Uso de Residuos Biológicos Bovinos para Aplicaciones Rurales a Pequeña Escala en Colombia Mediante un Sistema de Biogás de Ciclo Cerrado

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RESUMEN

Desde el establecimiento de Colombia como un estado independiente, se han librado guerras y se siguen librando para lograr la igualdad en un país lleno de contrastes, un país con historia pero sin memoria. La verdadera revolución comienza cuando aquellos que alimentan al país tienen la misma oportunidad que los que controlan las industrias, la Colombia rural es un lugar lleno de oportunidades que reconocemos pero que a la vez no hacemos nada para desarrollarlas.

Una revolución tecnológica donde algo básico como dar a todas las familias en áreas rurales la oportunidad de cocinar sin necesidad de leña, cocinar sin importar si llueve y de igual manera tener un ambiente saludable dentro de su hogar sin los humos peligrosos generador por las cocinas a leña, esas son las revoluciones que realmente importa en el campo.

El uso de lo que se ha considerado desperdicio durante siglos para producir biogás cambiará la forma en que se vive la vida en las zonas rurales de Colombia, esta revolución funcionará como una plataforma para una vida mejor y más saludable. El principal objetivo de este trabajo es el desarrollo de biodigestores robustos y que pueden alimentarse del estiércol para producir biogás y fertilizantes como subproducto, que pueda satisfacer fácilmente las necesidades de un hogar, un biodigestor que se adapte a las necesidades sociales y económicas de las zonas rurales del país y a su entorno geográfico. Una investigación en profundidad de los avances tecnológicos actuales, acompañada del conocimiento de quienes han trabajado en los campos de Colombia.

Conversion of Cow Manure Biowaste into a Closed Loop Biogas System for Small Scale Rural Application in Colombia

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Dedicated to my parents Humberto & Margarita, life is a marathon rather than a single race.

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Every process has a beginning but not all have an end, for all of my professors that helped as a beacon of knowledge in sea full of doubts. I wish to express my sincere appreciation to my father whose support and patience guided me in the road of knowledge even after several wrong turns, he was always there trying to show me the right path always with my mother by his side. To my sister whose incredible persistence and resilience was the best example life gave to me, and to Natalia who stood by my side all the time.

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Abstract

Since the formation of Colombia as an independent state, wars have been fought and are still being fought in order to bring equality in a country full of contrast, a country with a history but no memory. Real revolution starts when those who feed the country have the same opportunity as the ones that control the industries, rural Colombia is a place full of opportunities that we acknowledge but we don't do anything to develop them. A technological revolution were things as simple as giving all the families in rural areas the opportunity to cook without needing wood, to cook no matter is raining, to have a healthy environment inside your home without hazardous fumes from fuelwood, those are the revolutions that really matter in the countryside. Using what has been considered waste for centuries to produce biogas will change the way life is lived in rural Colombia, this revolution will work as a platform for a better and healthier life. Robust and off the grid biodigesters that can be fed from manure in order to produce biogas and fertilizers as a by-product that can easily supply the needs of a home is the main purpose of this work, a biodigester that suits rural Colombia's social, economic and geographical environment. An in-depth research of current technological breakthroughs accompanied by the knowledge of those who have work the fields in Colombia sets the base for a design that accommodates to all of the objectives set in this project in order to developed a full working prototype of biodigester that will be tested in Soto Norte.

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CHAPTER 1 Introduction

1.1 Introduction & Background

Rural Colombia's dependency in fuelwood has been one of the most important topics contemplated by the UPME (Mineral and Energetic Plan Unit) in Colombia, by 1985, 35 % of Colombia's population had a dependency in fuelwood for residential use as an energy source [8], this represented over 10 million tons of wood consumed each year to satisfy energy requirements in rural areas. By the year 1998 the use of fuelwood decreased to 12.1% of the population usage [9] [5], this signified almost a 20% reduction in fuelwood as energy source however with the Nation wide deployment of natural gas network in the year 2000 fuelwood consumption increased by 0.7%, this being a clear sign that the natural gas entered the market primarily to replace mineral coal and oil derivatives rather than fuelwood as it was expected by the analyst.

Currently, small cattle farms in rural areas of Colombia are not using the biowaste (manure) of their economic activities as an energy source due to the lack of knowledge on this specific subject. However, in some special cases, this biowaste has been used as an organic fertilizer without any previous treatment. The lack of exploitation of this resource generates a niche in the market for small biodigesters that could use manure in a closed loop system that generates biogas and fertilizers in tandem [10]. As an alternative for this closed loop system, biogas could be used to generate electricity in rural locations where energy supply hasn't been covered or as an alternative for the current electrical supply, ultimately, reducing costs related to energy usage. [11]

If peole in rural areas were able to exploit what has been considered waste until now, there could be a new economic shift in the making, the use of a closed loop system means that not only they could use manure as a fuel, but also, the byproducts would be of great use; a high quality organic fertilizer that would improve the current agricultural system [12] and reduce the amount of money invested in commercial fertilizers. These systems would be designed to work off grid and to have a basic functioning mechanism, thus avoiding the need for specialized intervention and making them more adequate for remote installation areas.

A contrast with developed countries such as the U.S. were the application of biodigesters is directly related with the reduction of the environmental footprint [13] [14] [15] in countries such as Colombia the use of biodigesters while helping with the environmental footprint is directly related with the exploitation of available resources for own use [12]. Even though the main objective of both deployment processes of biodigesters differs the final result is the same thus giving us ground bases to learn from the deployment AgSTAR project of the EPA whose main objective is to reduce at least 25% of the environmental footprint of dairy farms in the country. [13]

1.2 Problem Definition

This research and development project aims to solve the actual problem related to the lack of utilities in rural Colombia, especially regarding natural gas. The lack of residential natural gas evolves into the use of fuelwood as a substitute for an energy resource. The main objective of this project is to offer a low cost and efficient energy source for off-the-grid farmers, while obtaining high quality fertilizers as a byproduct. This will be solved by using bio-waste (manure) of their main economic activities as the main to power and feed a closed loop anaerobic biodigester.

1.3 Significance

Enabling Colombian's living in rural areas to achieve independence from utility companies and the government itself, will provide a new platform for social and economical development while improving the quality of life of those directly and indirectly involved in the conversion of biowaste into a Closed Loop System. Biowaste for this kind of applications is not limited to cow manure, porcine and aviary manure are alternatives that could be use, however due to the use of cattle and dairy farms as the prime economic activity in rural areas of the country all the research will be done based on the implementation of this kind of biowaste as the main source, according to UPME Colombia has a cattle manure biowaste energy resource sufficient to supply biogas to the whole population [16] [10].

Colombia reported for the year 2012, 5864 deaths due to the inhalation of gases related with the residential usage of fuelwood [17]. Taking into account that around 53% of rural population uses fuelwood as an energy source in contrast with 1.2% in urban areas [18] , the vulnerable part of the population is located in the rural areas. The use of biogas as a new and safer alternative is relevant as a matter of national safety and health, developing an alternative for fuelwood such as the one proposed in this document could have the potential of improving national statistics regarding energy efficiency, household safety all of this while offering better life standards for the vulnerable population located in rural areas.

An average Colombian farmer spends more than 10USD per acre in fertilizers in order to prepare the land for new seasonal crops [17] [19], besides this, long term crops such as coffee and avocado require constant use of fertilizers that ensure a good production, that being said the byproduct of the biowaste to biogas process would become an alternative for commercial fertilizers while keeping its organic signature. This would improve the quality of the crops while reducing the maintenance costs thus improving the revenue from the crops production enhancing the economy of all the actors involved in the process. [20]

The deployment of this project will also have a significant impact in the environmental footprint that derivates from methane emissions of manure related with small farming applications. Even though this is not the main objective it offers an important platform to receive financial support and recognition from national and international organizations. Reducing methane emission in small farms could be the first step towards a shift in national politics that could gain force in order to reduce methane emissions in industrial farming. [21] [22]

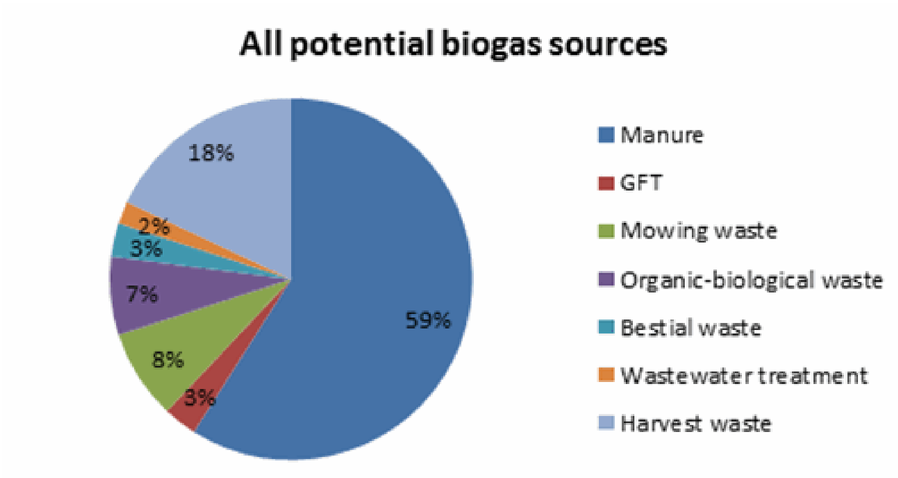

Figure 1.1: Biogas Potential Sources [3]

Manure biogas potential accounts for over 50% of all biogas plausible sources, this means that countries such as Colombia that historically have been considered agricultural countries could benefit from the use of manure and harvest waste to serve as a supplier of their energy grid creating another strong point towards the implementation of this system. The idea of having a country whose economic development is closely tied with agricultural development would eventually means that any agricultural project that impacts this are would sooner or later have a positive or negative impact in the economy. [23] [24]

1.4 R&D Objectives & Thesis Contributions

Due to the policies adopted by the Colombian government that focus in the development of the rural area of the country and the improvement of the quality of life of those living in those areas [9], the design and implementation of an off grid process that satisfies the biogas and fertilizer requirements of the population while using biowaste becomes an attractive ideas for all of the parts involve in this development process. The main objective of the research is to determine an efficient system that allows us to convert biowaste, more specifically manure into biogas and produce quality fertilizer as a byproduct, an alternative use of biogas could be the generation of electricity for residential or agricultural use. The research project will cover the following:

- Research of current developments in biowaste use in Colombia rural area.
- Current status of Colombia rural area energy resource and usage focusing on natural gas and electricity for residential applications.
- Technologies for the conversion of biowaste, specially manure for biogas and fertilizer as a byproduct.
- Comparison of conversion technologies sand its scalability and applicability in Colombia rural area.

1.5 Thesis Outline

Chapter 1, Section 1.1-1.4 introduces the reader to the topic from a current and historical perspective, defines what the real problem is and the importance of tackling this problem while defining the main objectives of the work it self and what the author is trying to achieve in this work.

Chapter 2, Sections 2.1–2.2 review literature about different designs of small-scale anaerobic digesters. Introduces the reader to the current solutions of the problem and focuses in the important design parameters defined in the objectives:

- Ease of use.
- Low cost and affordability.
- Input and output requirements
- Operation and maintenance complexity

Chapter 3,collects gathered information for the elaboration of a tool that will help with the related calculation in order to size and design the anaerobic digester. Will also brief the reader into what the author is trying to build and all of the components at different levels that will enable the development of the project.

Chapter 4, using the calculation from chapter 3 a final design and implementation methodology will be describe in order to have a functional prototype that could be use for tests and simulations.

Chapter 5, with the elaborated prototype simulations and experiments must be conducted in order to characterize the performance of the prototype and to work in improvements or makeovers of the device.

Chapter 6, conclusion from the whole process and final experimentation should be exposed in order to show the reader the final conclusion on the development of the whole project.

CHAPTER 2 Background & Literature Review

2.1 Background

Rowayda S. Ali work on biogas production from manure assisted by solar energy was a great starting point for the development and orientation of this work, based on Palestine a country whose rural areas lacks government involvement and are in constant search for alternatives to improve the socioeconomical indicators of the population is perhaps the same situation faced in Colombia. Both thesis support themselves in the use of biological waste (manure) for the operation of the bioreactors and have the main objectives of producing biogas as a main element with fertilizer as a by-product. While analyzing the rural situation in both countries there are clear similarities between both populations however geographical and environmental components could no be more different, that's one of the reason Rowayda's work uses solar thermal energy as a heating [25] unit to maintain and reach optimal mesophilic temperatures in the reactor (25-45°C) a problem that could probably affect the projects in Colombia but that isn't addressed in this thesis due to weather characteristics of where the project is planned to be deployed.

The size of the project is similar to the one planed to be implemented in Colombia making it a great guide for the development of the project, however an scalability solution is missing from Rowayda's work that is necessary for the development of this work since this allows farmers to grow in biogas production according to their growth in terms of demand and biowaste production. [1]

Following the research a work by Mansour Al-Sadi came to my attention due to the depth

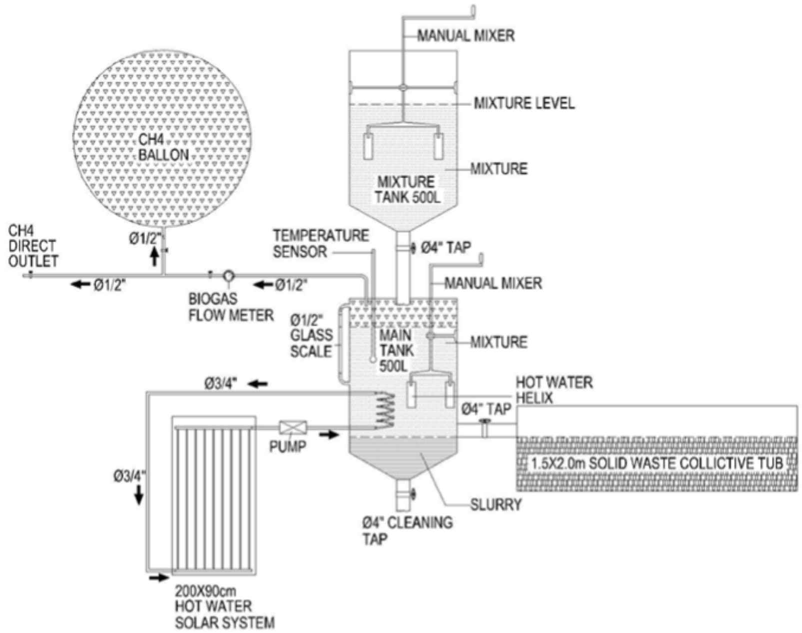

Figure 2.1: Biogas Plant Proposed by Rowayda [1]

of his research in biogas production from solid waste, even though the main material considered for the development of biodigesters in Colombia is considered to be manure, Mansour approach for all kinds of solid waste projects an interesting alternative for farmers whose production of manure doesn't reach the minimum quotas for the biodigesters production rate. The work is based in large scale biodigesters that could be implement by ELIPSE a Colombian national entity whose main objective is to bring electric energy and utilities to isolated communities around the country. [26] [27]

Animals	**Amount of biogas (liter/kg wet manure)**
Dairy Cattle	30
Beef Cattle	42
Swine	42
Poultry	116

Table 2.1: Gas production potential for different types of manure [1]

Mansour's thesis has a solid background in environmental impacts of using solid waste as an alternative for biogas production, it also does an in-depth analysis of different types of manures and its gas production potential, situating cattle as a viable alternative for gas production, this confirms what was projected in our initial research. The thesis has some experimental work that could be implemented and put into test in Colombia, since Mansour already developed a comparison point of the behaviour of digesters with different fuels this could work as a base line for developments in Colombia. As a final point, the development of an economical an reliable biowaste digester is contemplated in Mansour work, having that similarity with the objectives proposed in this thesis. [4]

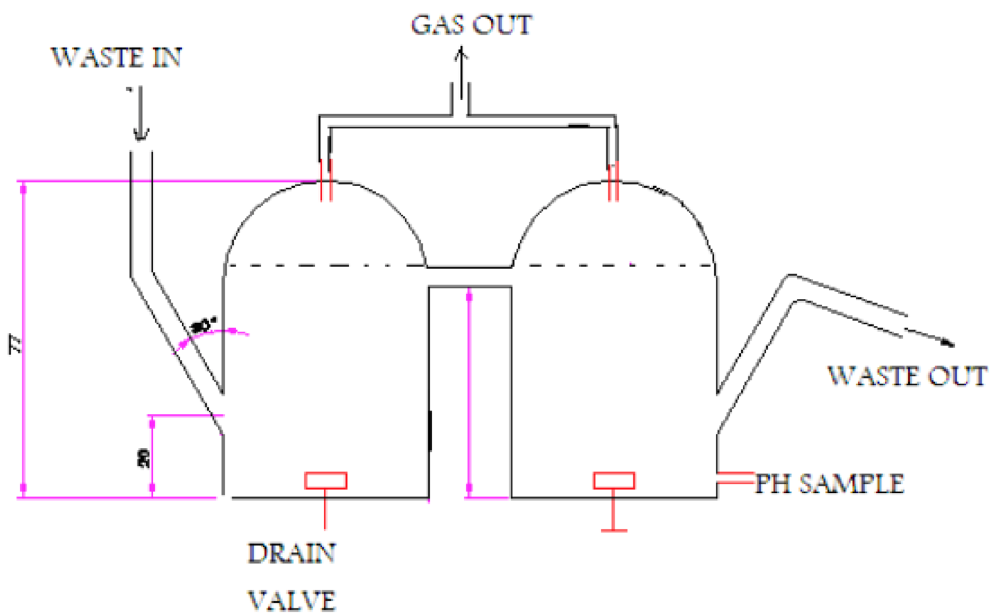

Figure 2.2: Biogas Plant Proposed by Mansour [4]

Taking into account that biogas production could surpass the demand for the biogas in a rural home or village, an alternative to generate electric energy while burning the gas was presented for this thesis, taking into account that the thesis developed by Godswill Megwai was an interesting project that accommodated to the requirements for a small scale biomass power plant. Both works use biogas as the main fuel for the generation system even though Megwai's thesis doesn't care about the origin of the biogas. Megwai analyses several setups for electric generation out of all the different alternatives Megwai's work sets the base for internal combustion engine generation, this will be the type of generating system implemented in Colombia due to the simplicity and reliability of the system, even

Technology	Rating	NOx [ppm]	CO [ppm]	HC [ppm]
Micro Turbines	30-100 kW	9-25	25-200	9-25
Gas Turbines	0.8-100 MW	6-140	1-460	6-560
IC Engines	35kW	30-450	240-380	
IC Engines	1160.17-1.5 MW	30-3200	320-830	2750
Phosphoric Acid Fuel Cells	200 kW	1	2	

Table 2.2: Typical Emission values for micro gas turbines to other technologies utilizing natural gas for power production [2]

though is not the most efficient it is suitable for the requirements of the proposed work. Megwai analyses several setups for electric generation out of all the different alternatives Megwai's work generates a table of the rating of the simulated technologies and the typical emissions. [2] [28] [29]

As a final note work by Samuel Carrara on Small-Scale Biomass Power Generation was analyzed however it was considered not to applicable to the current thesis since his work was based on an in depth analysis of generation system rather than in the implementation of those system in rural areas. The work illustrates an interesting graphic in which we can clearly see the share biomass and waste has in the current energy consumption worldwide. This gives us a broad idea of the growing prospective biomass and waste has in the energy market worldwide. [5] [30] [31]

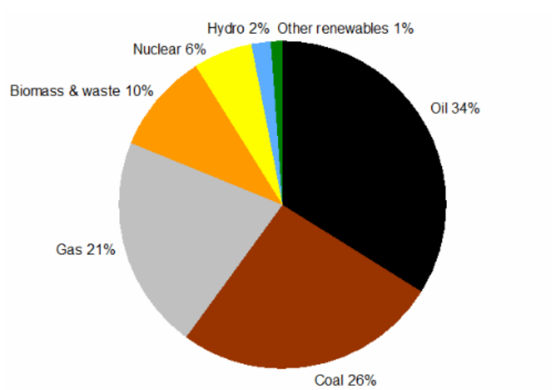

Figure 2.3: World Energy Share by Main Fuel [5]

A table was elaborated in order to organize the information recollected during this part of the thesis, it gives a simpler view of the authors analyzed and how their work differentiates or complements this thesis.

Author	**Key Similarities**	**Key Differences**
Rowayda S. Ali	**-Developed for rural areas. -Biowaste based on manure. -Fertilizer as a by-product. -Similar size reactor and biogas production rate.**	**-Uses solar thermal as an aid mechanism to maintain digesters working. -Tackles environmental issues of biowaste. -Model doesn't allow scalability.**
Mansour Al-Sadi	**- Biodigesters working in tandem allow for scalability. -Cattle manure as a viable biowaste for biodigesters. -Economic and reliable system.**	**-Allows biowaste different from manure as fuel. - Focuses in large biogas production facilities.**
Godswill Megwai	**-Energy generation as a complement for biogas production. -Generators design to work with small scale biodigesters. -Internal combustion engine generator as an option.**	**-Biogas origin is not important as long as its available. -Contemplates de use of gas turbines and micro turbines.**

Table 2.3: Comparison of Related Work Analysis

2.2 Literature Review

The use of anaerobic digestors has a important impact in the communities that implement this technology, indoor air quality has always been an issued in rural areas were fuel wood is the main energy resource. Combustion of solid biomass such as fuelwood results in elevated levels of particulates in indoor environments, this particulates have been associated with respiratory and chronic diseases such as cancer. [32] According to Bergman, the amount of indoor particulates reduces drastically when replacing solid biomass for cleaner alternatives such as biogas produced by biodigesters. Ivet Ferrer analyses the use of effluents from biodigesters as an organic alternative to commercial fertilizers, these effluents are rich in nitrogen and phosphorous making them a viable alternative to synthetic fertilizers thus decreasing the costs of production and maintenance in the fields. [33] The developments of this by-products has been done in the Peruvian Andes were the effluents have been used as organic fertilizers showing great results at a fraction of the cost, even making the commercialization of this organic fertilizer an alternative source of income. The disadvantage both authors discuss is that in small scale biodigesters a constant water input has to be added to achieve the balance of the biodigester, however both authors agree anaerobic biodigesters is a great alternative as a valuable technology that could be deployed in countries with a fair amount of rural population.

Anaerobic biodigesters have four main microbiological processes: hidrolisys, fermentation, acidogenesis and methanogenesis. A visual representation of this process is shown in the following diagram.

Hidrolisys breaks down complex organic compounds into soluble organic molecules, once we have this molecules, fermentative bacteria feed from them to break them down into much simpler forms such as organic acids, hydrogen and carbon dioxide in a process knows as fermentation. After fermentation process is over a new group of bacteria then oxidises this organic acids into volatile fatty acids in a process know as acidogenesis. Then in a syntrophic

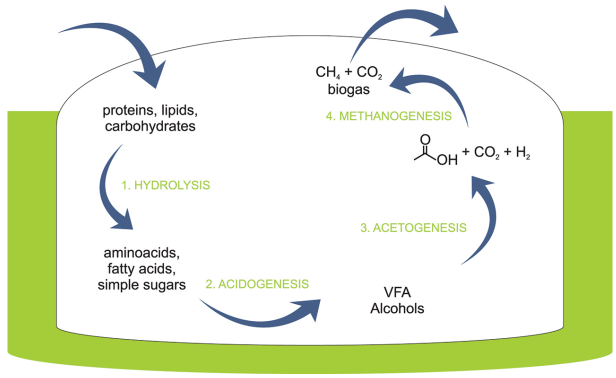

Figure 2.4: Anaerobic Digestion Process [6]

process of methanogeneisis and acetogenesis this volatile fatty acids in presence of hydrogen and carbon dioxide react to form methane. [6]

Currently several designs and types of biodigesters have been developed according to the needs and environmental characteristics of their deployment, a group of this biodigesters are known as simple reactors ,from this reactors only one is applicable in rural areas according to the characteristics they have to comply with to work in the proposed conditions, this biodigesters are known as batch reactors, being the ones with the most deployement in rural areas around the world due to their simplicity and efficiency. [?] Batch reactors work as the

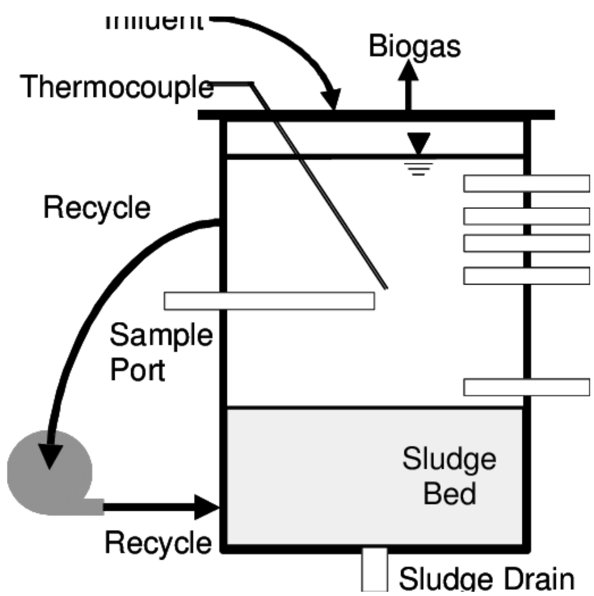

Figure 2.5: Anaerobic Batch Reactor [?]

name indicates by batches or loads, the reactor must be filled with the manure slurry and then all of the processes are completed in a determine period of time, after this all or some of the contents of the reactor are removed. Mechanical mixing is not needed but could be use at the beginning of the process. From semi batch reactors three types of biodigesters have been developed to work in rural areas: polyethylene tubular digesters, floating-drum digesters and fixed dome digesters.

Fixed dome digesters and floating drum digesters essentially work the same way a slurry feed enters the reactor, were the biogas is produced after completing all of the processes and we have a min product called biogas and a by-product of solid waste that could be used as organic fertilizer. The main difference between both digesters is the ability of the floating

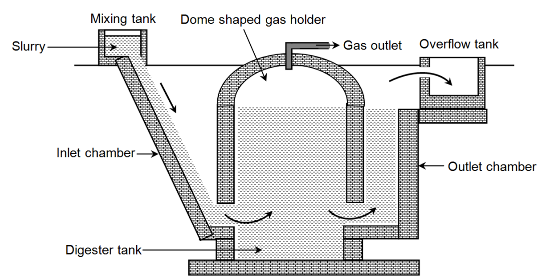

Figure 2.6: Fixed Dome Digester

drum digester to increase or decrease the storage capacity of biogas, besides this design difference another important factor is the design life of both digesters, fixed dome digesters have a spam of over 20 years that's 5 more years than the average floating drum digester.

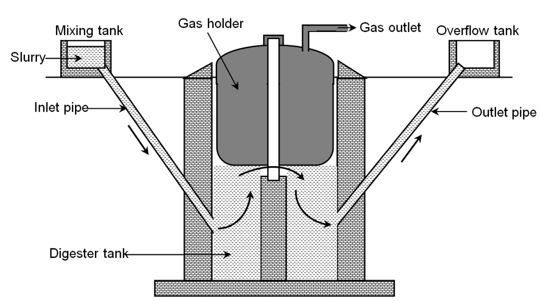

Figure 2.7: Floating Dome Digester

In the other hand we have Polyethylene Tubular Anaerobic Digester, this type of digesters work as a semi batch process digesters but are modeled based on Plug Flow Reactors or PFR, this type of rreactors are the most economic and the ones of fastest deployment however their life spam only reaches 10 years tops, that's half the life spam of fixed dome digesters. Once this digesters reach equilibrium their output is similar to their input creating a constant flow of both biogas and slurry for fertilizer. They are the ones that have been implemented in Peru biogas projects for rural areas. [34] [?]

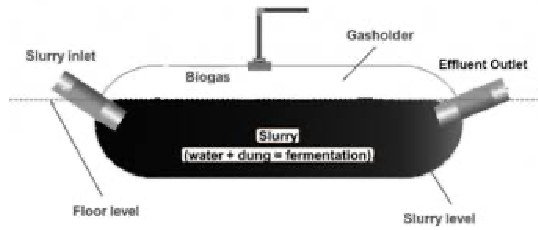

Figure 2.8: Polyethylene Tubular Anaerobic Digester

As the final part of this digesters topic, we have talked about scalability of the system, there are several configurations that allows us to increase the capacity of the system by increasing the amount of digesters or by recycling slurry in some processes. The recycle process allows us to achieve a more efficient treatment of the slurry thus increasing the amount of effluents such as biogas with the same amount of inputs. The way of increasing capacity by increasing the number of digesters is determined by the configuration of the new digesters, they can be installed in series or in parallel. Installing reactors in series allows us to add different types of digesters (reactors) in the same process. Installing digesters in parallel is not a great idea for small rural application since the operations costs are higher than the returns making them economically non-viable. [35]

A patent search showed us that many advances have been done in biodigesters technology focusing in the simplicity of the process rather than in its efficacy, new trends try to incentive the use of biodigesters by creating simple to use solutions. Patent with international publication number WO 2018/102847 Al provides a prefabricated biodigester to be implemented in areas with little to no access in order to produce biogas for a household. This patent contemplates the use of manure a biowaste for the biodigester and other organic waste. Besides the installation of the biodigester the only necessary adaption is a room to protect the device from the environment this way enchasing its life spam. [7]

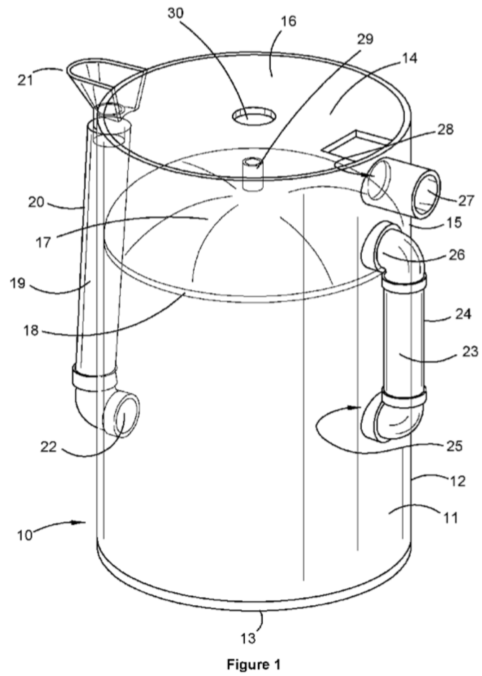

Figure 2.9: Prefabricated Biodigester [7]

Analyzing this patent we can clearly observe a trend towards an easy implementation technology that tries to give the final user full control over its own system, the negative part of this patent is that it doesn't contemplate an easy removal system for effluents thus making the organic fertilizer recollection from effluents somewhat difficult.

Another clear trend that was observed during the patent research was the one focusing in improving the life spam of biodigesters, this is really important for rural applications, since a better life spam allow for a wider time frame for the return over the inversion to happen. Patent US2019/0344547 A1 talks about a newly developed flexible geomembrane that has excellent barrier properties against organic solvents and gases as the ones found in biodigesters as well as a good flexibility that allows it to be installed inside polyethylene tubular digesters thus improving their life spam. This geomembrane addresses the issue of adhering ethylene terpolymer sheets to PVC without the use of a thermal process that weakens both materials, thus solving the problem and in the same process creating a more flexible and durable geomembrane. [36]

Compiling all the information gathered so far we have encountered that several types if digesters have been developed and many other are under current development and deployment however no matter what digester is going to be chosen and deployed all of this digesters have several factors that directly affect their performance. The most common and important operation parameters are

- Hydraulic Retention Time. (HRT)

  HRT is the amount of time (in days) actively digesting sludge stays within the reactor and it define by the following:

  $$HRT = \Theta = \frac{VolumeReactor}{inputflowrate} = \frac{V}{Q}$$

  HRT is important to reactor design and operation since it defines the amount of time particular material will be in contact with the biomass within the reactor affecting chemical processes inside the digester. [37]

- Solid retention Time (SRT)

  SRT is defined by the following expression:

  $$SRT = \Theta_C = \frac{ActiveBiomass}{ProductionRateofActiveBiomass} = \frac{V * X}{Q_w * X_w}$$

  $$V = ReactorVolume$$

  $$X = Cellconcentrationinthereactor$$

$$Q_w = FlowrateOUTofthereactor$$

$$X_w = CellconcentrationinQ_w$$

SRT is an important parameter because a short SRT means organism washout and a long SRT would mean the digester will be nutrient limited. SRT impacts organism growth and the microbiology within the reactor. Longer SRT will eventually mean lower by products and higer biogas production. [38] [39]

- Organic Loading Rate (OLR)

OLR is the amount of mass of volatile solid added each day per reactor volume:

$$OLR = \frac{Q}{V_{reactor}} = \frac{C_{vs}}{HRT}$$

$$V = ReactorVolume$$

$$Q = Volumetricflowrate$$

$$C_{vs} = Concentrationofvolatilesolids$$

$$X_w = Hydraulicretentiontime$$

If the loading rate is not adecuate the digester could become inhibited stopping all biochemical process, causing a failure in the whole process. [40] [41]

- Mixing

Mixing parameter increases the rate of kinetics within the digester accelerating the biochemical conversion process. Besides that mixing allows uniform reaction inside the digester. Mixing process could be done mechanically though impellers or turbines o pneumatically by injecting methane or carbon dioxide. [42] [43]

- pH

pH is perhaps one of the most important parameters in anaerobic digestion, pH should be maintain between 6.6 and 7.6. pH could be an indicator of debalance inside the digester low pH indicates great concentration of organic acids which decrease methane production and can cause a rector failure. Carbonic acid is the role player in pH control for most of the time in anaerobic digestion, since carbon dioxide equilibrium is approached in anaerobic digestion. [44] [45]

- Temperature

Since all reaction rate of chemical reaction depend directly on temperature we can satte that bacterial growth also depends on temperature. Baterial growth rate normally double for every 10°C rise in temperature, however this rate depends on the bacterial species. Normal anaerobic operational temperature range is 10°C to 30°C, this gives us a wide range that could be use full taking into account Colombia's geography and location of the rural areas that are likely to be in different geographic and meteorology conditions. [46] [47]

- Alkalinity

Alkalinity is the capacity of water to neutralize acid, in anaerobic digestion the following condition applies:

[H+] + [Alkalinity] = [HCO -] + 2 [CO 2-] + [OH-]

To have a working reactor bicarbonate alkalinity must be within the range of 500 to 900 mg/L, this in order to maintain a pH higher than 6.5. [48]

As a final part of this literature review, when we talk about organic fertilizers coming from manure we have to be really careful of the pathogenic load of this fertilizers, pathogen reduction is one of the goals of anaerobic digestion. Different types of digesters provide different amounts of pathogens in the by products, however this reductions are completely linked to enviromental conditions. Porr literature regarding this topic was found however the folowwing graphics show the difference in pathogen load of two tpes of pathogen in diferent models of anaerobic digesters. [49] [50]

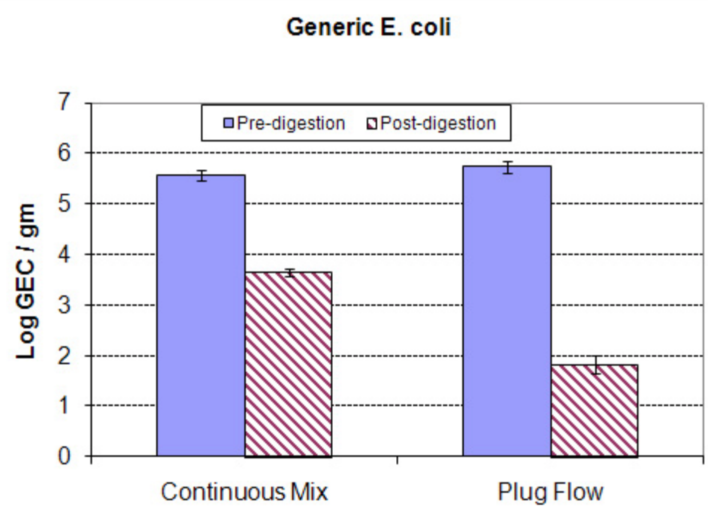

Figure 2.10: E. Coli Pathogenic Load Comparison

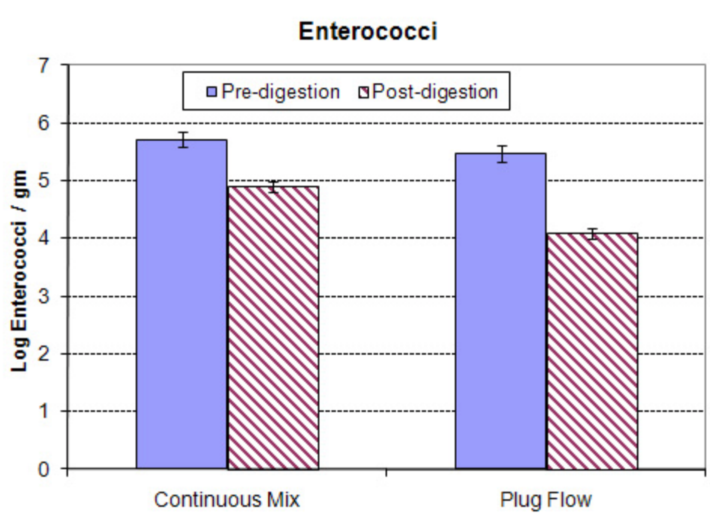

Figure 2.11: Enterococci Pathogenic Load Comparison

CHAPTER 3 System Design & Specifications

3.1 Design Specifications

A simple closed loop biodigester system consists of two inlets and three outlets as describe in the following diagram, in order to size the anaerobic biodigester a design tool must be developed that takes into account all the collected data so that it gives the user enough information to develope the project in accordance to the specific requirements, another option is to size the biodigester in accordance to the offer of input products rather than the demand of the household. [51] [52]

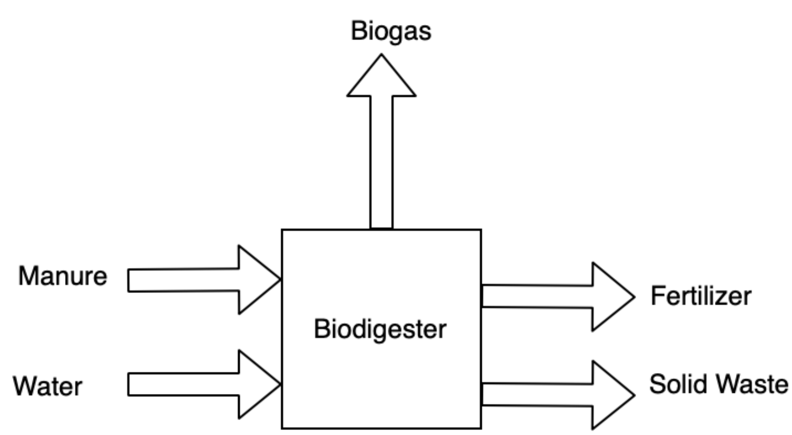

Figure 3.1: Biodigester Flow Diagram [1]

A sample design was developed as a guidance tool based on the information collected through the research, this model offers a simple equation that allows us to dimension the impact the digester will have in the community:

1. Design by demand This was developed by calculating the amount of cows needed to

supply te average demand of biogas of a household in Colombia. [53] [33]

$$1\ Cow = 25kg\frac{kg\ manure}{day} = 0.75\frac{m^3\ \ biogas}{day}$$

$$1\ household = 0.9\frac{m^3\ \ biogas}{day}$$

$$therefore$$

$$1\ household = 1.2\ cows$$

2. Design by supply This was developed by calculating the amount gas that could be supplied by an average household in rural Colombia which owns 3 cows.

$$1\ household = 4\ cows$$

$$1\ Cow = 25kg\frac{kg\ manure}{day} = 0.75\frac{m^3\ \ biogas}{day}$$

$$therefore$$

$$1\ household = 2.25\frac{m^3\ \ biogas}{day}$$

3.2 System Level Design

Work on a full working tool to analyze client requirements is currently ongoing, this in order to calculate the dimension and type of reactor. The ides of this tool is to be used with local farmers in order to offer them tailor made reactors that adjust to their requirements and to their manure offer rather than to have an oversized reactor that wont be able to work with the current conditions of the clients.

CHAPTER 4 Design & Development

4.1 Design

4.2 Implementation

CHAPTER 5 Results and Performance Assessment

5.1 Simulations

TBC

5.2 Experimentation Results

TBC

5.3 Performance Characterization

TBC

CHAPTER 6 Conclusions

6.1 Contributions

6.2 Future Work

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