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ALINE CASTRO PRACIANO

ENERGY BALANCE OF SMALL SCALE BIOGAS SYSTEM FOR FAMILY FARMING AGRICULTURE

FORTALEZA
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Dissertation submitted to the Graduation Program in Agriculture Engineering of Universidade Federal do Ceará, in partial fulfilment of the requirements for the degree of Masters of Agriculture Engineering. Concentration area: Engineering of Agriculture Systems

Supervisor: Prof. Dr. Daniel Albiero.
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To God.

To my family.

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"Determination, courage, self-confidence are decisive factors for success. If an unshakable determination possesses us, so we will get to overcome. Regardless the circumstances, we should always be humble, modest and stripped of pride.

(Dalai Lama)

RESUMO

O biogás é uma energia renovável interessante ao meio rural, pois este pode ser gerado a partir do esterco dos animais de produção, como bovinos, suínos, caprinos, ovinos e aves. Esse biocombustível pode ser convertido em energia elétrica e térmica, possibilitando diversos ganhos econômicos e ambientais, para o meio rural, principalmente para a agricultura familiar, através da economia gerada pela redução dos custos com energia elétrica e gás de cozinha (GLP - Gás Liquefeito de Petróleo). Além de ganhos ambientais, através da redução da Emissão de Gases do Efeito Estufa (EGEE), do desmatamento do bioma caatinga, da contaminação de solo e de aquíferos. A energia elétrica gerada por biogás pode ser utilizada em diversos setores da agricultura como a iluminação das instalações agrícolas, zootécnicas e residenciais, funcionamento de equipamentos agrícolas como motobombas, forrageira e ordenhadoras. Esse biocombustível também pode ser utilizado para gerar energia térmica, que pode ser utilizada em substituição ao gás de cozinha ou lenha, para a cocção de alimentos ou na ambiência animal, através do aquecimento de animais, como suínos e aves. Esse estudo avaliou a produção de biogás a partir de esterco bovino, a concentração de metano do biogás bruto e purificado (em filtros de sílica gel e carvão ativado) por cromatografia gasosa, a conversão de biogás em energia elétrica e térmica, o consumo de biogás de uma motobomba de irrigação de 0,33 CV, de lâmpadas LED de 12, 16 e 24 W e de um fogão de duas chamas, foram determinados o poder calorífico do esterco fresco, esterco digerido e do biofertilizante e foi realizada a avaliação química do biofertilizante. O objetivo do trabalho foi avaliar o balanço energético do sistema termodinâmico de conversão de esterco bovino em biogás, que foi gerado em um biodigestor tubular de PVC (Policloreto de Vinila) e a eficiência energética, através da determinação do poder calorífico superior dos produtos envolvidos. O sistema termodinâmico avaliado apresentou um balanço energético de 142,75 MJ e uma eficiência energética de 89,30%.

Palavras-chave: Esterco Bovino. Poder Calorífico Superior. Energia Renovável

ABSTRACT

Biogas is an important renewable energy in the rural areas, for it can be generated from the manure of livestock, such as bovines, swine, goats, sheep and birds. This biofuel can be converted into electric and thermal energy, which allows several economic and environmental gains for rural areas, especially for the family agriculture because of the savings resulted from the reduction of costs with electricity and gas for cookery (LGP - Liquefied Gas of Petroleum). Beyond that, benefits to the environment such as the reduction of Greenhouse Gas Emission (GGE), deforestation of the biome caatinga, contamination of soil and aquifers. The electricity generated by biogas can be used in several sectors of agriculture such as illumination for agricultural, zootechnical and residential facilities, agricultural equipment operations, such as motor pumps, forage, and milking machines. This biofuel can also be used for generating thermal energy, which takes the place of cooking gas or firewood for cookery or for animal welfare by heating the sheds, as for swine and poultry. In the present study, we assessed the biogas production from bovine manure, the methane concentration of crude and purified biogas (filters of in silica gel and activated carbon) by gas chromatography, the conversion from biogas to electric and thermal energy, the consumption of biogas of a 0.33 HP irrigation motor pump, 12, 16 and, 24 W LED bulbs, and a two-flame stove, we determined the calorific value of fresh and digested manure, and of the bio-fertilizer, and we conducted the chemical evaluation of the bio-fertilizer. The study aimed to evaluate the energy balance of the converting thermodynamic system from bovine manure into biogas generated in a PVC (polyvinyl chloride) tubular digester plant and the energy efficiency by determining the higher calorific power of products involved. The assessed thermodynamic system had energy balance of 142.75 MJ and energy efficiency of 89.30%.

Keywords: Bovine manure. Higher Calorific Value. Renewable Energy

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SUMMARY

1 INTRODUCTION

Biogas is a source of renewable energy, product of the biological fermentation of organic matter, composed mainly of methane (CH_4) and carbon dioxide (CO_2). This biofuel may be generated from manure of livestock production, such as cattle, pigs, goats, sheep and birds, which makes this biofuel an attractive source of energy to rural areas. It generates income and growth to the field, beyond the reduction of Greenhouse Gas Emission (GGE) and use of biofuels from fossils.

Per the last agricultural census, around 75% of agricultural establishments of Ceará hold less than 10 ha and are classified as small properties, generally exclusively managed by family members, being characterized as family farming. This field generally faces several financial and technological limitations that harm social and economic development on the agricultural sector.

We assume that biogas is an important source of alternative energy. The biogas can be used in family farming as a substitute to the cooking gas (LPG - Liquefied Petroleum Gas) or firewood, which reduces the consumption of fossil fuels and reduces the deforestation pressure on the biome caatinga, producing income and increasing life quality, since the logging is an arduous job usually performed by women. Beyond that, the biogas can also be converted into electrical energy that supplies the energy demand for several activities in agriculture, such as illumination to the agricultural and zootechnical facilities, water pumps for irrigation and supply for human and animal consumption, agricultural equipment functioning. The implementation of biogas mapping projects can be financed by the National Program for Strengthening Family Agriculture (Pronaf, in Portuguese), which maintains a funding line named Pronaf Eco, that provides credit for the execution of projects that generates renewable energy for the family farming.

The aim of this research was to evaluate the energy balance and the energy efficiency of a thermodynamic system for energy conversion from bovine manure to biogas in tubular PVC (polyvinyl chloride) digester by determining the calorific value in related products.

2. OBJECTIVE

2.1 General Objective

The aim of this research was to evaluate the energy balance in the biogas generation process from bovine manure in small-scale tubular digester plant for the family agriculture.

2.2 Specific Objective

- To generate biogas from bovine manure
- To evaluate the gross calorific value from bovine manure in calorimetric pump
- To evaluate the concentration of methane (CH_4) of the biogas through chromatography
- To evaluate the calorific value from bio-fertilizer in calorimetric pump
- To evaluate the biogas consumption during the conversion of biogas into electrical energy through motor-generator.
- To evaluate the biogas consumption during the conversion of biogas into thermal energy.
- To calculate the energy balance during the process of energetic conversion from bovine manure to biogas.
- To calculate the efficiency during the process of energetic conversion from bovine manure to biogas.

3 LITERATURE REVIEW

3.1 Biogas

The biogas is a biofuel, source of renewable energy, which is generated from the fermentation of organic matter, being of animal or vegetal origin. The anaerobic fermentation of organic matter is carried out by bacteria and is grouped in four stages as described by Silva (2013).

1st Stage: Hydrolysis, at this phase the bacteria excrete extracellular enzymes that perform the hydrolysis of particles and convert larger molecules into smaller ones, soluble in the medium. Hydrolytic bacteria transform proteins into peptides and amino acids, polysaccharides, fats into fatty acids. This stage limits the speed of which organic matter will be converted into biogas, during this stage it takes place the transition from the anaerobic to the aerobic phase, when occurs the production of slurry (Bio-fertilizer in the instance of the digestion of manure and agro industrial residues).

2nd Stage: Acidogenesis, during this phase the acidogenic bacteria convert the products from the first phase into organic acids, ethanol, ammonia, hydrogen, and carbon dioxide. The pH reduction promotes the predominance of long chain organic acids, also occurring release of nitrogen and phosphorus, the current stage aerobic and anaerobic microorganisms, in the first ones they take out oxygen from the compounds that constitute the organic matter.

3rd Stage: Acetogenesis, during this phase the products from the previous stage are converted into acetate - reaction (1), this stage is crucial in the degradation process, being a preparation for the next stage.

Acetogenic reaction (1):

$$CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2$$

$$CH_3(CH_2)COOH + 2H_2O \rightarrow CH_3COOH + 2H_2$$

4th Stage: Methanogenesis, during this phase it takes places the methane production (CH_4) - reaction (2). The archaebacteria transform the hydrogene and the carbon dioxide into acetic acid, methane, and carbon dioxide, the archaeobacteria that produce methane from hydrogen show a higher growing rate rather than the ones that produce methane from acetic acid, in this way, the acetotrophic methanogenic bacteria limit the conversion speed of the organic matter into biogas. Throughout this process, it may also to be produced nitrate and sulfate, the sulfate reduction is undesirable process, for it hinders the methane formation and favors the sulfuric gas production that is corrosive and produces unpleasable odor.

Methanogenic reaction (2):

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Although complex the stages involving the anaerobic fermentation, this process occurs continuously inside the digester. The reaction (3) that occurs inside the digester during the organic matter degradation explains the conversion of organic matter into the main biogas constituents (SILVA, 2013):

Organic matter digestion reaction (3):

$$Organic\ Matter + H_2 \rightarrow CH_4 + CO_2 + BIOMASS + NH_3 + H_2S + HEAT$$

The biogas composition may vary per the source material; however, Table 1 presents a general biogas composition (ANASTÁCIO, 2008). The higher the concentration of methane, higher will be the calorific value and lower the concentration of other gases (SILVA, 2013).

Table 1 – Biogas Composition in Percentage

Composition	**Composition in Biogas (%)**
Methane (CH_4)	50 to 80
Carbon Dioxide (CO_2)	20 to 40
Nitrogen (N_2)	0.5 to 3
Hydrogen (H_2)	1 to 3
Oxygen	0 to 1
Other Gases (H_2S, CO, NH_3)	1 to 5

Source: Anastácio (2010).

The table 2, groups the volumetric relation of other fuels corresponding to 1m^3 of biogas, according to Oliver (2008).

Table 2 - Volumetric Relation of Other Fuels Related to $1m^3$ of Biogas

Biogas	Other Fuels
$1\ m^3$	469 g of Gasoline
	456 g de Kerosene
	550 g of Diesel Oil
	450 kg of LPG (Liquefied Petroleum Gas)
	624 g of Ethanol
	1538 kg of Wood
	1.428 kwh of Electrical Energy

Source: Oliver (2008).

3.1.1 Factors that influence the anaerobic digestion

Several factors may interfere the anaerobic digestion process of the organic matter, these factors usually are related to the characteristics of the organic matter utilized during the process of anaerobic digestion, characteristics of the reactor and the operations conditions, among other factors.

3.1.1.1 Quantity of dry matter (DM)

According to José Filho (1981), the methane production is related to the dry matter concentration of the organic matter utilized in biogas production, that might present a rate of 7 to 9% of DM, that means, each 100 liters of biomass must contain 9 kg of DM. Mazzucchi (1980), affirms that for continuous flow digesters the rate of DM must to be around 7 to 9%, however for batch flow digesters the rate of DM must to be higher, the ideal is that biomass has at least less 25% of DM.

3.1.1.2 Nutrients concentration

In order to the methane-producing archeobacteria, responsible for the methane (CH4) production, satisfactorily develop. the biomass must contain some macronutrients concentrations, such as carbon, nitrogen, potassium, phosphorus and sulfur, as well as some micronutrients like vitamins and amino acids. This way, knowing the chemical composition of the utilized biomass guarantees success of biogas production, and the possibility to correct some nutrient deficiencies through chemical activators and correction with nutrient dosage, regarding the improvement in the fermentation process of biomass (JOSÉ FILHO, 1981).

3.1.1.3 pH - Acidity or Alkalinity

The adequate level of pH for biogas production varies between 6.8 and 7.2 (WARD *et al*., 2008). The appropriate levels of pH for hydrolysis and acidogenesis are 5.5 and 6.5, respectively (KHALID *et al*., 2011). The pH control during the biomass anaerobic digestion may ensure a better biogas production (ZHOU *et al*., 2016). According to Zhain *et al.* (2015), the ideal cow's manure pH for the best biogas production is 7.5, moreover for biogas production from swine manure the pH is 6.81.

3.1.1.3 Temperature

The temperature is one of the main factors that exert influence during the anaerobic fermentation, this factor may accelerate the biogas production by reducing the time of hydraulic retention of the biomass inside the digester, the temperature may also to effect the concentration of methane existing in the biogas, that is, the highest the temperature highest will be the concentration of methane in the generated biogas, thus higher calorific value, which improves the biogas combustion power (SOUZA, 1984)

According to Barrera (1983), the methanogenic archaebacterial are more sensible to abrupt temperature variations, that being so, maintaining the temperature constant is a factor that optimizes the biogas generation, even though the methane production occurs under extreme conditions with temperatures of 0 to 97ºC. The mesophilic methanogenic archaebacteria act in the temperature interval from 20 to 40ºC, moreover the thermophilic archaebacteria act in the interval from 50 to 60 ºC (KELLEHER *et al.*, 2002). The processes of digestion and gasification is accelerated in temperatures from 35 to 37 ºC (CHERNICHARO, 1997). Temperatures below 35 ºC decelerate the process of biogas generation and are paralyzed in temperatures lower than 15ºC (BARRERA, 1983).

3.1.1.4 Hydraulic retention time

According to José Filho (1981), the hydraulic retention time is the length of time that the organic matter passes through the internal part of the digester, that means the interval in which the material enters and leaves the digester. The hydraulic retention time is determined in function of the type of organic matter, the biomass granulometry, the digester temperature and the biomass pH, however this period usually comprehend the interval from 4 to 60 days, for livestock manure the period goes from 20 to 30 days (JOSÉ FILHO, 1981).

3.1.1.5 Volatile solids concentration

It is recommended a minimum of 120 g volatile solids (VS) per kg od dry matter for the biogas production, the higher the VS concentration the better will be the biogas production, for the volatile solids are fermented elements during the production of biogas. The bovine manure has the concentration of 80 to 85% of volatile solids (JOSÉ FILHO, 1981).

3.1.1.5 Carbon/nitrogen ratio (CN)

The CN ratio is related to the conditions in which the biological process of fermentation occurs, the optimal CN ratio for biogas production is about 20 to 30: 1, that means, 20 to 30 parts of carbon per one part of nitrogen, the majority of animal manures have a low CN ratio, since they have plenty of nitrogen, what can be compensated with addition of vegetal residues, such as straw, corncob, sawdust and crop stubs in order to reach the ideal CN ratio (JOSÉ FILHO, 1981).

3.1.1.6 Toxic substances

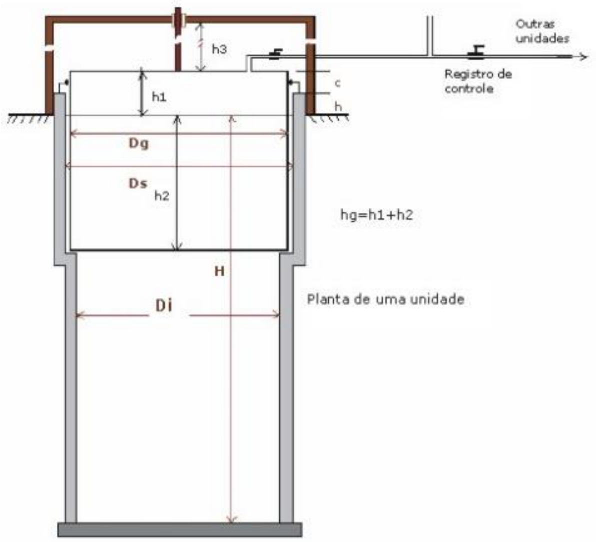
The surplus of nutrients or elements in solution inside the digester may cause toxicity, in the same way, disinfectants and bactericides used in facilities where the animals are raised can cause contamination to the manure and be lethal to the bacteria involved in the manure fermentation process for the biogas production (JOSÉ FILHO, 1981).

3.2 Digester Plant

The digester plant is a structure made of a totally sealed dome, i.e. a hermetically closed chamber, except for the inlet and outlet pipes in which during the storage of organic material, it occurs the degradation of this material and by the anaerobic fermentation it generates biogas, in this way, the digester works as a chemical reactor (QUADROS, 2009). This equipment can be built of several materials, being the most common the PVC and the burnt-clay bricks.

The digester plants used in the agricultural sector, are classified according to their form of supply: continuous flow and batch flow (QUADROS, 2009). The batch flow is the kind of digester that obtains the whole volume of organic matter at once, remaining for an average of 90 days for the final production of the biogas, after its removal it should be cleaned for beginning a new cycle (DEGANUTTI *et al.*, 2002). The simplest batch flow digester consists of a cylindrical body, a floating gasometer and a guide for the gasometer, that model (FIGURE 1) is ideal for managements in which biomass availability occurs for long periods, e.g., such as poultry farms, in which the residue is available after birds are sold (DEGANUTTI et al., 2002).

Figure 1 - Frontal Scheme of a Batch Flow-type Digester

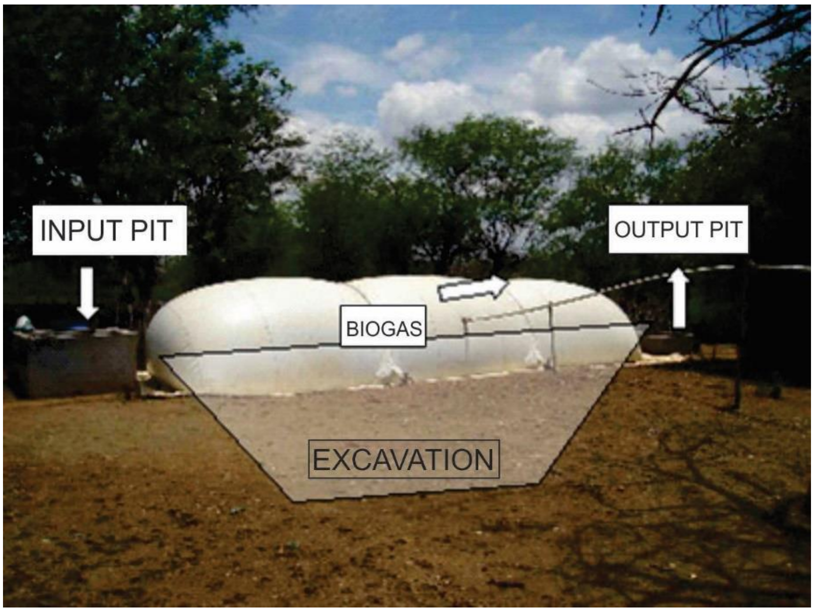


Source: DEGANUTTI *et al.* (2002).

The most used digesters of continuous flow are: Canadian, Indian and Chinese. Those are fed daily with the volumes of organic matter.

Currently in Brazil the most used model of digester is the Canadian model, also known as tubular (FIGURE 2), built in PVC (Polyvinyl Chloride) flexible blanket, this kind of digester is cheaper and it is easy to place, being utilized for small or big properties, due to the varied sizes (HAACK, 2009).

Figure 2 - Canadian-type or PVC Tubular-type digester

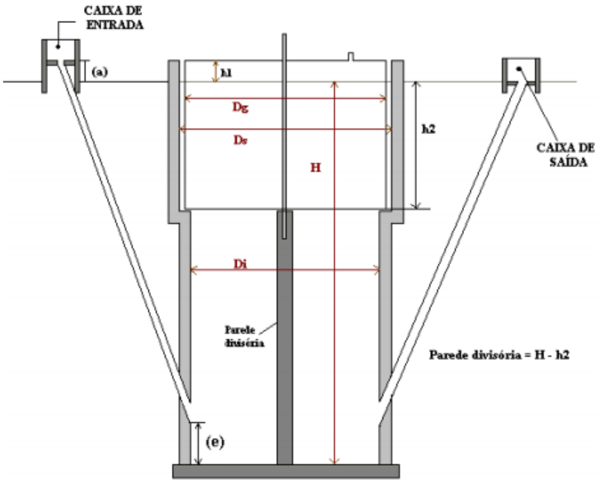


Source: QUADROS (2009).

The Canadian-type, or tubular-type digester is made up of one inlet pit, one underground fermentation dome, which is coated with a waterproof material, usually PVC, the top hood made of a plastic tarpaulin for retaining the biogas that is produced and one outlet box where the final effluent passes through (OLIVEIRA JÚNIOR, 2012).

The most common digester is the Indian-type (FIGURE 3), it consists of a mobile hood which works as gasometer and it is possible that it stays immersed in the fermenting biomass or water seal, and a central wall that separates the fermentation tank in two chambers, allowing the residue movements in every part of digester, this type holds constant internal pressure, as the biogas is produced but not consumed, the hood expands, which guarantees that the pressure does not change (DEGANUTTI *et al.* 2002).

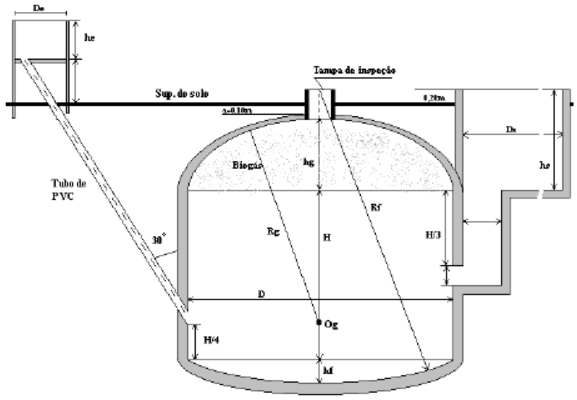
Figure 3 - Indian-type Digester



Source: DEGANUTTI *et al*. (2002).

The Chinese-type continuous flow digester (FIGURE 4) was inspired by the Indian model, however its project was modified in order to be adapted to the conditions in China, because the adjustments made it more efficient in countries with climate conditions of low temperatures, since the model reduces heat losses, as its gas reservoir is usually buried under the ground (ANASTÁCIO, 2010). The Chinese model does not have a mobile gasometer, which reduces the building costs of the structure. This type consists of a cylindrical chamber, for the fermentation, built in burnt-clay brick, the top is impermeable and has the shape of cylindrical half-sphere, which stores the biogas, this being above the organic matter (OLIVEIRA JÚNIOR, 2012). Unlike the Indian model, the Chinese model does show variation on its internal pressure, working as with the principle of hydraulic press, such a way that the pressure increasing will move the effluent from the fermentation chamber into the outlet box, and in the opposite direction when decompression occurs (DEGANUTTI *et al*., 2002).

Figure 4 – Chinese-type Digester



Source: DEGANUTTI *et al.* (2002).

3.3 Bio-fertilizer

Bio-fertilizer is a by-product from of the biogas production process, especially when it is produced from the organic material from the agriculture, for when the biogas comes from sanitary landfills this material is named as slurry. The bio-fertilizer is rich in organic matter that provides essential elements to plant nutrition, such as NPK (Nitrogen/Phosphorus/Potassium) (INOUE, 2008). According to Kiehl (1985) bio-fertilizers from the manure anaerobic fermentation show concentrations of NPK as follow (Table 3).

Table 3 – NPK Concentration in Bio-fertilizers

Manure	N (%)	P (%)	K (%)
Goat Manure	2.33	0.47	1.58
Buffalo Manure	0.26	0.14	0.09
Swine Manure	3.64	3.39	3.34
Bovine Manure	2.14	1.92	2.82

Source: Kiehl (1985).

The bio-fertilizer provides the soil with better chemical and physical quality, this material if well decomposed (or humidified) favors soil aggregates, which reduces and provides better porosity and reduces salts leaching (OURIVES *et al.*, 2010). According to Brito *et al.* (2005), the bio-fertilizer from bovine manure promoted changes of the chemical properties, once it increased the rates of calcium, organic matter and CEC (Cation Exchange Capacity), promoting better results if compared with bio-fertilizers produced from manure of other animals such as birds, sheep, poultry litter and silage residues.

The bio-fertilizers contain substances that act as natural defenses when regularly applied on leaves (EMBRAPA, 2006). Beyond that, the use in soil favors the microbiological balance in the soil, which indirectly collaborates on the nematodes control for the nutrition of the plants make them more vigorous and so less susceptible to the increase of antagonistic microorganism populations, besides releasing toxins during the decomposition that contribute to their mortality (EMBRAPA, 2015).

3.4 Livestock Manure as Raw Material for the Biogas Production

According to the agricultural sense of 2006 (IBGE, 2006) the state of Ceará holds a total of 341,479 agricultural establishments, these properties sums a total od 7,922,214 hectares (ha), however about 75% of agricultural establishments are less than 10 ha, being characterized as family agriculture properties.

Table 4 shows numbers of livestock accounted by the last agricultural sense of the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese) in the state of Ceará.

Table 4 - Livestock Population in the State of Ceará

Species	Nº of Establishments	Nº of Heads
Bovines	124.456	2.105.441
Buffalos	44	1.443
Equines	53.126	102.505
Donkeys	65.430	106.701
Mules	35.229	50.678
Goats	38.114	748.866
Sheep	58.399	1.564.907
Swine	110.940	690.966
Birds	207.355	20.556.359
Other Birds (1000 Head)	73.154	614.330
Rabbits	479	4.015

Source: IBGE (2006).

Manure is the main raw material used for the production of biogas in agricultural properties. In order to produce biogas, the manure should be diluted in water, which favors anaerobic fermentation, according to Quadros (2009), for bovine manure the water concentration is 1 liter of water for each kilogram of manure, for swine manure the concentration is 1.3 L for 1 kg, for sheep and goat manure they must undergo the process of 24 hours hydration, besides it is recommended to crush the fecal pellets, for this type of manure the concentration of water is 4 L for each kg of manure. Table 5 presents the annual produce of manure for 450 kg of live weight per species.

Table 5 - Annual Manure Production per Species (450 kg of live weight)

Species	**Tons of manure per year**	**Average of manure production (kg per day)**
Bovine	8.5	10.00
Dairy Cows	12.0	10.00
Sheep and Goats	6.0	0.36
Swine	16.0	2.25
Equines	8.0	10.00
Birds	4.5	0.18

Source: Adapted from QUADROS (2009); COLATTO; LANGER (2012).

The potential for biogas production of manure varies according to species or life stage. Table 6 gathers the potential for biogas production for man the manure of some animals according to Quadros (2009).

Table 6 - Potential for Biogas Production from Animal Manure.

Biomass Utilized (Manure)	**Biogas Production (From dry material in m³/t)**	**Percentage of Gas Methane Produced**
Bovines	270	55%
Swine	560	50%
Equines	260	Variable
Sheep	250	50%
Birds	285	Variable

Source: Adapted from QUADROS (2009); COLATTO; LANGER (2012).

3.4.1 Greenhouse Gases Emission and Carbon Credits

Methane (CH4) is one of the gases that cause the greenhouse effect, and it has a 21 times higher potential than CO_2. The use of digesters in the rural areas is an interesting alternative, beyond reducing emissions of greenhouse gases (GHG) it promotes rural sanitation which eliminates odors and insects (causes of diseases in animals, e.g., myiasis) (QUADROS, 2009), supplies rural area with fuel by the use of biogas and bio-fertilizer, it gives value to the detritus for agronomic purposes, it reduces pollution of aquifers and soil, and reduces pathogens in agriculture (COLATO;LANGER, 2011).

Global emissions of methane from livestock waste are estimated in about 25 million tons per year, which correspond to 7% of total methane emissions (EMBRAPA, 2015), the use of digesters for reducing these gases emission, beyond all the advantages above it generates income from the sale of carbon credits (Currently 1 t of CO_2 is equivalent to € 10.00), the swine industry is the agricultural sector that stands out in this market, this is an activity of great polluting potential for it produces large amounts of waste, bad odor and soil and groundwater contamination, the use of intensive raising and confinement gathering several animals in small areas (KUNZ *et al*., 2005).

Multinational companies ultimately have set digesters in the partners facilities at rural areas in trade for carbon credits, Sadia ® obtained in the United Nations (UN) the registration for a program of greenhouse gases capture, untitled Sustainable Swine Farming Program (Programa 3S, in Portuguese), adopted for 38% of the company's swine farmers, with 1,086 digesters set, the company expects to generate 600 thousand tons of CO_2 equivalent, the company has invested about R$ 90 million to the Programa 3S, this is the first time the UN grants this kind of certification to a company in the agricultural sector (ESTADÃO, 2009).

3.5 Electrical Energy Generation

The potential energy of biogas varies according to the concentration of methane in its composition, the higher this concentration, the higher the calorific value of biogas (COSTA, 2006). Biogas produced from animal manure holds an average of 50% of methane in its concentration (COLATTO; LANGER, 2012)

According to Zilotti (2012), the quantity of available energy during combustion per unit of mass or volume in a fuel is named as calorific value. Biogas has a lower calorific value (LCV) around 19,500 $KJ.kg^{-1}$, being characterized as a good source of energy (LIMA, 2005). The biogas calorific value varies from 5,000 to 7,000 $kcal.m^{-3}$ which depends on the methane concentration (EMBRAPA, 2015).

Table 7 shows the main constituents of the biogas physical properties. Biogas presents one characteristic that makes it difficult to be stored, it has a high specific volume, what makes it difficult to compress (ZILOTTI, 2012).

Table 7 - Physical Properties of Methane, Carbon Dioxide and Sulfide Gas

Properties:	**Methane (CH_4)**	**Carbon Dioxide (CO_2)**	**Sulfide Gas (H_2S)**
Molecular Weight	16.04	44.01	34.08
Specific Weight	0.555[a]	1.52[a]	1.189[b]
Specific Volume	1473.3 cm^3/g[a]	543.1 cm^3/g[b]	699.2 cm^3/g[b]

*a) 60 ºC, 1 atm; b) 70 ºC, 1 atm; 77 ºC, 1atm

Source: PECORA (2006).

The conversion from biogas into electrical energy may occur in several ways. Energy conversion is understood as the process that transforms one type of energy into another one, during the energetic conversion of biogas, the chemical energy contained in the molecules are converted into mechanical energy by a process of controlled combustion, this energy activates an alternator that converts mechanical energy into electrical energy (COSTA, 2006).

The main adopted technologies are the gas microturbines and internal combustion engines (PRATI, 2010). The cost-benefit analysis for both technologies points the best one as the internal combustion engines, since biogas microturbines have very high costs and a short life time (SOUZA *et al.*, 2004).

3.5.1 Biogas Purification

The biogas cleaning, or purification, systems work by eliminating natural biogas properties in order to attend the technical specifications for energy conversion equipment (COSTA, 2006). The nonfuel biogas elements, such as water and carbon dioxide, harm the burning process which makes them less efficient, such substances take the place of the fuel in the combustion process and absorb part of the energy, which may cause uncompleted combustion, feeding failure, loss of power, and early corrosion caused by the presence of hydrogen sulfide (H_2S), that makes smaller the calorific power of the biogas (COSTA, 2006).

There are different alternatives for purification that may apply to the biogas, then the best suitable one to the intended application should be sought (COSTA, 2006). Table 8 lists some possible purification alternatives to the biogas:

Table 8 – Techniques of Impurity Removal from Biogas.

Impurities	General description	Details
Water	Adsorption	Silica Gel
		Molecular Sieve
		Aluminina
		Glycol Ethylene
	Absorption	(Temperature -6.7 ºC)
		Selexol
	Refrigeration	Cooling to 2 ºC
	Adsorption	Activated Carbon
		Light oil
Hydrocarbons	Absorption	Glycol Ethylene
		Selexol
		(Temperature between -6,7 ºC e -33,9 ºC
	Combination	Cooling with glycol ethylene and adsorption in activated carbon
CO_2 e H_2S	Absorption	Organic solvent
		Selexol
		Fluorine
		Rectisol
		Alkaline salts solution
		Alkanolamines
		Mono, di-tri-etanolamine
		Deglycolamine
		Ucarsol-CR
	Adsorption	Molecular Sieves
		Activated Carbon

Source: Adapted from Costa (2006).

3.5.2 Public Polices in Mini and Micro Generation Distributed

Since April 17, 2012, when ANEEL Normative Resolution 482/2012 came into effect, the consumers in Brazil can generate their own electricity from renewable sources and even offer the surplus to the local distribution network. These are the micro and the minigenaration distributed electrical energy, innovations that can associate the financial economy, social-environmental awareness and self-sustainability (ANEEL, 2015).

The National Program for Strengthening Family Agriculture (Pronaf, in Portuguese) Eco is a governmental program that aims to encourage and finance people who are family farmers to execute, to use and/or to recover renewable energy technologies, environmental technologies (water, detritus, effluents, composting and recycling treatment plant), among other activities concerned with environmental liability. The financing ranges from 150 to 300 thousand, with interest rates from 2.5 to 5.5% a year, with 2 to 8 years grace period (BNDES, 2015).

According to the last agricultural census from IBGE (2006) 4,367,902 family farm establishments were recognized, which represents 84.4 of the establishments in Brazil, taking up an area of 80.25 million hectares, that represents 24.3% of the areas taken by agricultural establishments. The average area of family establishments is 18.37 hectares, and the non-family establishments is 309.18 hectares (IBGE, 2006). The Brazilian Northeast comprises 2,187,295 family establishments, which represent 50% of all family establishments in Brazil, together those establishments sums up a total of 28,332,599 hectares (IBGE, 2006). The State of Ceará contains 341,510 family establishments, which represent 15% of the family establishments in the Brazilian Northeast, The State is the second one with the largest number of family establishments in the Northeast, being the first one the State of Bahia with 665,831 family establishments.

3.6 Energy Balance

The energy balance is based on the two Laws of Thermodynamics. The First Law of Thermodynamics (Law of Conservation of Energy) states that energy cannot be created or destroyed, but it can only be transformed from one form to another, and the second Law of Thermodynamics (Law of Entropy) which states that no process of energy transformation will occur spontaneously, unless there is a degradation of energy from a concentrated form to a dispersed form (NISHIMURA, 2009).

Every process of transformation of the form of energy causes losses in the system, part of the energy will always turn into unavailable thermal energy. The study of the energy used in agricultural systems, their flows, distribution and conversion are important tools to the evaluation of the sustainability of these systems (NISHIMURA, 2009).

The energy balance works toward establishing the energy flows, identifying the total demand and efficiency, which is a evidenced by the energy gain and the output/input ratio, plus the needed quantity to produce or process one kilogram of a given product, for this process all the inputs used and produced are quantified and transformed into energy units, the determination of energy balances and energy efficiency are important tools for the agricultural monitoring regarding the use of non-renewable energy sources (BUENO *et al.*, 2000).

The energy balance is a fair tool for analyzing the technical viabilities of a bio-energetic system, which allows to identify points of greater consumptions and thus implement corrections that increase the efficiency of the system and its profitability (NISHIMURA, 2009).

3.6.1 System, Property and State

A System is defined as any arbitrary mass of material or part of an assemblage to be studied, the system is unconnected from the vicinity by the control surface, also known as outline or boundaries, a closed system is the one with no matter crossing the boundaries while the process occurs, closed systems are found in batches, the open systems are those in which the matter continually crosses the system boundaries during the process (BADINO JUNIOR; CRUZ, 2010).

A Property is a specific magnitude of a system that can be measured, e.g., pressure, volume, or temperature. Intensive property are properties that do not vary with the system. Extensive properties are those in which the mass (size) depended of the system (BADINO JUNIOR; CRUZ, 2010).

A State is a system that is defined as an assemblage of properties during a certain period of time and is depended of the intensive properties of the system only, such as temperature, pressure and composition (BADINO JUNIOR; CRUZ, 2010).

3.6.2 Calorific value

According to González et al., (2010), the calorimetry studies the exchanges of energy in form of heat, between different systems, where its main objective is to measure the amount of energy involved in a given chemical reaction. In the thermodynamics heat can be defined as the form of transferred energy, a result of a difference of temperature (ATIKINS; JONES, 2001). According to the International System of Units (SI), calorific power is expressed in Joule per gram (Jg^{-1}).

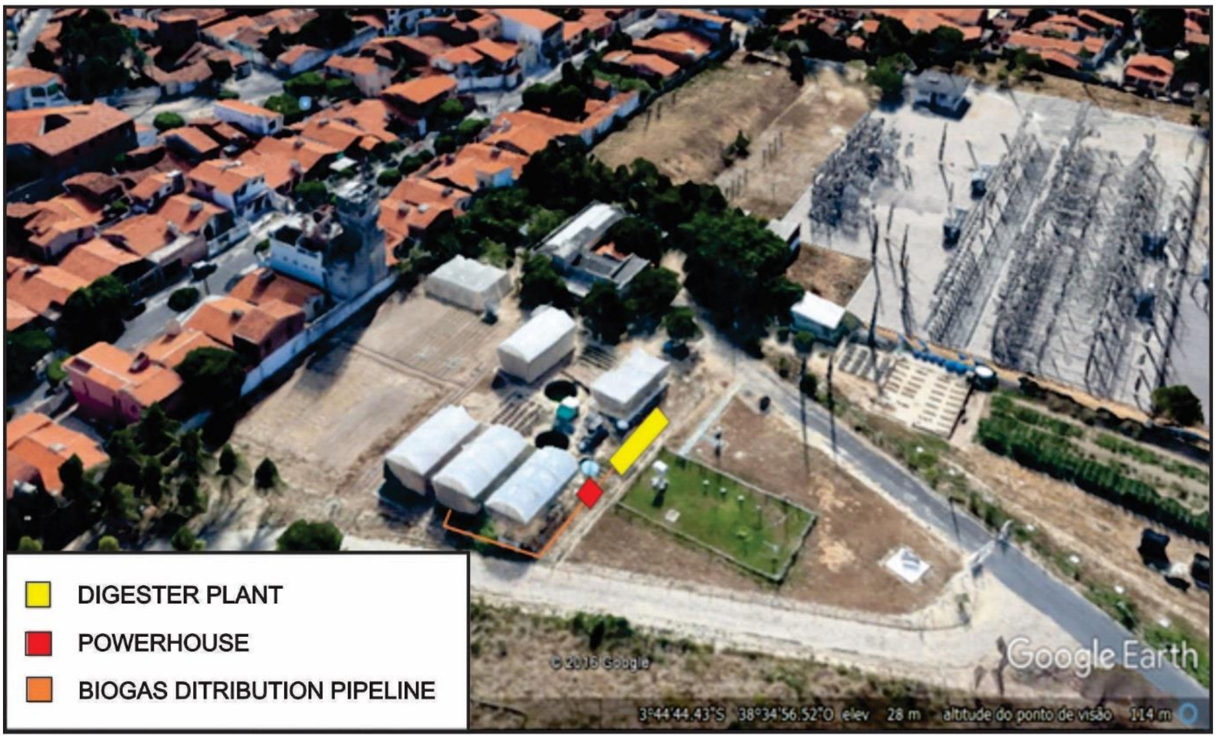
The calorific value can be classified into higher calorific value (HCV) and lower calorific value (LCV). The HCV takes as consideration the latent heat of condensation of water in which the water formed during combustion is condensed and the heat produced from this condensation is recovered (JESUS; RODRIGUES, 2011). The LCV can be given by deduction, from the HCV, the quantity of relative heat to the condensation of the water vapor. Among analyzing methods for the calorific value of gases we cite: experimental method, analytical method (empirical), correlative methods, stoichiometric methods and state reconstruction (ULBIG; HOBURG, 2002).

4 MATERIAL AND METHODS

4.1 Location

The experiment was conducted at the Weather Station experimental area (FIGURE 5) of the Department of Agricultural Engineering, Federal University of Ceará, located at the geodesic coordinates: latitude 3º44'43.82 "S and longitude 38º34'55.41" W Grm, with altitude of 23 meters and climate Aw, according to the Köppen climate classification (1918). During this study time period the highest temperature was 33 ºC and the lowest 22.8 ºC, in accordance with information from the Meteorological Observing Unit at Federal University of Ceará.

Figure 5 - Experiment Location.



Source: Google Maps® with adaptations made by the author (2017).

4.2 Material

4.2.1 Biodigester

We utilized a tubular digester, brand Recolast®, tubular model 3000 (FIGURE 6), of prefabricated system in PVC membrane of 1 mm, with dejects capacity of 5 (five) cows in stable, according to the equipment technical manual. With 1.4 m in diameter and 3 m in length, total area of 16.27 m^2 and 4.61 m^3 in volume. The equipment has two orifices in the extremities, one for the dejects inlet, and other for the digested manure and the bio-fertilizer outlet . Other two orifices are located vertically, the first one for the biogas outlet and the second for cleaning purposes.

Figure 6 - PVC Tubular Digester

Source: Prepared by the author (2017).

4.2.2 Gas Meter

The biogas generated volume was measured by a gas meter, diaphragm type, model Deaflez® G2.5 (FIGURE 7), which has an eight (8) digits counter with frontal pressure outlet. The maximum working pressure is 50 kPa, maximum flow of 4.5 m^3h^{-1} and a minimum flow of 0.0025 m^3h^{-1}.

Figure 7 - Gas meter

Source: Prepared by the author (2017).

4.2.3 Motor-generator

In order to convert the biogas generated into electric energy, we utilized a motor-generator, brand Toyama® (FIGURE 8), model TF1200 CX, gasoline engine originally, and adapted for running on biogas. The generator maximum power is 1200 W, and the nominal power is 1050 W. And a 4-stroke engine, single cylinder, and air cooling.

Figure 8 – Motor-generator

Source: Prepared by the author (2017).

4.2.4 Motor Pump

Part of the electric energy generated from the conversion of biogas was consumed by the motor pump, brand King, with 1/3 of HP (FIGURE 9). The volume of water, pumped by it, was measured through a hydrometer.

Figure 9 - Motor Pump

Source: Prepared by the author (2017).

4.2.5 LED Light Bulbs

The second part of the electric energy generated from the biogas conversion was consumed by LED (Light emitter diode) light bulbs. We utilized bulbs of 12, 16 and 24 W (FUGURE 10).

Figure 10 –LED light bulbs

Source: Prepared by the author (2017).

4.2.6 Stove

In order to convert the biogas into thermal energy we utilized a 2-flame stove (two Burners) (FIGURE 11).

Figure 11 – Two-flames stove

Source: Prepared by the author (2017).

4.2.7 Calorimetric Pump

In order to determine the higher calorific value of the fresh, digested bovine manure, and of the bio-fertilizer, we utilized a calorimetric pump, brand IKA, model C200 (FIGURE 12), at Table 9 are listed the technical data of the equipment.

Figure 12 – Calorimetric Pump

Source: Prepared by the author (2017).

Table 9 - Calorimetric Pump Technical Data

THECNICAL DATA	
Input Maximum Power	120W
Nominal Tension	24 V DC, 5A
Fuse	1 x 2.5 AT
In Continuous Operation in Time	Continuous Operation
Measurement Range	40,000 J
Oxygen Work Pressure	30 bar
Reproducibility of 0,1% RSD According to the Normative NBS 39i based on the analysis of 1g of benzoic acid	0.1% RSD

Source: Equipment Manual.

4.2.8 Humidity Determination Scale

We utilized a humidity scale, brand Marte, model ID-200 (FIGURE 13). The humidity meter has infrared source of heating, generated by resistance enclosed in quartz quartz infrared heating and dot matrix LCD display. Table 10 lists the equipment technical data.

Figure 13 - Humidity Scale

Souce: Prepared by the author (2017).

Table 10 – Humidity Scale Technical Data

THECNICAL DATA	
Maximum Load	210 g
Sensibility	0.01 g
Reproducibility	0.01 g
Range of Tare	210 g
Temperature Increment	1º C
Temperature Range	60 a 180º C
Humidity Range	0 a 100%
Stabilization Time	3 s
Resistor Power	250W
Plate Diameter	90 mm
Scale Dimensions (C x L x A)	292 x 210 x 190 mm
Weight	6.4 kg
Voltage	220 V
Consume	7 W

Source: Equipment Manual.

4.2.9 Biogas Purification Filters

For the generated biogas purification, we utilized a system with experimental filters, designed by the author (2017). The filters were built we PVC tubes and connectors, tubes with 100 mm diameter and 50 cm in length, and connectors of 50 mm. The first filter contains 3.5 kg of silica gel, and the second one, 1.9 kg of activated carbon.

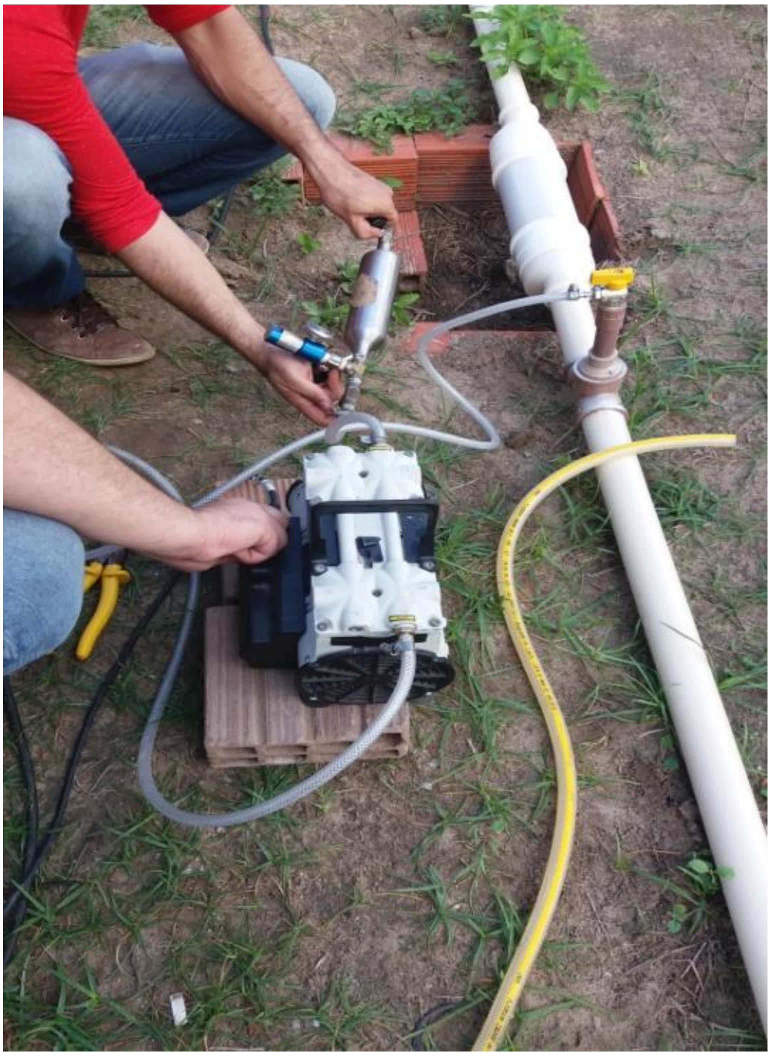
Figure 14 – Silica Gel and Activated Carbon Filters

Source: Prepared by the author (2017).

4.2.10 Vacuum Pump and Cylinder

We collected the biogas for chromatographic analysis through a vacuum pump and a stainless cylinder (FIGURE 15). At Table 11 are listed the equipment technical data.

Figure 15 - Biogas Capture for Chromatographic Analysis



Source: Prepared by the author (2017).

Table 11 – Technical Data of the Vacuum Pump

TECHNICAL DATA	
Flow	120 L/min
Power	250 W/h
Tension	110/220 v
Vacuum Maximo	120 - 450
Current	1.3 A - 1.15 A
Crankcase Capacity	250 ml

Source: Equipment Technical Manual.

4.2.11 Chromatograph

For the biogas chromatographic analyses, for methane (CH_4) concentration measurement, we utilized a gas chromatograph TCD Micro GC 480 Agilent Technologies (FIGURE 16). We utilized carrier gases Argon (Ar) and Helium (He). At Table 12 are listed the chromatograph technical data.

Figure 16 – Gas Chromatograph

Source: Prepared by the author (2017).

Table 12 – Chromatograph Technical Data

THECNICAL DATA	
Input tension	85 - 264 Vac
Input Frequency	47 – 63 Hz
Output Tension	12 Vcc
Output Power	180 W
Operating Temperature	-30º a 70º C
Safety Regulations	UL60950-1, TUV EN60950-1, BSMI CNS14336, CSA, C22.2, CCCGB4943, PSE J60950-1
Normative RFI / EMC	According to the Normative CISPR22 (EN55022) Class B, FCC Part 15/CISPR 22 class B, CNS13438 class B, GB9254, EN61000-3-2, EN61000-3-3, EN61000-4-2, EN61000-4-3, EN61000-4-4, EN61000-4-5, EN61000-4-6, EN61000-4-8, EN61000-4-11

Source: Equipment Technical Manual.

4.3 Methods

4.3.1 Biogas Generation

The biogas in study was generated from bovine manure. Considering that an animal with an average weight of 300 kg produces an average 10-15 kg (BAUNGRATZ *et al.*, 2013) of manure a day, we utilized 75 kg of fresh manure, regarding technical specifications of the digester manufacturer about its capacity, for a volume from the excreta of 5 (five) cows in stable. This was we could evaluate the process of daily biogas generation, in a digester in production.

According to Quadros (2009), the ideal concentration of water for each kilogram of bovine manure is 1:1, i.e., for each kilogram of manure we added 1 (um) liter of water. The bovine manure was mixed with water for the mixture to become as homogeneous as possible (FIGURE 17), in order to improve the fermentation process, before being deposited in the digester, where it spent 20 days of hydraulic retention.

The manure, that we utilized, was submitted to evaluations such as pH, density and dry mass measurements. The biogas production process was performed in 4 (four) replications.

Figure 17 - Mixture of Manure and Water

Source: Prepared by the author (2017).

4.3.2 Biogas Consumption

The biogas generated was converted into electric energy and thermal energy. In order to convert it into electric energy we utilized a motor-generator and for thermal energy we utilized a 2-flame stove (two burners).

The electric energy was consumed by an irrigation motor pump and LED light bulbs of 12, 16 and 24 W. The motor pump ran in closed circuit (FIGURE 18) pumping the water stored in a 5,000 L tank, we evaluated the biogas consumption needed for pumping 1 m^3 of water, we measured the water volume through a hydrometer and the biogas volume by a gas meter.

Figure 18 - Motor Pump

Source: Prepared by the author (2017).

We evaluated the hourly biogas consumption for lighting one LED bulb of 24 W, for a set of two LEB bulbs, being one of 12 W and other of 16 W, and for a set of three bulbs, being one of 12 W, one of 16 W and other of 24 W.

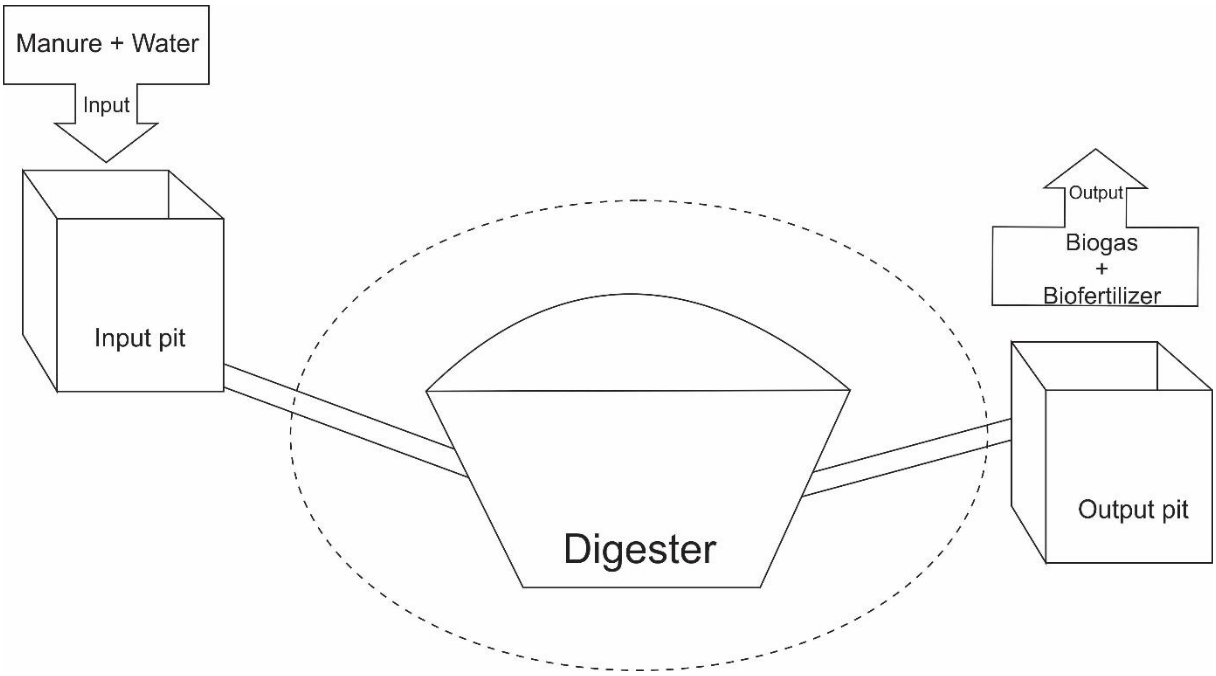
We measured the biogas consumption, to generate electric energy, through a gas meter. We evaluated the biogas hourly consumption for operating a stove with two flames lit.

We performed the evaluations of the biogas consumption in 5 (five) replications and we presented the mean of consumption, standard deviation, the maximum and minimum. The statistical data were performed the software Excel.

4.3.3 Control Volume of the Thermodynamic System

Based on the Thermodynamic Laws, the thermodynamic system in study is classified as open, which the mass can cross the system boundary, this way considering the quantity of energy input and output in the volume of the control for purpose of the energy balance calculus (BORGNAKKE *et al*., 2009). Figure 19 represents volume of the control and the boundaries of the studied thermodynamic system.

Figure 19. Control Volume and The Boundaries of the Studied Thermodynamic



Source: Prepared by the author (2017).

4.3.4 Calculus of Energy Balance of the Thermodynamic System

According to Viana et al. (2012), regardless the systems considered and the forms of energy involved, all processes of energy conversion are led by two fundamental physical laws. The first basic law is the Law of Conservation of Energy, i.e., the 1st Law of Thermodynamics, according to which nothing is created, nor is it destroyed. Therefore, we can state that, in a given period of time, the sum of the energy flows and energy storages, in a process or system, is constant. In this way, the 1st Law of Thermodynamics allows to effectuate the energy balance of a system through the following Equation 1 (VIANA *et al*., 2012). The sum of energy input and output of the system were obtained through the calorific value of the products involved.

$$\Delta E = \Delta E_I - \Delta E_O \qquad (1)$$

Where:

$\Delta E = Energy\ Balance$

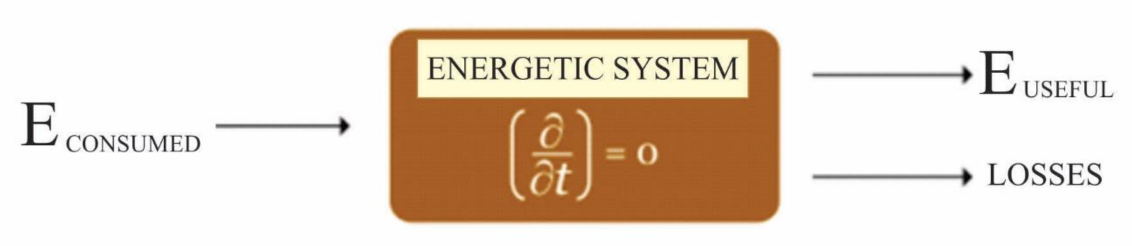
$\Delta \boldsymbol{E_I} = = Sum\ of\ Energy\ input\ of\ the\ system$

$\Delta \boldsymbol{E_O} = = Sum\ of\ Energy\ output\ of\ the\ system$

4.3.5 Calculus of Efficiency of The Thermodynamic System Energy Conversion

According to Viana *et al.* (2012), the concept of performance or energy efficiency of an energy system is also based on the 1st Law of Thermodynamics, if relating the usable energetic effect with the energy consumption of the system, represented inFigure14. This concept is valid for a permanent system, i.e., when there is no variation of energy in the system. For energy is not destroyed, but it only changes form, converting into another type of energy.

Figure 20 – Generalized Energetic System



Source: VIANA et al., (2012)

Other basic law of the energy processes is the Law of Energy Dissipation, according to which, in all real processes of energy conversion, there are unavoidable thermal losses, as affirmed in Kelvin-Planck's statement, related to the 2nd Law of Thermodynamics. These losses also summed up to other unavoidable losses due to the technological and economic limitations of real systems such as imperfect thermal insulation, friction, charge losses and inertia (VIANA *et al.*, 2012). In this context, it is possible to calculate the system efficiency or energy efficiency of the system by the Equation 2, showed below (VIANA *et al.*, 2012).

$$Energy\ Efficiency\ (\%) = \frac{Usable\ Energy}{Energy\ Input} \times 100 \qquad (2)$$

4.3.6 Calculus of Higher Calorific Value

4.3.6.1 Manure Higher Calorific Value

The higher calorific value of fresh bovine manure was determined by means of a calorimetric pump at the Laboratory of Reference in Biofuels - LARBIO (in Portuguese) of

Nucleus of Industrial Technology of Ceará - NUTEC (in Portuguese), according to normative D5865-13 (ASTM, 2016). We performed the analysis in a duplicate.

Before analyzing in calorimetric pump, we weighed the sample with a humidity scale.

4.3.6.2 Bio-fertilizer Higher Calorific Value

The digested bovine manure and bio-fertilizer (liquid) higher calorific value were determined by a calorimetric pump at the Laboratory of Reference in Biofuels - LARBIO (in Portuguese) of the Foundation Nucleus of Industrial Technology of Ceará - NUTEC (in Portuguese). The analyses were performed induplicate, with experimental procedure according to the normative ASTM D5865-13.

4.3.6.3 Biogas Higher Calorific Value

According to Hosseini et al. (2016), the average biogas calorific value is 21.5 MJm^{-3}. However, Li *et al* (2016) state that the biogas calorific value varies from 20 to 36.2 MJm^{-3}, the biogas calorific value varies with the methane (CH_4) concentration present in the biofuel, the higher the methane (CH_4) concentration, higher will be the biogas calorific value. Therefore, for this study, we will take the value of 21.5 MJm^{-3} as reference for obtaining the energy balance and energy efficiency of the studied system.

4.3.7 Biogas Evaluation Through Chromatography

For the methane concentration analysis in biogas, we utilized a gas-solid gas chromatography (GSC), the analyzes were carried out in the Laboratory of Research on CO_2 Adsorption and Capture (LPACO_2, in Portuguese) of the Federal University of Ceará. The biogas capture was carried out at the pipeline, for the biogas distribution, with a vacuum pump, then stored in a stainless cylinder. We collected four samples of crude biogas and four samples of purified biogas. The purification of the biogas was performed by dry adsorption with silica gel and activated carbon filters (FIGURE 18), aiming to remove humidity and hydrogen sulfide gas (H_2S).

4.3.8 Bio-fertilizer Chemical Evaluation

The liquid bio-fertilizers were analyzed in the laboratory of soil UFC/FUNCEME - Meteorological and Water Resources Foundation of Ceará. For this analysis we measured the concentrations of macronutrients (N, P, K, Ca, Mg, S, Na, Fe, Cu, Zn, Mn), pH value and electrical conductivity of the materials assessed. For the analysis, we collected 1 liter of liquid bio-fertilizer after a time period of 25 days of hydraulic retention.

5 RESULTS AND DISCUSSION

The process of energy conversion from the bovine manure into biogas begins with the preparation of a mixture of bovine manure and water to be put into the digester, in this study we evaluated the energy balance of a tubular PVC biodigester during operation, classified as continuous feeding, i.e., the digester receives the organic matter periodically. We deposited a mixture of 75 kg of fresh bovine manure and 75 L of water into the digester. We evaluated pH, density, dry matter, calorific value and humidity of the fresh bovine manure used in the study. The results of these analyzes are listed in Table 13.

Table 13 – Analysis Performed on the Fresh Bovine Manure

	pH	**Density (g/ml)**	**Dry Matter (%)**	**Humidity (%)**	**Calorific Value (MJ/kg)**
Bovine Manure	5.4	0.93	26	74	17.84 (0.24) 17.56 - 18.11

Source: Prepared by the author (2017).

According to McMahon *et al*. (2004), the initial phase of anaerobic digestion is critical for the proper functioning of an anaerobic digester, as well as the influence of microbial communities involved at the degradation of organic residues. During the initial phase of biogas production many drastic changes that may inhibit methanogenesis occur at the biomass environment. The diverse methanogenic communities guarantee a stable methane production, for that, inoculate can be used in order to improve the quality of microbial community, however the use of fresh bovine manure is a very common alternative, since bovines possess abundant and diverse microbial community inside the Rumen, and consequently in the manure (SKILLMAN *et al*., 2006).

According to Zhain *et al*. (2015), the optimum initial pH value of manure for the biogas production is 7.5. For this study, the manure pH was below the optimum value, however within the an acceptable range, pH values below 4 and above 9 can be used for the process of biogas production. Ohimain end Izah (2017) state that neutral pH favors the methanogenesis rate during biogas production, for most anaerobic bacteria, mainly the methanogenic one, increase the rates of biogas production with the pH of 6.5, pH values below 6.5 and above 7.6 may effect the biogas production and methane concentration. However, some studies have shown that even when increasing the pH values the production of methane (CH_4) had changes, which implies that pH is not the only factor that influences the methane production.

In order to the methane production be successful, the biomass used must contain at least 7% to 9% of dry matter (JOSÉ FILHO, 1981). The concentration of the biomass dry matter used for this study higher than the minimum required for a good biogas production, according to the literature cited.

The higher calorific value found in this study corroborates with values found by Thygesen and Johnsen (2012), in their studies the authors obtained higher calorific value of the bovine manure of 17.8 MJ/kg. With the calorific value of bovine manure determined, it is possible to calculate the quantity of initial energy, i.e., the energy that entered in the studied thermodynamic systems. At Table 14 the calculated results of the initial energy of the process of energy conversion from bovine manure to biogas are presented.

Table 14 – Initial Energy of the Thermodynamic System

	Calorific Value ($MJkg^{-1}$)	**Quantity of Biomass (kg)**	**Initial Energy of the Thermodynamic System (MJ)**
Bovine Manure	17.8	75	1.335

Source: Prepared by the author (2017).

The biomass remained inside the digester for 20 days. The period of time that the biomass remains in the digester is called hydraulic retention, this period of time varies, since it mainly depends on the type of biomass, pH, biomass granulometry and the internal temperature of the digester. According to José Filho (1981), the period of hydraulic retention for domestic animal manure varies from 20 to 30 days. The lower the temperature of the digester operation, the longer is the hydraulic retention time. There are three different ways of operation: temperatures below 20°C with retention of 70-80 days (psychrophilic conditions), between 30 and 42° C for 30-40 days (mesophilic conditions) or 42 and 46 °C for 15-20 days (thermophilic conditions) (LEON; MARTÍN, 2016). After 24h of hydraulic retention the tubular digester already had a substantial volume of biogas inflating the PVC balloon, which shows daily availability of biogas.

After 20 days, the period of time for the hydraulic retention, the tubular digester accumulated some volume of biogas, still unknown, which was evaluated by chromatography in order to determine the concentration of methane (CH_4). We conducted 4 samplings, the chromatographic analyzes were performed on samples of crude biogas and purified biogas. The analyzes results are listed on Table 15.

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Table 15 – Concentration of Methane (CH_4) – Determination by Gas Chromatography

	Crude Biogas (%)	**Purified Biogas (%)**
Methane Concentration of the Biogas Generated	52.24 (2.58)	57.78 (1.87)
	44.89 - 50.50	55.68 – 60.12

Source: Prepared by the author (2017)

According to Matuszewska *et al.* (2016), the biogas is a mixture consisted essentially by 40-75% of methane (CH_4) and 15-60% of carbon dioxide (CO_2). Phetyim *et al*. (2015), on their studies, obtained the biogas from bovine manure with an average concentration of 44.6% of Methane (CH_4), these results corroborate with the found methane concentration. The methane concentration in the biogas is an important parameter, especially when this biofuel is used in internal combustion engines, as it is the case of the motor-generator used in this study.

The biogas purification was carried out by the process of dry adsorption. Two filters were designed then built with PVC pipes and connectors. The tubes are 100 mm in diameter and 50 cm of length, the first filter contains 3.5 kg of silica gel and the second filter contains 1.9 kg of activated carbon.

The purification occurred in two stages, in the first one the biogas passed through a pipe of larger diameter in order to reduce moisture present in the biogas, and retain in that container the volume of condensed water (FIGURE 21), then it passed through the first filter (FIGURE 21), containing silica gel, aiming to reduce moisture to the maximum, after this first purification the biogas passed through a second filter, containing activated carbon (FIGURE 21), during this stage of purification, the hydrogen sulfide gas (H_2S) and the carbon dioxide (CO_2) are removed. Biogas samples were collected prior the purification at the point A (FIGURE 21) and after purification at the point B (FIGURE 21).

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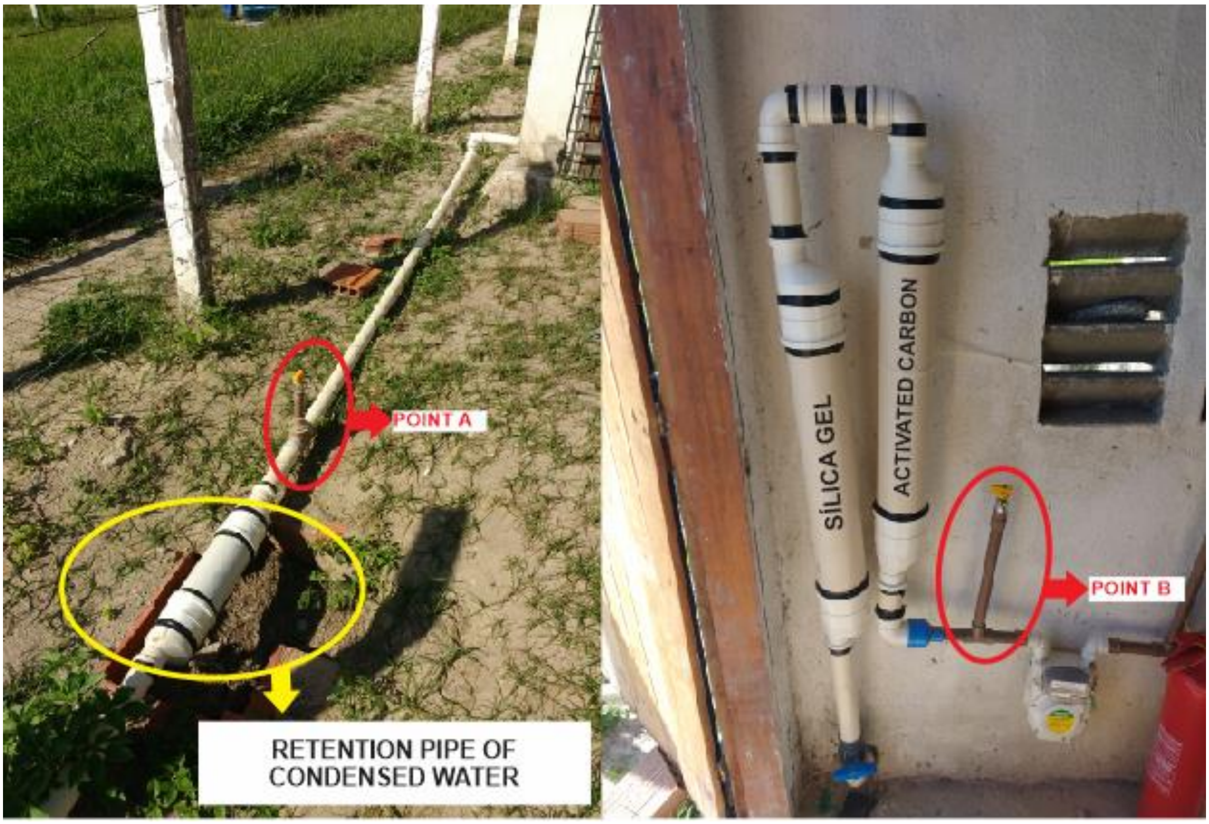
Figure 21 - Biogas Purification



Source: Prepared by the author (2017).

The sulfide gas (H_2S) present in the biogas is a corrosive element that can harm the equipment used to transform biogas into electric energy, for that reason, it is important to perform this purification in order to guarantee a longer lifetime of the components and less equipment stops for maintenance, in addition, hydrogen sulphide may generate SO_2 formation, which in combustions causes acid rains (Maat *et al.*, 2005). The water present in biogas can also oxidant equipment, however in addition to these aggravating facts cited, these impurities reduce the calorific value of the biogas, thus affects its combustion and its electric energy generation. The purification method used has already been evaluated by Okamura (2013), which was satisfactory to the moisture and sulfuric gas removal, it resulted in a more purified biogas with a higher calorific value. The result obtained from the chromatographic analyzes showed that, after purification, the biogas had an increase of approximately 10% of the methane concentration. Magalhães *et al.* (2004) points the importance of biogas purification for the carbon dioxide (CO_2) removal, since it is largely present and it is considered as an inert gas, this element can be removed by biogas washing, i.e., moving the biogas through a column of water.

The biogas, generated from bovine manure, was measured by means of a gas meter and it was consumed by a 1200 W motor-generator and a two-flame stove, so this way it was possible to know the volume of the biogas generated, i.e., part of the final energy from this thermodynamic system. In order to use a motor-generator to generate electric energy, firstly it is required to conduct the quantification of energy demand. For that, we need to sum up the power of all equipment will be used and choose a motor-generator with a nominal power higher than the equipment demand, keeping a safety margin of at least 15%, so that the motor-generator can fulfill the demand of energy, what will guarantee the required supply of electric energy. However, we should note that when the motor-generator used is adapted for biogas, it loses power (SOUZA, 2006).

The internal combustion engines are primary machines most used for electric power generation, which make use of the biogas as primary fuel, they are engines of otto or diesel cycle connected with electric generators (SOUZA, 2016). Otto cycle engines are easier to be adapted for the biogas, the main modification is the adjustment in the carburetor to burn a poorer mixture of air and fuel, for diesel engines, because of its compression ignition, it is necessary to be modified as an otto cycle engine, this type of conversion is complex, since it requires an injection pump removal, introduction of a carburetor and a spark ignition system and a reduction of the compression ratio (SOUZA, 2016).

The motor-generator used, originally runs with gasoline, i.e., the otto cycle. This was adjusted in order to runs with the biogas, for that, some adaptations were made such as the addition of a mixture of air and fuel (FIGURA 22.5), with a Venturi connected to the carburetor inlet.

Figure 22 – Adaptation of a Motor-generator

Source: Prepared by the author (2017).

In order to make the adjustments we removed the air filter (FIGURE 22.1), we forged a piece (FIGURE 22.2) that was screwed to the carburetor inlet, to the piece we attached the air and fuel mixer (FIGURE 22.5) that has valves which control the air and biogas admission. This adapter (air and fuel mixer) was designed by Praciano (2014) with the purpose to adapt a gasoline moto-generator, so it could runs with biogas at low cost. According to Praciano (2014), the adapter costs approximately R$ 250,00, the material is easily accessed and simple to be assembled. The authors Praciano and Albiero (2015), have composed a guidebook that demonstrate step-by-step the construction and assembly of this adapter. The Brazilian Congress of Agricultural Engineering in 2015, 64th edition, has awarded the authors Praciano *et al.* (2015), for the work that focuses on the designing of the adapter mentioned, the evaluation committee justified the award for being about a simple, accessible technology that provides a return from the academy to society.

This motor-generator has a nominal power of 1,050 W, according to the technical manual. However, when using for a motor-pump of 0.5 CV of power, i.e. 367.75 W, the motor-generator was able to attend the energy demand when running with biogas, but when running gasoline it generated enough energy for running the pump satisfactorily, which suggests that, when running biogas, the motor-generator had considerably loss of power, some around 40%. Considering this limitation, we replaced the motor-pump for a smaller one, of 1/3 HP, i.e., 245.17 W, which has run satisfactorily. Souza (2006) studied the performance of biogas running generators compared with gasoline running motor-generators and has obtained results of 10% power loss, but the biogas used in the study had methane concentration of 95%.

For the evaluation of biogas consumption to generate electric energy, at first we measured the biogas consumption necessary to generate electric energy that would meet the energy demand of a 1/3 HP motor-pump, running in closed circuit, during the time needed to pump 1 m³of water. Table 16 lists the obtained results.

Table 16 - Biogas Consumption of the Motor-pump

	Biogas Consumption for Pumping 1 m³ of Water (m³)
Motor-pump 1/3 CV	0.134 (3.19) 0.130 - 0.138

Source: Prepared by the author (2017)

The motor-pump is an equipment broadly used in agriculture, especially in the semi-arid of the Northeast of Brazil, where the rains are irregular and scarce. The motor-pump is commonly used for irrigation, but may also be used in the supply of water for animal and human consumption, i.e., to attend the daily needs of a residence by pumping water from the reservoirs or aquifers. The irrigation allows family farms to produce when it is not the rainy season, which guarantees income during all the year, although for this, water resources are required. Due to the scarce and irregular precipitation of the semi-arid in the Brazilian Northeast, water is a resource that must be intensively managed aiming the sustainable management of the water, in order to avoid wasting. The correct sizing for irrigation systems, the use of drip irrigation systems that assures supplies of water to the plants and reduce losses caused by drifting and evapotranspiration. The use of salvation irrigation techniques, defined as the water being applied to crops during Indian summers (veranico, in Portuguese), interval of 20 to 30 days with no rains during rainy season, that damaging crops (SILVA, 2007). Techniques of living in the semi-arid region such as the program created by the Brazilian Semiarid Articulation (ASA, in Portuguese) in 2007, called One Land and Two Waters - P1 + 2, which aims to expand the water supplies of families from rural communities in order to fulfill the needs of the crops and animal husbandry, assuring the food and nutritional security of these family farms, beyond creating income.

Illumination is an indispensable resource for zootechnical, agricultural and residential facilities, it represents about 18% of all electric energy consumption (BRASIL, 2014). In face of this scenario, we evaluated the hourly consumption of biogas for LED light bulbs of 24, 16 and 12 W. The results obtained are listed at Table 17.

Table 17 - Biogas Consumption of LED Light Bulbs

	Biogas Consumption (m^3/h)
Light Bulb of 24 W	0.072 (0.01) 0.071 – 0.073
Light Bulbs of 12 + 16 W	0.089 (0.022) 0.087 – 0.093
Light Bulbs of 12 + 16 + 24 W	0.112 (0.001) 0.111 – 0.115

Source: Prepared by the author (2017).

Many jobs in farms begin early in the morning before sunrise, so artificial illumination is widely used during numerous activities, including mainly the illumination of rural residences and animal sheds. Among the livestock, birds stand out as the predominant consumers of electric energy for illumination, since artificial illumination systems have the intent to improve weight gain, age control for sexual maturity and increase egg production for laying hens and matrices (ARAUJO *et al*., 2011). Thus the cost of such resource is high-priced on the production process, in that way the use of biogas may represent a compelling saving, that increases profits and improves the income in the sector.

The use of biogas for thermal energy conversion is a very applicable resource in rural areas, since it takes the place of cooking gas or firewood for cookery and thermal heating of livestock, such as first day pigs and birds. Therefore, we evaluated the hourly consumption of biogas for a two-flame stove, the results are presented at Table 18.

Table 18 - Biogas Consumption of a Two-flame (/hora).

	Biogas Consumption (m^3)
Two-flame Stove	0.135 (2.302) 0.133 - 0.139

Source: Prepared by the author (2017).

The semi-arid region in Brazil holds the largest number of family farms establishments in the country (GNADLINGER, 2007). This agricultural sector shows several resources. technology and development limitations. The use of firewood for cookery is still very common and its harvesting in the caatinga is performed by the women. Besides being a hard job, this activity, leads to disorderly deforestation in the biome caatinga, which causes ecological imbalances, such as desertification. By replacing the firewood for biogas to cookery, the farms avoid health problems, since the exposure to the smoke of wood or charcoal can cause respiratory problems (DIACONIA, 2016).

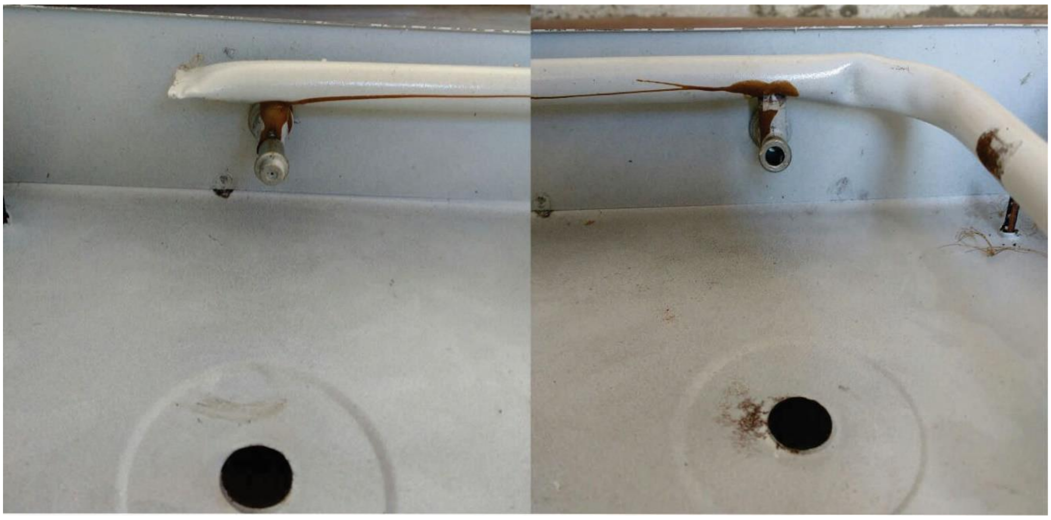
The cooking gas (LPG) is expensive for those families, since it has the costs of transportation beside the gas cylinder, plus the stores are located far from the rural properties. Interviewed by Rede Globo's Nordeste Rural television program, women who work in these farms report the importance of using the biogas and how this changed the reality of their families, because in addition of saving the price for gas cylinders, the gas is now more available to these women, which allows them to implement their tasks with activities previously not accessible, such as preparing deserts, cakes and tapiocas (GLOBO, 2016). These goods add value to the agricultural products manufactured by the family, which generates income and development for these communities.

The biogas flame burns with a characteristic blue color (FIGURE 23). In order to use biogas as cooking gas, some changes must be done because the commercially available stoves are designed for LPG cylinders which the gas is compressed at a pressure that varies from 2.9 to 9.67 atm (LIQUIGAS, 2016), the biogas does not have this same pressure condition, because it is distributed at atmospheric pressure, a simple modification is needed by enlarging the orifice diameter from the gas distribution pipe to the stove burners, or as popularly known, "bocas do fogão" (lit. stove mouths, in Portuguese),Figure23 shows the adaptation made.

Figure 23. Biogas Blue Flame

Source: Prepared by the author (2017)

Figure 24. Stove Adaptations



Source: Prepared by the author (2017)

After we evaluated the biogas consumption to generate electric and thermal energy, we could measure the volume of biogas generated from 75 kg of bovine manure during 20 days of hydraulic retention, the results are presented at Table 19.

Table 19. Biogas Volume

	Volume (m^3)	**Biogas/Manure Relation (m^3/kg)**
Biogas	2.836	0.038

Source: Prepared by the author (2017)

According to Baungratz et al. (2013), the relation between the biogas volume and the bovine manure mass is 0,049 m^3 /kg. This way, the volume of biogas generated from 75kg of bovine manure is close to the average value mentioned in the literature.

The biogas is an alternative source of energy that promotes several benefits, such as economic, environmental and social gains. The use of biogas can be applied in rural establishments, i.e., large or small properties. According to Brazil (2014) the electric energy consumed in agriculture is basically utilized in two systems: the irrigation systems (in agriculture) and the refrigeration systems (in livestock), in livestock it is increasing the number of refrigeration units for milk production and freezer storage units for cattle slaughter as the main demands. Barbosa Filho (2013) states that the adaptation of animals to hot climates is a critical factor for production, especially when the animal breed is original from a temperate climate, such thing may prevent the animals to express all the genetic and productive potential, a strategy to overcome this problem is to provide thermal comfort, by the use of fans and nebulizers in cattle and poultry farming. For swine farming, at birth they require thermal heating, because in the first 21 to 28 days the swine have only 1% body fat, which hinders the thermal insulation in these animals, so they become very vulnerable to weather changes, so it is necessary providing heat by incubators that work with gas or electric energy (SARUBBI *et al.*, 2010). According to Abreu (2003), in the first days of the life of birds, they still do not have a totally developed thermoregulatory system, for this reason, during the cold weathers it is important to supply young birds with thermal comfort, so they maintain ideal body temperature. The heating can be provided in many ways, being the gas heating the most used. Other than irrigation, illumination, thermal comfort for animal ambience and for cooking gas replacement, the biogas can also be used for other agricultural activities, as well for the use of stationary machines such as milking machines and foragers.

In order to generate a daily volume of 2.836 m^3 of biogas, it is required 75 kg of manure, this amount of manure is equivalent to the daily production of 5 dairy cows, this way it is possible to obtain approximately 85.08 m^3 of biogas monthly. By the energetic equivalence rule, the monthly volume of biogas generated has 34.03 kg of LPG, i.e., more than 2 cooking gas cylinders, if we take as reference the 13 kg cylinders, or approximately 52 L of gasoline, or 106 kWh of electric energy, or about 213 kg of firewood (FLORES, 2014). On that account, it is possible to state that with a herd of just 5 animals it is possible to obtain the profit of at least R$ 200.00 a month or R$ 2,400.00 a year, if regard only the use of the biogas and not considering the use of the bio-fertilizer. This income can make significant changes on the lives of countrymen in the Northeast of Brazil.

The Federal Government holds a funding line for family farming that aims to back implementation of renewable energy technologies, irrigation programs and water storage, forestation and reforestation, soil protection and recovery. This funding line is entitled Pronaf Eco, and it is possible to finance up to R$ 165 thousand, with interest rates of 2.5% per year for projects on ecology, this financing can be paid in up to 12 years, with a grace period from 2 to 8 years (BNDES, 2015). Diaconia is a non-profitable, Christian-inspired organization of social services that has a project entitled "Digesters: A National Program of Social Technology Rural Habilitation, carried out with support of the Social-Environmental Fund CAIXA. This project has already enabled the construction and capacitation of 335 digesters in the states of Pernambuco, Bahia, Minas Gerais, Goiás, Santa Catarina and Rio Grande do Sul (DIACONIA, 2016).

The biogas generated showed average methane concentration of 57.78%. According to Iannicelli (2008), for methane concentration of 60% and carbon dioxide concentration of 40% the biogas density is 1.46 kgm^{-3}, taking this value as reference, we have the generated biogas density is of approximately 1.40 kgm^{-3}. Considering the methane higher caloric value of 55 MJ kg^{-1} (OKAMURA, 2013), it is possible to affirm that the biogas with 57.78% of methane has a calorific value of approximately 31 MJ kg^{-1}. Li *et al.* (2016) state that the biogas higher calorific value varies from 20 to 36.2 MJm^{-3}. According to Hosseini et al. (2016), the average value of the biogas calorific value of bovine manure is 21.5 MJm^{-3}. Considering reference values cited in the literature, we chose to take the value of 21.5 MJm^{-3} in order to calculate the energy of the biogas volume generated. The results are shown at Table 20.

Table 20 - Biogas Calorific Value

	Volume (m3)	Higher Calorific Value (MJm-3)	Total Energy of the Biogas Volume (MJ)
Biogas	2.836	21.5	60.97

Source: Prepared by the author (2017)

Bio-fertilizer is a biogas generated by-product, after being digested and generate biogas, the manure can still be used in agriculture for its biomass is rich in macro and micronutrients. Biogas is generated from a mixture of water and manure, after the biogas generation process, we have a mixture of digested water and manure, new loads of biomass into the digester make the bio-fertilizer (liquid effluent) to be pulled out by the negative pressure. Besides the liquid bio-fertilizer, the digested manure (solid effluent), or tanned manure, is also expelled from the digester, with texture of paste. All material expelled from the digester is usable in agriculture, because both bio-fertilizer and digested manure can be utilized for soil nutrition, which replaces the use of commercialized mineral fertilizers.

Besides being a source of renewable energy, the biogas generation from manure, promotes rural sanitation, for in order to load the digester, zootechnical facilities have to be cleaned periodically, which eliminate odors, and verminosis and fly infestations that cause disease to the animals. The use of digesters is an alternative to the treatment of livestock waste, which reduces greenhouse gases emission and soil and water contamination.

According to Dairy Partners Americas (DPA) (2014), livestock manure are thought to be the biggest polluters of water resources and therefore it is very important to conduct correct management, otherwise it may contaminate soil, rivers and groundwater. According to Imaflora (2015), the agriculture accounts for 30% of greenhouse gas emissions in Brazil, these have grown about 160% since 1970, reaching 418 Mt CO_2 in 2013. The emissions by enteric fermentation of the agricultural sector are responsible for most of GHG emissions, where cattle farming is the main responsible for these emissions, which represents about 60% of those (IMAFLORA, 2015).

Brazil has the largest commercial cattle herd in the world with approximately 172 million head, taking approximately 20% of the world meat market, besides that Brazil ranks as the sixth largest milk producer in the world, the third largest poultry producer and the fourth largest in swine production (Oliveira *et al.*, 2011). On that account, in Brazil, the proper management for livestock waste of fundamental, for the high volume of greenhouse gas emissions. This volume of manure also stands for the meaningfulness of such renewable energy source.

According to Estadão (2009), Sadia S.A. have announced their acquisition of the United Nations registration for a program that aims at capturing greenhouse gases. The company is pioneer for obtaining such concession in the agricultural sector. The certification allows Sadia S.A to store, to register and to commercialize carbon credits generated by the Sadia Sustainable Swine Program (Programa $_3$S, in Portuguese), employed for 38% of the company's pig farmers, the emission reduction occurs by the installation of digester plants in the farms, it is expected to generate 600 thousand tons of CO_2, equivalent to 600,000 carbon credit units issued by the Executive Board of the Clean Development Mechanism (CDM) of the Kyoto Protocol. The company has already placed digesters in 1086 properties, the company still plans on integrating other 2.5 thousand properties (ESTADÃO, 2009).

According to DAP (2014), the bovine liquid wastes applications during two years have improved the structural quality of the soil by altering physical attributes such as soil density, macrospores and humid weighted average diameter of aggregates, also, it was noticed the improvement of hydrological attributes, increase of soil hydraulic conductivity and water infiltration rates, improving water infiltration in soil and reducing the surface runoff and the transport of nutrients to waterbodies in the long term.

According to Silva *et al.* (2007), due to bacteria, yeasts and bacilli during the fermentation, the bio-fertilizer can present effects such as phytohormonal, fungicidal, bacteriological, nematicide, acaricide and insect repellent effects, acting as a natural protector on cultivated plants against diseases and pests, which avoids the need to apply pesticides, which reduces the harm on environment and human health.

The use of organic fertilizers is an economical and viable choice, especially for small and medium farmers, the concentrations used will depend on the type of soil, texture and organic matter content. which increases its potential for mineralization and the availability to the plants (ARAÚJO *et al.*, 2005). Bovine manure is the most used by farmers, and it should be mainly applied in soils that are poor in organic matter and soils of low natural fertility, such as the soils of the semi-arid in the Northeast of Brazil (SILVA *et al.*, 2007).

As we acknowledge the importance of the benefits that the bio-fertilizer can add to agriculture, we evaluated the average concentration of the macronutrients, the pH and the electrical conductivity of the liquid bio-fertilizer, the results obtained are listed at Table 21.

Table 21 - Chemical Characteristics of Bio-fertilizer.

Material Identification	(gL^{-1})							(mgL^{-1})					(dSm^{-1})
Bio-fertilizer	N	P	P_2O_2	K	K_2O	Ca	Mg	Fe	Cu	Zn	Mn	pH	CE
	0.60	0.05	0.11	0.30	0.36	0.09	0.26	44.12	0.01	1.78	40.35	7.9	3.97

Source: Prepared by the author (2017).

According to Morocco (2011), the pH value decreases in the first hours of fermentation and gradually increases with the fermentation process advancement, reaching final values between 7 and 8, these values do not interfere with the soil microbiota or plant physiology, the values that we found in this study corroborate with values mentioned above. The electrical conductivity of the bio-fertilizer is an indicator to the maturation level of the bio-fertilizer, the mineral fraction increases while electrical conductivity decreases (KEIHL, 1985). Morocco (2011), found electrical conductivity of 4.49 dSm^{-1} in chemical evaluation of bovine bio-fertilizer.

Nitrogen was the element with the highest concentration in bovine manure bio-fertilizer. Araújo (2007), found a concentration of 0.24 gL^{-1} in anaerobic medium, the value lower than the one found in this study may be related to the hydraulic retention time, the longer the retention time, lower the N concentration. Santos and Nogueira (2011), in their studies, found values of phosphorus and potassium of 0.04 and 0.09 gL^{-1} respectively, this way the values found for the concentrations of phosphorus corroborate with the values found in this research, still the concentrations of potassium differ greatly, however Marocco (2011) found the concentration of 0.36 gL^{-1}, corroborating with the values found in this assessment, the author also shows in his research that these values increase as the days of hydraulic retention increase. The use of bio-fertilizer may be responsible for mitigation of 79% of greenhouse gases, when replacing the use of the chemical fertilizer, which emits large amounts of greenhouse gases during its process of production (SANTOS; NOGUEIRA, 2011). In accord to these results, we can state that the bio-fertilizer can be used as a soil nutrient, which reduces the export of nutrients from fodder crops used to feed livestock.

In order to evaluate the bio-fertilizer calorific value, a sample of 1 L of bio-fertilizer was collected and exposed to sun for 192 h (8 days). After water evaporation the dry matter was collected and weighed, the procedure was carried out in 5 replications, this way, we could observe that each 1 liter of bio-fertilizer has an average of 5 g of dry matter. The results of the higher calorific value of digested manure and bio-fertilizer were evaluated in a calorimetric pump, and they are shown at Table 22.

Table 22 - Digested Manure and Bio-fertilizer Calorific Value

	Higher Calorific Value (MJkg^{-1})
Bio-fertilizer (Liquid)	6.56 (0.06) 6.51 -6.61
Digested Manure	14.83 (0.09) 14.76 - 14.9

Source: Prepared by the author (2017).

In accord to the results above, it is possible to calculate the quantity of energy released from this thermodynamic system, then to calculate the energy balance and the efficiency of the energy conversion process from bovine manure into biogas. The quantitative results of energy output, or final energy, of the thermodynamic system are listed in Table 23.

Table 23 - Thermodynamic System Final Energy

	Calorific Value	**Volume**	**Thermodynamic System Initial Energy**
Biogas	21.5 MJm^{-3}	2.836 m^{-3}	60.974 MJ
Bio-fertilizer	0.328 MJL^{-1}	75 L	24.6 MJ
Digested Manure	14.83 MJkg^{-1}	74.625 kg	1,106.68 MJ
		Total	**1192.25 MJ**

Source: Prepared by the author (2017).

Table 24 presents the results of the energy input, or initial energy, and the quantity of energy output, or final energy, of the studied thermodynamic system.

Table 24 - Initial Energy and Final Energy the Thermodynamic System

	Calorific Value (MJ)
Initial Energy	1,335.00
Final Energy	1,192.25

Source: Prepared by the author (2017).

With the presented results in Table 25 it is possible to calculate the energy balance, aiming to improve the comprehension of biogas energy from the manure. The energy balance was calculated based on the first Law of Thermodynamics, law of conservation of energy, where the energy balance is given by the difference between the initial energy and the final energy of the energy conversion process. For quantifying the initial energy and the final energy, we took the higher calorific values of the products included. As follows, we have the calculus of energy balance.

$$\Delta E = \Delta E_I - \Delta E_O$$
$$\Delta E = 1335 - 1192.25$$
$$\Delta E = 142.75\ MJ$$

The energy balance allows the diagnosis of the dynamics of production activities, transformation, import and energy consumption, which turns to be useful for studies of projection and evaluation of energy production in a given energy resource (BRASIL, 2005). The energy balance aims to reckon the energy flows associated in the process of converting the primary energy source into secondary energy sources. In this case, the primary energy source used was bovine manure, the technological resource used for the conversion was the PVC tubular digester, therefor we observe at the end of the conversion process as secondary energy the biogas, the liquid fertilizer and the digested manure.

According to Brasil (2005), the transformation groups the transformation centers where all input energy (primary and/or secondary) becomes one or more forms of secondary energy, with the corresponding losses of transformation, in this case, the transformation center is the digester. Considering this context, we have that the process of manure energetic conversion into biogas resulted in an energy balance of 142.75 MJ. This result stands for the amount of dissipated energy during the energy conversion process, i.e., part of the energy from the primary source that did not convert into secondary energy, since it became other forms of energy, e.g., work and heat. Therefore, 142.75 MJ is the result of the difference between the quantity of energy of existing energy in a 75 kg volume of manure (primary energy) and the quantity of existing energy in 2.836 m^3 of biogas, 75 L of liquid bio-fertilizer and 74.625 kg of digested manure (secondary energies).

As follows we present the calculus of energy efficiency, which is given by the ratio between the usable energy (secondary energies) and the energy input (sum of the primary energies).

$$Energy\ Efficiency\ (\%) = \frac{Usable\ Energy}{Energy\ Input} \times 100$$

$$Energy\ Efficiency\ \ (\%) = \frac{1192.25}{1335}\ x\ 100$$

$$Energy\ Efficiency\ \ (\%) = 89.30\%$$

According to Viana *et al.* (2011), for all real processes of energy conversion it should always exist a parcel of thermal energy as a product, in conformity with the Law of Energy Dissipation premises, i.e., for all process of energy transformation it will always exist unavoidable thermal losses, which are given due to technological and economic limitations of the real systems, such as imperfections of thermal insulation, friction, vibrations, load losses and inertia, among other losses. In the view of this context, we can state that 10.70% of the initial energy, or primary energy, was dissipated in thermal energy.

If we compare the energy efficiency of bovine manure conversion process into biogas with other renewable energy sources such as solar and wind, we can observe that it has a very high efficiency when contrasted with the energy efficiency of a commercial wind power plant, that is about 35% (TERCIOTE, 2002), or of a solar plant that has energy efficiency of 14 to 22% (ANEEL, 2008).

In the view of this scenario, the use of digesters is a viable choice for the agricultural sector, that provides economic, environmental and social benefits. The employment of digesters is a technology for small family farms up to large farms of livestock in Brazil. However, the use of these reactors can promote significant changes for the lives of farmers in semi-arid regions, being an alternative for living in semi-arid conditions, which promotes the growth of local economy, women and family farming empowerment by a sustainable, economically viable technology and socially just. This demonstrates the importance of studies that assess existing natural resources, aiming to acquire technologies that allow the sustainably use of these resources, and promoting development and causing minimal environmental impacts.

6 CONCLUSION

The conversion process of bovine manure into biogas, by digester, has generated an energy balance of 142.75 MJ, with energy efficiency of 89.30%.

It was generated a daily volume of 2,936 m^3 of biogas from 75 kg of bovine manure, with calorific power of 17.84 $MJkg^{-1}$.

The biogas was evaluated by chromatography, which presented methane (CH^4), concentration of 57.78% after purification.

It was generated 75 L of bio-fertilizer, which presented calorific value of 0,328 MJL^{-1}, while digested manure presented calorific value of 14.83 $MJkg^{-1}$.

When evaluating biogas consumption for electric energy conversion we obtained a biogas consumption of 0.134 m^3 for pumping 1m^3 of water in a closed circuit with a motor pump of 1/3 HP. The hourly consumption of a 24 W LED bulb was 0.072 m^3 of biogas, for the two LED bulbs set of 12 and 16 W, consumption was 0.089 m^3 and for the three LED bulbs set of 12, 16 and 24 W the consumption was 0.112 m^3. In order to convert biogas into electric energy we used a motor-generator of 1200 W of power.

To evaluate biogas consumption in the conversion into thermal energy, we utilized a two-flame stove, obtaining the hourly consumption of 0.135 m^3 of biogas.

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