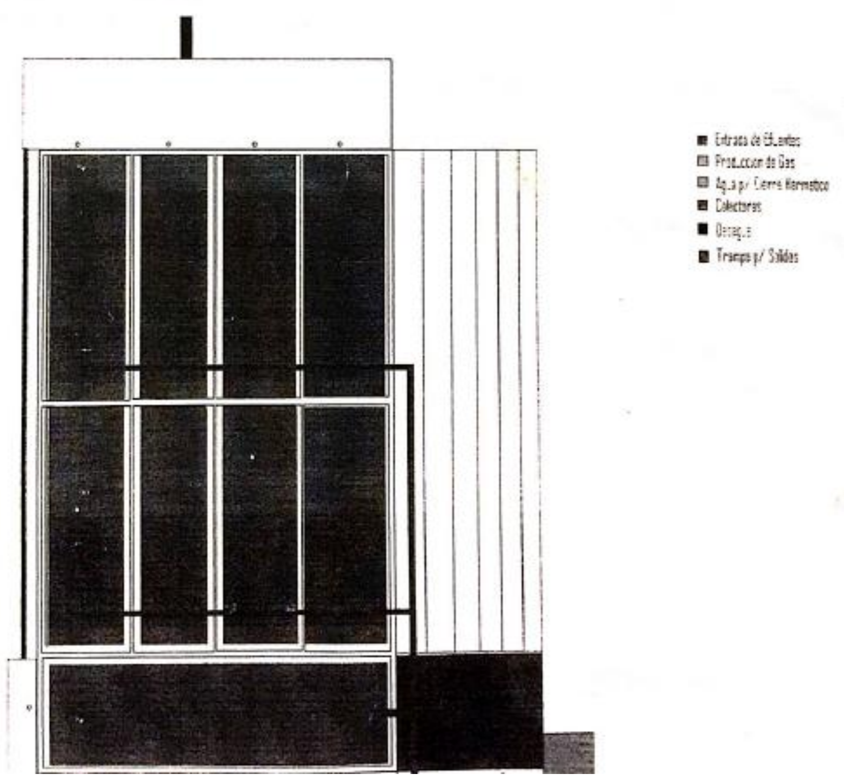
Utilizado debidamente y con criterios técnicos puede significar una herramienta eficaz para el tratamiento de las aguas negras de las ciudades, así como en las explotaciones agropecuarias.

Por otro lado, es sabido que la captación de carbono es bastante rentable (enmarcado en el tratado de Kioto, 1997) y debería ser aplicado para generar divisas al país, a mas de generar fuentes de trabajo.

CALCULO DE UN BIODIGESTOR PARA PORCICULTURA

Tipo de animal	No. animales	Peso promedio
Hembras Vacias	20	1650
Hembras Gestantes	50	200
Hembras Lactantes	30	180
Lechones Lactantes	200	3
Precebos	200	25
Machos reproductores	8	250
Porcinos ceba	100	80

CARACTERISTICAS RECOMENDADAS PARA SU BIODIGESTOR			
Clima	Estiercol Dia Kg	Volumen Total m3	Biogas Dia m3
CALIDO	3.225,30	250,94	41,12
MEDIDAS RECOMENDADAS			
Longitud mts	Diametro mts	Mezcla Dia m3	Tiempo de retencion dias
24,87	3,55	14,51	13



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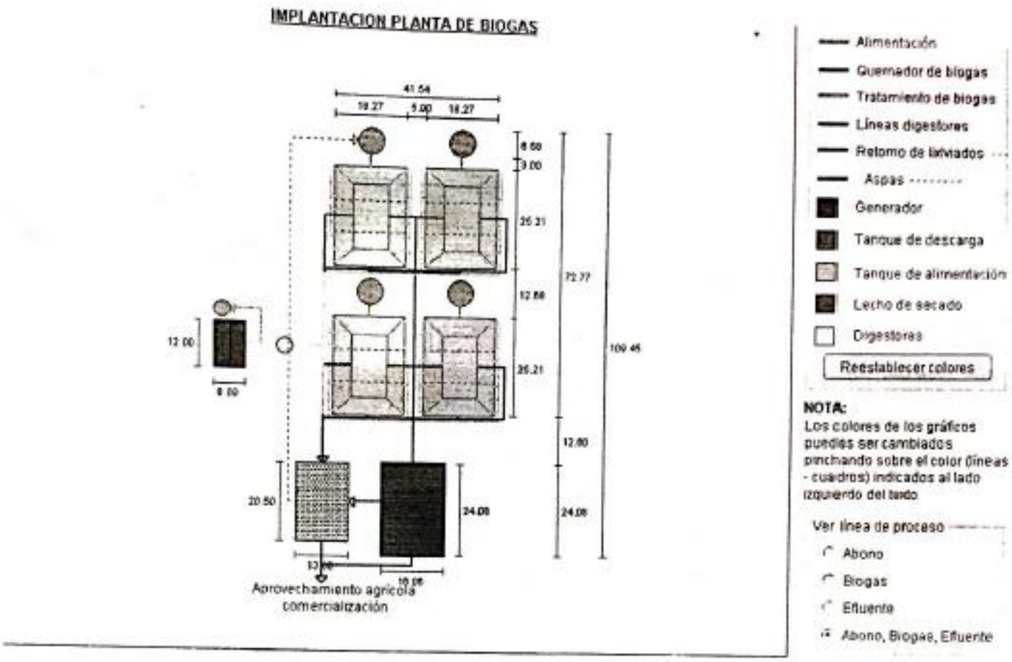

- How we will use the gas - If you produce this amount of gas
- Think about it in terms of how much heat the piglets need
- Extra manure
- How much gas do you actually need
- If its not being used right
- Currently use the extra heat from the boiler for the water in the boy dorm