Addis Ababa University

Addis Ababa Institute of Technology

Centre of Energy Technology

Study on biogas energy production from cactus Opuntia ficus-indica (L.) Mill.

By

Jemal Beshir Belay

August, 2016

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

Centre of Energy Technology

Study on biogas energy production from cactus Opuntia ficus-indica (L.) Mill.

A thesis submitted to the Center of Energy technology of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment of the Requirements for the attainment of the Degree of Master of Science in Energy Technology

By

Jemal Beshir Belay

Advisor: Dr-Eng. Abubeker Yimam

August, 2016

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

Centre of Energy Technology

Study on biogas energy production from cactus Opuntia ficus-indica (L.) Mill.

A thesis submitted to the Center of Energy technology of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment of the Requirements for the attainment of the Degree of Master of Science in Energy Technology

By: Jemal Beshir Belay

Approved by the Examining Board:-

1._______________________	__________________	__________________
Chairman, Center Graduate Committee	Signature	Date
2. Dr-Eng. Abubeker Yimam	__________________	__________________
Advisor	Signature	Date
3. Dr-Eng S. Anuradha Jabasingh	__________________	__________________
Internal Examiner	Signature	Date
4. Dr. Feleqe Zewge	__________________	__________________
External Examiner	Signature	Date

Declaration

I declare that this thesis for the M.Sc. Degree at Addis Ababa Institute Technology, Addis Ababa University, Ethiopia hereby submitted by me, is my original work and has not previously been submitted for the degree at this or any other university, and that all resources of materials used in this thesis have been duly acknowledged.

By: Jemal Beshir

Signature: _______________ Date: ______________

This thesis has been submitted for examination with my approval as University Advisor.

Advisor Name: Dr-Eng. Abubeker Yimam

Signature: ____________ Date: ______________

ACKNOWLEDGMENT

My special gratitude goes to the almighty ALLAH for his will of my belonging today.

My Special thanks go to Wolkite University which sponsored me and Addis Ababa university which accepted me to attend MSc in Energy Technology program.

I gratefully acknowledge my advisors Dr.-eng Abubeker Yimam for his helpful guidance, supervision and for his invaluable critical comments and patiently assisted me in various aspects of this thesis work from the very beginning of the proposal development.

My deepest gratitude and grateful appreciation also extends to the center of energy technology helping me to get laboratory facility and giving supportive comments, school of chemical and bio engineering department for providing me the laboratory room and equipment needed to perform experimental tasks.

I am also very thankful to my family and to all of my friends for their help during this thesis work.

Table of Contents

Acknowledgment……………………......………………………………………….…………………..I

Table of Content……………………………………………………………………………………II

List of table…………………………………………………………………………...…………...V

List of figure………………………..………………………….…...…………………...….......…VI

List of Appendices………………………………………………………….....………………..…VII

Acronomy……………………………………………………………………….....……...……VIII

Abstract………………………………………………………………………………….....…..X

1. Introduction………………………………………..…………………………………….…………1

1.1. Stetment of the Problem…………………..…...……………………………………..……………3

1.2. Significant of the Research……………………………………………………………………….3

1.3. Objective of the Research…………………………………………………………………....4

   1.3.1. General Objective…………………………………………………………………...…...4

   1.3.2. Specific Objective……………………………………………………………….….……4

2. Litreture Review………………………………………………………………………………5

   2.1. Biomass Energy..……...5

   2.2. Biomass and Environment...…..5

      2.2.1. Environmental Sustainability…....………………………………………………….…….6

   2.3. Bio energy Supply and Demand in Ethiopia………………………………………….………6

      2.3.1. Bio gas in Ethiopia………………………………………………………………….…….6

   2.4. Conversation Technology for bio power and bio heat……………………………….……….7

      2.4.1. Direct Combustion………….………………………………………………………………7

      2.4.2. Co firing……………………………………………………………….……………….7

      2.4.3. Gasification……………………...………………………………………………………….7

      2.4.4. Pyrolysis……….……………………………………………………...…………….8

      2.4.5. Bio chemical Conversion………………………………………………..……………….8

2.4.6. Thermo-chemical Conversion……………………………………………….………………..9

2.4.7. Transesterfication…………………………….……………………….……………………9

2.4.8. Anaerobic Digestion………………………………………………………………………10

2.5. Biogas Energy……………………….…………………………………..………………11

2.5.1. The Biogas Process……………….…………………………..……………………………12

2.5.1.1. Hydrolysis…………………………………………………………………….…....12

2.5.1.2. Acidoginesis……………………………………...….……………………………13

2.5.1.3. Methanoginesis………………...……………………..……………………………13

2.5.2. Process Parameter for a Biogas plant……………………………………………………….14

2.5.2.1. Temperature……………………………………..…………………………………14

2.5.2.2. Acidity (PH)…………………………………………………….……………………15

2.5.2.3. Dry matter Content………………………………………………...…………………15

2.5.2.4. Carbon/Nitrogen (C: N) ratio……………………………...……………………….15

2.5.2.5. Organic Load…………...……………………………………………………….……16

2.5.2.6. Inoculation…………………..……………………………………………………..…16

2.5.2.7. Total Solid (TS) and Volatile Solid (VS)…………………………………………….….....16

2.5.2.8. Retention time……………………………………………………………………..17

2.5.2.9. Pre- treatment of Feed stock…………………………………….…………….………..17

2.5.3. Digester Technologies……………………………………………………….……………..18

2.5.3.1. Continuous wet and dry process...…...18

2.5.3.2. Batch dry processs…………………………………………………….…………..19

2.6. Different application of cladodes of cactus……………………………………………...…...19

2.6.1. Dye…………………………...……………………………………….……………………20

2.6.2. Energy……………………………………………………………………………………...20

2.6.3. Other uses…………………………………………………………………………………..21

2.7. Renewable Energy from cactus……………………………………………………………21

3. Materials and Methods……………………………………………………..………………………23
3.1. Description of cactus………………………….……………………………………….….…...23
3.2. Feed stock……………………….…………………………………………………………….23
3.3. General Procedure……………………………………………………………………………..24
3.4. Determination of physico chemical property of the feed stocks…………………...………….24
3.4.1. Total Solid……..……………………………………………………….…………………24
3.4.2. Volatile and Fixed solid……………………………………………….…………………….25
3.4.3. Carbon to Nitrogen ratio……………………………………………………………….…....25
3.4.3.1. Carbon Determination…………………………….…………………….………………….25
3.4.3.2. Nitrogen Determination………………………………………………….…………………25
3.5. Digester Composition……………………………………………………………………….....27
3.5.1. Feed stock Content..……………………………………………………………………………27
3.5.2. Water Content...….…..27
3.5.3. Inoculation………………………………………….…………………………………….27
3.6. Setup………………………………….………………………………………………………….28
3.7. Controlling Condition…………………………………………...………………………….29
3.8. Temperature...…..29
3.9. PH………………….……………………………….…………………………………………30
3.10 Biogas yield and its quality...…..30
3.11 Data analysis..…..31
4. Result and Discussion……………………………………………………………………………32
4.1. Characterization of Feed stock………………………………………………………………..32
4.2. Characteristics of Digesters……………………………………..……………………….34
4.3. Amount and Quality of Biogas Production…………………………………………………35
4.4. Comparison of Treatments……………………………………………………….……………37
4.5. Energy Determination…………………………………………………………………….…...38

4.6. Characteristics of Digestate…………..……………………………………….…………….39

5. Conclusion and Recommendation……………………………………………………………………40

5.1. Conclusion……………………………………………………………………………….…...40

5.2. Recommendation………………..…………………………………………………………41

6. Reference...….....42

7. Appendix………………………...………………………………………………………………46

List of table

Table 1. Composition of each digester ……………….…………………………………………28

Table 2. Characteristics of feed stock……………………………………...…………….32

List of figure

Figure 1. Composition of biogas……………………………………………………….…..11

Figure 2. Energy yield of methanogens from decomposition of different sources……...…14

Figure 3. Cultivated Opuntia (prickly pear cactus)……………………………….….….22

Figure 4. Utilization of cactus……………………………..……………………….……22

Figure 5. Experimental setup……………………………………….…………………....29

Figure 6. Biogas quantity measurement setup……………………………………..…….30

Figure 7. Biogas production comparisim between treatments………………...…...………35

Figure 8. Percentage of methane in each treatment……………..…….…………….….…..36

Figure 9. The total biogas, methane and its overall percentage of treatments…….…...…...37

Figure 10. Volume of gas, volume of pure methane and equivalent energy…….…..…..39

List of Appendices

Appendix A. Amount and Quality of biogas in every measured day………………..……….46

Appendix B. Amount of biogas after day 20…………………………...……………….48

Appendix C. Quality of methane (%)……………………………………. ……………….49

Appendix D. Methane value (ml) each of 5 days…………………………………….………50

Appendix E. Energy Equivalent…………………………………………….………………..51

Appendix F. Statistical output ……………………………………………………….....52

Acronyms

AAiT= Addis Ababa institute of Technology

AD= Anaerobic Digestion

ATP= Adenosine Triphosphate

BOD=Biological Oxygen Demand

CHP= combined heat and power

cm= centimeter

C/N = Carbon to Nitrogen Ratio

COD=Chemical Oxygen Demand

CSA= Central Statistical Agency

CSTR=Continuous Stirred Tank Reactor

EPA= Environmental Protection Agency

g= gram

GHG= Green House Gas

H_2S= hydrogen sulfide

Kg= Kilogram

KWh= Kilo Watt hour

l= liter

m^3= cubic meter

MC= Moisture Content

MJ= Mega Joule

ml= milliliter

mm= millimeter

N= normal

NBP= National Biogas Program

NGO= Non-Government Organization

NRCS= Natural Resource Conservation Strategy

NREL= National Renewable Energy Laboratory

ppm= part per million

TS = Total Solids

UNDP= United Nation Development Program

US.DOE= United States Department of Energy

VS = Volatile Solid

Abstract

Energy plays a driving role in socio-economic development arena; poverty reduction and improvement of the quality of life. Conversion of animal waste to biogas energy to replace traditional fuel and use of the slurry as a fertilizer is the current focus of the national biogas program of Ethiopia (NBP 2013). This paper presents the experimental results of the anaerobic digestion of cactus (Opuntia ficus-indica) (L.) Mill. The total solid (TS), volatile solid (VS), fixed solid (FS) and the C:N ratio of the feed stock (cactus) had been determined before the anaerobic digestion process began and then estimation of biogas production and methane content of each of the treatments, T1 (<1 year cactus at 27^oC), T2 (<1 year cactus at 37^oC), T3 (1 year cactus at 27^oC), T4 (1 year cactus at 37^oC), T5 (2 year cactus at 27^oC), T6 (2year cactus at 37^oC), T7 (3 year cactus at 27^oC) and T8 (3year cactus at 37^oC) were performed. From 500g of cactus it was found that the amount of biogas production and quality was highest in T2 (3500ml of biogas and 49% CH_4) and T4 was the second highest in the amount of production and quality (3400ml of biogas and 45% CH_4). T7 produced the minimum biogas production and quality (2500ml of biogas and 33% CH_4). Moreover, compare to other source of energy, cactus produced a good volume of biogas but low in quality due to its C: N ratio. Thus, Cactus can be digested alone or it can be one of the feed stock for co-digestion process. This could give better quality biogas.

1. Introduction

Energy supply from renewables is an essential component of every nation's strategy, especially when there is responsibility for the environment and for sustainability. One requirement for sustainable development is the availability of adequate energy services for satisfying basic needs, improving social welfare, and achieving economic development (Rogner et al. 2004). Consequently, the challenge of energy for sustainable development will require uninterrupted effort on the part of international organizations, national governments, the energy community, civil society, the private sector and individuals (Green et al., 2004). Roughly half of the world's population burns solid biomass fuels for cooking and heating needs. Throughout poor, rural areas of sub- Saharan Africa, biomass is the dominant fuel, and cooking is usually performed using a simple three-stone fire or "open fire" It is responsible for around 5% of all greenhouse gas emissions worldwide, which is about 2 billion tons of CO_2 equivalent emissions per year. In Ethiopia energy consumption from biomass accounts for 92% of total national energy consumption in 2010. This makes Ethiopia as one of the most biomass energy dependent countries in the world. The major use of biomass energy is for household baking and cooking. Domestic energy requirements are mostly met from wood, animal dung and agricultural residues. About 81% of the estimated 16 million households use firewood, 11.5% use leaves and dung cakes while only 2.4% use kerosene for cooking (Ethiopian National Energy Policy 2012). In regions where biomass is scarce, time and effort spent gathering firewood can be a substantial burden on households, particularly children and women. And due to incomplete combustion of these fuels and poor ventilation result in high indoor concentrations of health-damaging pollutants including particulate matter and carbon monoxide. In places where wood and other fuels are in short supply, people often dry and burn animal manure. But the people who live in cities, the opportunity to search fire wood is difficult so they bought the fire wood in expensive price or they use alternative fuels like kerosene. The assumable most environmentally friendly way of energy usage is based on the use of renewable energies as primary energy source for cooking, Unlike fossil fuels, One of these is bio-fuel production from agricultural, municipal, and industrial wastes which is efficiently accomplished through conversion to biogas, biogas is permanently renewable, as it is produced on biomass, which is actually a living storage of solar energy through photosynthesis.

Biogas is somewhat lighter than air and has an ignition temperature of approximately 700 °C (diesel oil 350 °C; petrol and propane about 500 °C). The temperature of the flame is 870 °C. Biogas consists of about 60 % methane (CH_4) and 40 % carbon dioxide (CO_2). It also contains small proportions of other substances, including up to 1% hydrogen sulfide (H_2S). The methane content and hence the calorific value is higher the longer the digestion process. The first gas from a newly filled biogas plant contains too little methane. The gas formed in the first three to five days must therefore be discharged unused. Biogas will not only improve the energy balance of a country but also make an important contribution to the preservation of the natural resources and to environmental protection. It has the potential for reducing the use of traditional biomass, the demand for fossil fuels like coal, oil, and natural gas which continued exploitation will significantly impact our environment and affect the global climate (Wilkie, 2008). Consequently, the need for different substrates such as manure, organic wastes and green plant materials for biogas production is increasing from time to time. Cactus is one of the green energy biomass for biogas production. The idea of using cactus (Opuntia ficus indica) feedstock to generate methane-based biogas first took root in Chile. Although the process had been observed as early as 1984 in the lab, its commercial application was actually first realized by environmental engineer Rodrigo Wayland Morales, the owner and current manager of Elqui Global Energy in La Serena, Chile. Morales notes that Opuntia digesters are not only much smaller, but also much less expensive than those used for anaerobic biogas production from manure and it’s possible to generate as much as 2.5kwh of methane from 1kg of dry Opuntia. The beauty of this hardy, drought-resistant cactus, which can tolerate surprising bouts of cold weather, is that it can be grown on veritable desert-like wastelands, where conventional crops would wither and die. Although the cactus is native to semi-arid regions with stifling hot temperatures, it can also survive and even thrive in mountainous areas that can have temperatures as low as minus 15 degrees Celsius. The world has millions of hectares of land prone to drought and desertification, Opuntia helps create a vegetative cover, which enhances soil regeneration and improves the infiltration of rainfall back into the soil. Opuntia ficus-indica grows abundantly in northern part of Ethiopia. It is considered to be important energy crop for biogas production because of its high organic matter yield per hectare. In addition, this plant can easily be propagated and tolerate drought and poor soil fertility.

Given the large production of this species in northern parts of Ethiopia, this research investigated biogas production from cactus (Opuntia ficus-indica) through anaerobic biodegradation (digestion).

1.1. Statement of the problem

The Ethiopian government In 2007, under the program the National Biogas Program (NBP) was initiated with a project target of constructing 14,000 biogas digesters in 5 years (Ethiopian National Energy Policy 2012). To address the rural energy crisis and indoor pollution caused by the burning of traditional biomass. The only targeted raw material going to be used for the biogas production is manure. The government did not see other alternatives. Especially in arid and semi-arid zones, that was difficult to get enough amount of manure, from metrological data in Ethiopia the lowlands make up nearly 61 - 65 percent of the land-mass, this region is tropical and semi-arid. Those the minimum annual rain fall are recorded in this region, soil fertility are also not suitable for agriculture and the surface are not covered by plants, in this type of area the government have to consider other alternative biomass rather than manure the alternative have to tolerate this kind of environment and offer biogas as much as manure. Cactus is one and best alternative biomass for this kind of environment. The plant can tolerate temperature up to 45^{o}C and it can grow in fertile and non-fertile soil. So using cactus biomass for biogas production had advantageous.

1.2. Significant of the research

Producing biogas from cactus are significantly prevent soil erosion (by covering the open land) in tropical and semi-arid region of Ethiopia. Deforestation are prevented by using this biogas for cooking and baking activities, this energy also minimize the health problem that are related to burning of fire wood and minimize the problem of children absence from school. In addition the cactus is renewable which contracts to producers are based on service life of the project to 15 years which the producer cannot risk their capital and consumers are guaranteed production for a long period. The energy of the cactus is clean, inexhaustible, creates bonds of carbon, permanent jobs and solve the energy problem in a sustainable manner in the short, medium and long term. The production of biogas from cactus helps the people by suppling gas for lightning and cooking purposes.

1.3. Objective of the Research

1.3.1. General Objective

Evaluating the biogas production potential of cactus (Opuntia ficus-indica) through anaerobic digestion is the main purpose of this study.

1.3.2. Specific Objective

The specific objectives of this research include:

- To characterize the cladodes of cactus in terms of the total solid (TS), volatile solid (VS) and carbon to nitrogen ratio (C /N).
- To determine of the effect of cactus age.
- To find out the quantity of biogas production with different age of cactus and two different temperature.
- To determine the biogas production from cactus in terms of methane percentage
- To characterize the slurry in terms of the total solid (TS), volatile solid (VS).

2. Literature Review

2.1. Biomass Energy

Biomass is a collective term used for all materials that are biogenic in origin that is, derived from the product of photosynthesis (Kishore, 2008). Biomass can be of various types, it can have plant origin or animal-origin. Biomass in the form of fuelwood was perhaps the first energy source used by human beings and was the main fuel till the industrial revolution, after which fossil fuels like coal and oil replaced biomass as the main fuels. Biomass is still an important fuel in developing countries. As per International Energy Agency, biomass energy accounted for 11% of the world's final energy consumption in the year 2001 (Karekezi, Lata and Coelho 2004). This percentage was 18% for Latin America, 25% for Asia and 49% for Africa. Biomass energy offers several advantages in the form of energy security, socio-economic development and environment. It is estimated that around 2.4 billion people in the world depend primarily on biomass fuels to provide energy for cooking. Apart from cooking, biomass fuels are also used for process heating, steam generation, mechanical and shaft power, transport fuel and electricity production. The examples of biomass that are commonly used as fuel includes Fuelwood, Agricultural residues such as husks and stalks, Vegetable oils and Animal wastes. In recent year's world has seen tremendous interest in biofuels, and a large research effort is focused on finding new biomass resources and processes for production of biofuels. A variety of physical, thermo-chemical, chemical and biochemical processes are used for converting biomass into energy.

2.2. Bio mass and Environment

A primary motivation for using biomass for energy is that plants 'fix' carbon dioxide from the air. Although this CO_2 is subsequently returned to the atmosphere when the biomass is used as fuel, there is zero net GHG impact. This simple fact, however, is complicated by the many different energy requirements for agriculture, all of which can contribute to energy use and GHG emissions; it is therefore important to look at the broader picture.

2.2.1. Environmental sustainability

Environmental sustainability requires attention to land, air, water and biodiversity. The state of resources before bioenergy development and the changes in those resources caused by bioenergy development are both key factors for understanding sustainability. Water availability (quality and quantity) is of increasing concern globally, not only in relation to agricultural use, but also in relation to the rising demands for industrial and domestic water. Because agriculture is responsible for 70% of worldwide freshwater withdrawal, expansion of agriculture for energy production warrants special attention. Different bioenergy crops have different water requirements, so choosing appropriate crops for each geographic location is critical.

2.3. Bio-energy Supply and Demand in Ethiopia

Biomass energy accounts for more than 92% of the total final energy consumed. This makes Ethiopia as one of the most biomass energy dependent countries in the world. The major use of biomass energy is for household baking and cooking. The amount of wood and charcoal produced and used in the household sector far surpasses the amount used for other purposes. At a per-capita consumption of some 0.7 tons of wood and charcoal, the aggregate amount of wood consumed annually is 55 million tons.

2.3.1. Biogas in Ethiopia

Ethiopia has a high potential for biogas production with its sufficient resources. Ethiopia's livestock population according to 2009/10 CSA survey is about 150 million. One third of this is cattle, whose refuse can effectively be used for biogas generation. Recent estimates show that about 1.1 million potential owners of household-size digesters exist in the four major regions. The effort to generate biogas from cattle dung started in early 1970s in Ethiopia. Over these past four decades, the progress of biogas digester construction has remained very low. In 2007, the National Biogas Program (NBP) was initiated with a project target of constructing 14,000 biogas digesters in 5 years. However, it has managed to construct about 3,000 digesters in the past three years, where, the remaining digesters are planned to be constructed in the next two years. Targets is very low due to a number of factors, the NBP has managed to introduce appropriate setup for the management of a biogas program at a national scale.

2.4. Conversion technologies for bio power and bio heat

2.4.1. Direct Combustion

Solid Fuels to Electricity, Heat, or CHP. In direct combustion systems used to produce electricity, a solid biomass feedstock (e.g., agriculture residues, forest residue, municipal solid waste, wood waste) is combusted with excess oxygen (using fans) in a boiler to produce steam that is used to create electricity. Direct combustion, commonly used in existing fossil-fuel power plants, is a dependable and proven technology, and is the conversion technology most often used for bioenergy power plants. However, the typically small size of bioenergy power plants (often due to high costs of transporting feed stocks), coupled with the low efficiency rates associated with the direct combustion process, can result in higher costs to produce electricity than with conventional fossil-fueled power plants (U.S. DOE, 2007). Some new combustion technologies are using compressed hot air (either directly or indirectly through a heat exchanger) to fire a combustion turbine.

2.4.2. Co-firing

Solid Fuels to Electricity. Co-firing to produce electricity involves substituting solid fuel biomass (e.g., wood waste) for a portion of the fossil fuel (typically coal) used in the combustion process. In most cases, the existing power plant equipment can be used with only minor modifications, making this the simplest and most economical option for bio power.

2.4.3. Gasification

Gasification is a chemical or heat process that converts a solid fuel to a gas. To create bioenergy, solid biomass feed stocks (e.g., wood waste) are heated above 700 degrees Celsius inside a gasifier with limited oxygen, which converts the feedstock into a flammable, synthesis gas (syngas). Depending on the carbon and hydrogen content of the biomass and the gasifier's properties, the heating value of the syngas can range from about 15 to 40 percent of natural gas. Syngas can be burned in a boiler or engine to produce electricity and/or heat. Syngas can also be converted thermo-chemically to a liquid fuel (Kent, 2007). Gasification has high efficiencies and great potential for small-scale power plant applications. Because the gas can be filtered to remove potential pollutants, the process can produce very low levels of air emissions.

2.4.4. Pyrolysis

Pyrolysis also uses high temperatures and pressure in the absence of oxygen to decompose organic components in biomass into gas, liquid (bio-oil), and char products (bio-char) (U.S. DOE, 2003). The process occurs at lower temperatures than combustion or gasification. Controlling the temperature and reaction rate determines product composition (Southern States Energy Board, 2006).

2.4.5. Biochemical conversion

Solid Fuels to Cellulosic Ethanol, .Ethanol can be made from cellulosic materials such as grasses, wood waste, and crop residues. Cellulosic ethanol is made from plant parts composed of cellulose, which makes up much of the cell walls of plants, and hemicellulose, also found in plant cell walls. Lignin, another plant part that surrounds cellulose, can also be used to make ethanol. Feed stocks that use both cellulose and lignin are sometimes referred to as “lingo cellulosic” feed stocks; for simplicity, this section uses the term cellulosic to refer to both cellulosic and lignin-based ethanol production. Breaking down the cellulose in cellulosic feed stocks to release the sugars for fermentation is more difficult than breaking down starch (e.g., in corn) to release sugars; thus, cellulosic ethanol production is more complex and more expensive than conventional ethanol production. Cellulosic biofuel production uses biochemical or thermochemical processes (NREL, 2007). Biochemical conversion for ethanol production from cellulosic feed stocks involves:

- Pretreatment of the feedstock using high-temperature, high-pressure acid; enzymes; or other methods to break down the lignin and hemicellulose that surround the cellulose.
- Hydrolysis using enzymes and acids to break down the cellulose into sugars. Fermentation to convert the sugars into ethanol (as in conventional production)
- Distillation to produce purer ethanol (as in conventional production).

2.4.6. Thermochemical conversion

Thermochemical conversion uses heat and chemicals to break down cellulosic feedstock into syngas. Depending upon the process being used, the gas can be converted to liquid fuels such as ethanol, bio-butanol, methanol, mixed alcohols, or bio-oil (through pyrolysis). Thermochemical conversion is particularly useful for lignin, which cannot be easily converted to ethanol using the biochemical process described above; up to one-third of cellulosic feedstock can be composed of lignin. Forest and mill residue feed stocks generally have high lignin contents, and thus would be more suitable for thermochemical ethanol conversion than biochemical conversion.

The thermochemical conversion process involves:

- Drying the cellulosic feedstock.
- Gasification (using heat to convert the feedstock to a syngas) or pyrolysis (using heat and pressure to produce an oil).
- Contaminant removal.
- Conversion of the syngas to ethanol, bio-oil, or other products.
- Distillation to separate ethanol from water (if producing ethanol).

2.4.7. Transesterification

Oils to Biodiesel. Biodiesel production converts oils or fats into biodiesel, which can be used to fuel diesel vehicles (or stationary engines). In biodiesel production, fats and oils are converted into biodiesel through a process known as “transesterification.” The oils and fats are filtered and pretreated to remove water and contaminants (e.g., free fatty acids), then mixed with an alcohol (often methanol) and a catalyst (e.g., sodium hydroxide) to produce compounds known as fatty acid methyl esters and glycerin (U.S. DOE, 2008). The esters are called biodiesel when they are intended for use as fuel. Glycerin is used in pharmaceuticals, cosmetics, and other markets. Often biodiesel and glycerin are produced as coproducts.

2.4.8. Anaerobic Digestion

Solid Fuels to Gaseous Fuels for Electricity, Heat, or CHP. Anaerobic digestion is the decomposition of biological wastes (i.e., wastewater treatment sludge or animal manure) by microorganisms in the absence of oxygen, which produces biogas. Digestion occurs under certain conditions (psychrophilic, mesophilic, and thermophilic), which differ mainly based on bacterial affinity for specific temperatures. This process produces a gas that consists of 60 to 70 percent methane, 30 to 40 percent CO_2, and trace amounts of other gases (EPA, 2002). The methane can be captured (and sometimes filtered or cleaned) and used to produce electricity and/or heat, directly used to offset fossil fuels, up graded to pipeline quality gas, or used in the production of liquid fuels. Anaerobic digestion is commonly used at wastewater treatment facilities and animal feeding operations. Anaerobic digestion at wastewater treatment facilities is used to process, stabilize, and reduce the volume of bio solids (sludge) and reduce odors. It is often a two phase process: First, bio solids are heated and mixed in a closed tank for about 15 days as digestion occurs. The bio solids then go to a second tank for settling and storage. Temperature, acidity, and other characteristics must be monitored and controlled. Many wastewater treatment plants that use anaerobic digesters burn the gas for heat to maintain digester temperatures and heat building space. The biogas can also be used to produce electricity (e.g., in an engine-generator or fuel cell) or flared for disposal. Anaerobic digesters at animal feeding operations are used to process, stabilize, and reduce the volume of manure, reduce odors and pathogens, separate solids and liquids for application to cropland as fertilizer or irrigation water, and produce biogas. Farm-based anaerobic digesters consist of four basic components: the digester, a gas-handling system, a gas-use device, and a manure storage tank or pond to hold the treated effluent prior to land application. The biogas can be used to generate heat, hot water, or electricity, directly used to offset fossil fuels, upgraded to pipeline quality gas, or used in the production of liquid fuels. The captured biogas is typically used to generate electrical power, with many farms recovering waste heat for on-farm use.

2.5. Biogas Energy

Biogas is a combustible mixture of gases (figure 1). It consists mainly of methane (CH_4) and carbon dioxide (CO_2) and is formed from the anaerobic bacterial decomposition of organic compounds, i.e. without oxygen. The gases formed are the waste products of the respiration of these decomposer microorganisms and the composition of the gases depends on the substance that is being decomposed. If the material consists of mainly carbohydrates, such as glucose and other simple sugars and high-molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low. However, if the fat content is high, the methane production is likewise high. Methane and whatever additional hydrogen there may be makes up the combustible part of biogas. Methane is a colorless and odorless gas with a boiling point of -162°C and it burns with a blue flame. Methane is also the main constituent (77-90%) of natural gas. Chemically, methane belongs to the alkanes and is the simplest possible form of these. At normal temperature and pressure, methane has a density of approximately 0.75 kg/m^3. Due to carbon dioxide being somewhat heavier, biogas has a slightly higher density of 1.15 kg/m^3. Pure methane has an upper calorific value of 39.8 MJ/m^3, which corresponds to 11.06 kWh/m^3. If biogas is mixed with 10-20% air, you get explosive air, which as the name indicates is explosive. Biogas technology can be viewed as a vehicle to reduce rural poverty and leads to rural development. Biogas can be an energy substitute for animal waste, fire wood, agricultural residues, diesel, paraffin, petrol and electricity. In addition, eutrophication and air pollution are minimized furthermore, it eliminates the daily task of fire wood gathering. Biogas can be regarded as an eco-friendly fuel and can be used as a substitute for compressed natural gas. (Lantz et al., 2007).

Gas	%
Methane (CH_4)	55-70
Carbon dioxide (CO_2)	30-45
Hydrogen sulfide (H_2S)	1-2
Hydrogen (H_2)	1-2
Ammonia (NH_3)	1-2
Carbon monoxide (CO)	trace
Nitrogen (N_2)	trace
Oxygen (O_2)	trace

Figure 1. Composition of biogas

2.5.1. The Biogas process

The complete biological decomposition of organic matter to methane (CH_4) and carbon dioxide (CO_2) under oxygen depleted conditions i.e. anaerobic is complicated and is an interaction between a number of different bacteria that are each responsible for their part of the task. What may be a waste product from some bacteria could be a substrate (food) for others, and in this way the bacteria are interdependent. Compared with the aerobic (oxygen rich) decomposition of organic matter, the energy yield of the anaerobic process is far smaller. The decomposition of, for example, glucose will under anaerobic decomposition will yield 2 ATP molecules. This means that the growth rate of anaerobic bacteria is considerably lower than that of aerobic bacteria and that the production of biomass (in the form of living bacteria) is less per gram decomposed organic matter. Where aerobic decomposition of 1 g substance results in the production of 0.5 g biomass, the yield under anaerobic conditions is only 0.1 g biomass. The biogas process is often divided into three steps: Hydrolysis, acidogenesis and methanogenesis,

2.5.1.1. Hydrolysis

During hydrolysis long-chain molecules, such as protein, carbohydrate and fat polymers, are broken down to monomers (small molecules). Different specialized bacteria produce a number of specific enzymes that catalyze the decomposition, and the process is extracellular i.e., it takes place outside the bacterial cell in the surrounding liquid. Proteins, simple sugars and starch hydrolyze easily under anaerobic conditions. Other polymeric carbon compounds somewhat more slowly, while lignin, which is an important plant component, cannot be decomposed under anaerobic conditions at all. Cellulose and hemicellulose are long-chain polysaccharides that can be broken down by specific enzymes present in certain bacteria, but not in animals. Lignin has a compact structure and is practically biologically inert. Sugars are complex polysaccharides that, are easily hydrolyzed by specialized bacteria. In plant tissue both cellulose and hemicellulose are tightly packed in lignin and are therefore difficult for bacteria to get at. This is why only approx. 40% of the cellulose and hemicellulose in pig slurry is decomposed in the biogas process. Normally the decomposition of organic matter to methane and carbon dioxide is not absolute and is frequently only about 30-60% for animal manure and other substrates that have a high concentration of complex molecules.

2.5.1.2. Acidogenesis

In a balanced bacterial process approximately 50% of the monomers (glucose, xylose, amino acids) and long-chain fatty acids (LCFA) are broken down to acetic acid (CH_3COOH). Twenty percent is converted to carbon dioxide (CO_2) and hydrogen (H_2), while the remaining 30% is broken down into short-chain volatile fatty acids (VFA). Fatty acids are monocarboxylic acids that are found in fats. Most naturally occurring fatty acids contain an even number of carbon atoms. VFAs have fewer than six carbon atoms. LCFAs have more than six carbon atoms. If there is an imbalance, the relative level of VFAs will increase with the risk of accumulation and the process "turning sour" because the VFA-degrading bacteria have a slow growth rate and cannot keep up. A steady degradation of VFAs is therefore crucial and often a limiting factor for the biogas process. Hydrolysis of simple fats results in 1 mole glycerol and 3 mole LCFA. Larger amounts of fat in the substrate will thus result in large amounts of long-chain fatty acids, while large amounts of protein that contain nitrogen in amino groups ($-NH_2$) will produce large amounts of ammonium/ammonia (NH_4+/NH_3). In both cases this can lead to inhibition of the subsequent decomposition phase, particularly if the composition of the biomass feedstock varies.

2.5.1.3. Methanogenesis

The last step in the production of methane is undertaken by the so called methanogenic bacteria or methanogens. The methanogens belong to a kingdom called Archaea, part of a taxonomic system that also comprises eukaryotes and bacteria at this level. A kingdom is the highest taxonomic level and Archaea are therefore at the same level as the other kingdoms plants, animals, bacteria (Eubacteria), protozoa and fungi. Methanogens are believed to have been some of the first living organisms on Earth. Two different groups of bacteria are responsible for the methane production. One group degrades acetic acid to methane and the other produces methane from carbon dioxide and hydrogen. Under stable conditions, around 70% of the methane production comes from the degradation of acetic acid, while the remaining 30% comes from carbon dioxide and hydrogen. The two processes are finely balanced and inhibition of one will also lead to inhibition of the other. The methanogens have the slowest growth rate of the bacteria involved in the process, they also become the limiting factor for how quickly the process can proceed and how much material can be digested. The growth rate of the methanogens is only around one fifth of the acid-forming bacteria. As previously mentioned, the methanogens do not release much energy in the process (figure 2). But due to the anoxic conditions, the competition from other bacteria is limited, which is why they manage to survive.

Source	Process	Energy yield KJ/mole methane
Hydrogen	$4H_2+CO_2 \longrightarrow CH_4+2H_2O$	131
Formic acid	$4HCOOH \longrightarrow CH_4+3CO_2+2H_2O$	145
Methanol	$4CH_3OH \longrightarrow 3CH_4+CO_2+H_2O$	105
Acetic acid	$CH_3COOH \longrightarrow CH_4+CO_2$	36

Figure 2. Energy yield of methanogens from decomposition of different sources

2.5.2. Process Parameters for a biogas Plant

In order for a biogas process to be effective and productive, there are a number of parameters that have to be optimized. Anaerobic environment as mentioned earlier, the methanogens need an oxygen free environment they are obligatory anaerobic. A biogas reactor therefore has to be airtight. The small amount of oxygen dissolved in the liquid/biomass fed to the plant is quickly used up by, for example, aerobic bacteria that must have oxygen, or by facultative anaerobic bacteria that can use oxygen for their respiration, if it is present.

2.5.2.1. Temperature

The rate of biochemical processes generally increases with temperature. As a rule of thumb, the rate is doubled for every 10 degree rise in temperature within certain limits (Q10= 2). This is also the case with the biogas process. In this situation there are, however, several types or strains of K2 bacteria involved that have adapted to the different temperatures:

- psychrophilic 0 – 20°C
- mesophilic 15 – 45°C
- thermophilic 40 – 65°C

Common to the bacteria is that they are very sensitive to changes in temperature. This sensitivity increases with temperature. In practice, biogas plants are run at either a mesophilic level of around 37°C, where fluctuations of approx. ± 2°C, are tolerated, or at a thermophilic level of around 52°C, where fluctuations of only approx. ± 0.5°C, are tolerated.

2.5.2.2. Acidity (pH)

Despite the methanogens using organic acids for some of their food intake, they cannot cope in an acidic environment. The optimum environment is a pH of Between 6.25 to 7.5 which is conducive for methanogenic bacteria to function properly as indicated by Rai (2004). When the process is in balance, the acidity in the reactor will be within this range and as the buffer capacity in the reactor is very large, it takes a lot to alter it. The system is, in other words, very robust and stable. Slurry based plants often have a somewhat higher pH (8-8.3) due to a higher ammonium content.

2.5.2.3. Dry matter content

For bacteria to be able to degrade the material, the dry matter content must not be higher than around 50%. In a biogas plant, however, it should only be around 8-10%, if it is to remain liquid enough to be pumped. A slightly higher level can be tolerated in special reactor types with a direct feed line.

2.5.2.4. Carbon/nitrogen (C/N) ratio

Just like any other organism, methanogens need a number of macro- and micronutrients in order to grow. The most important macronutrients are nitrogen (N), phosphorus (P) and potassium (K). Nitrogen is used by bacteria to produce proteins. The nitrogen content is often quoted in relation to carbon, as this gives an indication of whether there is sufficient nitrogen available for bacteria. Normally the C/N ratio should be less than 30/1, as nitrogen otherwise becomes the limiting factor for bacterial growth. On the other hand, the nitrogen level should not be too high as this can then also inhibit the process.

2.5.2.5. Organic load

Organic loading rate (OLR) is a measure of the biological conversion capacity of the AD system. Feeding the system above its sustainable OLR results in low biogas yield due to accumulation of inhibiting substances such as fatty acids in the digester slurry (Vandevivere, 1999). In such a case, the feeding rate to the system must be reduced. OLR is a particularly important control parameter in continuous systems. The rate at which biomass is added to the reactor has to be adjusted to the growth rate of the methanogens and organic acids have to be removed at the rate at which they are produced. The normal load for a CSTR reactor is 1-6 kg COD/m^3 reactor volume/day. If more biomass is added than the bacteria are able to degrade, the process will become acidic. The biomass also has to be fed to the reactor at an even rate and volume, preferably as a continuous feed. If the substrate has to be changed, this must be done gradually, so that bacteria can adapt to the new conditions.

2.5.2.6. Inoculation

The use of anaerobic microbes (digestate for example) to start up an anaerobic system is called inoculation. According to Wilkie (2008), the quality and quantity of inoculums are critical to the performance, time required, and stability of bio-methanogenesis during commissioning (startup) or restart of an anaerobic digester.

2.5.2.7. Total Solid (TS) and Volatile solid (VS) Content

The composition of cladodes varies depending on the soil properties at the cultivation site, the season and age of the plant (Retamal et al., 1987; Rodriguez-Felix & Cantwell, 1988; Stintzing et al., 2005). Generally, fresh cladodes have a high moisture content of 85-92%. The balance 15-8% is termed as total solids. The adjustment of total solid content helps in bio-digesting the material at the faster rate, and also in deciding the mixing of the various crop residues, weeds, and plants etc. as feed stocks in biogas digester (Rai, 2004). The TS, VS and MC of cladodes of cactus were studied by Elias Jigar et al. (2011), the TS was 14%, moisture content 86% and the VS was 78%.

2.5.2.8. Retention time

Retention time (residence time), in the AD reactors, refers to the time that feedstock stays in the digester.

$$\text{retantion time } \theta \text{ (days)} = \frac{\text{operating volume V (m3)}}{\text{flow rate Q(m3/day)}}$$

The appropriate time depends on the type of feedstock, environmental conditions and intended use of the digested material (Ostrem &Themelis 2004) Furthermore retention time in the AD system depends on process temperature and total solid content. Mesophilic digesters have longer retention time (10-40 days) then thermophilic digesters. Also the high solid content systems ("dry" processes) have longer retention time then low solid content systems ("wet" processes). Commonly used method for shortening the residence time in AD reactors is mixing the digester. Usually it is done by recirculation of the produced biogas back in the reactor. Also the residence time affects the microbial communities in the digester. Different microbial communities develop in digesters operating on different retention times. This was one of the crucial parameters in the designing the acidogenesis experimental reactor.

2.5.2.9. Pre-treatment of Feed stocks

In biogas substrates, the main sources of methane are sugars and other small molecules. In plants (lingo cellulosic substrates) these small molecules come from the breakdown of starch, cellulose and hemicellulose. It is generally believed that lignin cannot be degraded by anaerobic bacteria, although this has been challenged (DeAngelis et al., 2011), and may even inhibit the degradation of other substances like cellulose. Pectin also affects breakdown, binding cellulose fibrils together and binding plant cells together (Carpita and Gibeaut, 1993). Breaking down this lignocellulose complex is the key to biogas production (Noike et al., 1985). Various pretreatment technologies have been developed in recent years to increase the availability for AD of sugars and other small molecules in biogas substrates, particularly in lingo cellulosic material. These pretreatment technologies aim to make AD faster, potentially increase biogas yield, Make use of new and/or locally available substrates, and prevent processing problems such as high electricity requirements for mixing or the formation of floating layers. Mechanical pretreatment is carried out by mills and either makes the pieces of substrate smaller or squeezes them to break open the cellular structure, increasing the specific surface area of the biomass. This gives greater possibility for enzymatic attack, which is particularly important for lingo cellulosic substrates. Particle size reduction not only increases the rate of enzymatic degradation, it can also reduce viscosity in digesters (thus making mixing easier) and can reduce the problems of floating layers. All particle size reduction is helpful, but a particle size of 1 to 2 mm has been recommended for effective hydrolysis of lignocellulose (Schell & Harwood, 1994.)

2.5.3. Digester technologies

There are several different digester technologies used for anaerobic digestion. Olsson et al. (2005) have divided biogas technology into three generations by level of technological approach and increase of bioconversion capacity, though not all of the technologies described are suitable for all types of raw materials. While CSTR is still the most common and widely-used process for digestion of manure, energy crops and diverse municipal and industrial raw materials.

2.5.3.1. Continuous wet and dry processes

Continuously fed biogas plants are filled and then emptied by different strategies. Wet processes (TS <14%, raw materials which are readily solubilized or already suitable for pumping) are often CSTRs fed in certain intervals (a few times per day or per hour) with simultaneous withdrawal (often by gravity) of digestate. The biogas production is thus rather constant, but as the new feed is mixed into the reactor contents, some by-pass occurs (i.e. not all raw material stays the whole HRT in the reactor). On the other and, mixing efficiently provides good contact between the raw materials and the microbes, no re-inoculation is required, the reactor content is homogeneous, and the reactor temperature stays stable. Continuous feeding may also be performed for raw materials with high TS content, such as food waste. A common reactor type is plug-flow, meaning a vertical cylinder being fed from one end and emptied from the other and using e.g. belts for transporting the materials. The raw material is firstly mixed with already digested material to provide the necessary microbial inoculum, which needs to be taken into account when designing the process. The process may also contain collection and recirculation of leachate from the digested material, further facilitating contact between the digested material and the microbes. The greatest challenge of these dry processes is mixing: the digestate is often still unestablished and requires post-treatment, such as composting.

2.5.3.2. Batch dry processes

Batch operation is usually used for raw materials with high TS content, such as solid manure. A garage type is probably the most common batch reactor. It is filled with a mixture of new raw material and digestate (to provide inoculum) using e.g. a front loader, then closed for biogas producing period of at least 20-30 days, and finally opened and emptied just to start the cycle again with new filling. As the biogas production thus varies depending on the stage of the operational cycle, it is usual to have at least three parallel batches in different stages of operation: one being filled, one in biogas producing phase and one being emptied. Also the batch digester may.

2.6 Different Applications of cladodes of cactus

The flattened, fleshy branches or stems, technically called cladodes, and popularly called pads (or sometime paddles or joints), have the appearance and function of leaves. While Opuntia species reproduce sexually by seeds, they also reproduce vegetatively when cladodes fall off the plant to the ground and produce roots and new daughter cladodes. Commercial plantations are established entirely with cladodes or portions of cladodes. Tender young pads, called nopales (also nopalitos when cut up for culinary use), have been consumed as a vegetable in central Mexico since pre-Hispanic times. In Mexico, most nopalitos come from O. ficus-indica, but in the United States, mostly in southern California and Texas, nopalitos often come from Nopalea cochenillifera. Some Mexican companies candy nopalitos, or process them for export as pickles, sauces, and jams. The pads are said to taste something like green beans, or between that of green pepper and asparagus, although when preserved in jars they have a tart, pickle like taste. Fresh nopales are sometimes available in supermarkets in North America as “cactus leaves” (although botanically they are flattened stems). Cactus pie is prepared from nopalitos, and tastes like apple pie, possibly because both the cactus and apples contain high levels of malic acid. Fried eggs with onions and diced cactus is huevos rancheros con nopalitos, a popular meal in Mexico as reported by E. Small & P. M. Catling (2011).

2.6.1. Dye

Before cheap synthetic aniline dyes were developed from coal tar in 1856, plantations of cactus, particularly of the Cactus Pear, were established for the production of cochineal (pronounced caw-chi-neel), a dye of outstanding quality. Cochineal (carminic acid or dacti dye) is obtained by extraction from cochineal insects, which are cultured on the cactus. There are about four species of cochineals, which belong to the genus Dactylopius (Homoptera, group Dactylopiidae). These feed exclusively on the genus Opuntia and related cactus genera. The main source of the dye is the females of D. coccus, which are much larger than the males, but are nevertheless quite small (about 32,000 weigh1 kg; 70,000 weigh 1 pound). This scale insect, which is native to Central America and Peru, feeds on the pads and fruit and develops a large quantity of the stain within its body (19–20% of its dry weight). E. Small & P. M. Catling (2011).

2.6.2. Energy

Coal, oil, and wood are examples of fuels containing chemically-stored energy that is extracted simply by burning. Crop residues also contain energy. Burning the residues is one of several methods of recycling agricultural waste. Other methods include the production of animal feed, fertilizer, building and industrial materials, and soil conditioners, but fuel use is attracting increasing attention. By fermentation of agricultural wastes, alcohol or methane fuels can be produced. The high productivity of Cactus Pear has led to its consideration as a possible source of biomass for energy production. When the plant is used as fodder, both the remains of the plant and the resulting animal waste can be used for biogas (methane) production. Although not yet practical, research has suggested that biogas production from Cactus Pear may be a good method for increasing the sustainability of agricultural systems in arid zones. E. Small & P. M. Catling (2011).

2.6.3. Other Uses

Prickly Pear cacti are frequently grown into hedges and fences by planting them a foot or so apart. Within several years the plants grow together to form a spiny barrier that will repel any intruder larger than a rabbit. Young cladodes of Cactus Pear are used in the cosmetic industry for production of shampoos, hair conditioners and moisturizing facial creams. Drugs derived from Cactus Pear are marketed for the treatment of prostate disease, and other medicinal uses relate to blood glucose and cholesterol regulation. Industrial uses include the production of pectin and fructose. In some rural areas of Mexico the sticky sap is boiled into a concentrate and mixed with whitewash and mortar to make a durable building material. The fibre from the pads can be woven into baskets and fabrics and can be pressed to make paper. The sap of prickly pear cactus pads when spread on water smothers mosquito larvae. E. Small & P. M. Catling (2011).

2.7. Renewable Energy from cactus (Opuntia ficus-indica)

Renewable energy almost for free**,** in the form of green fuel**,** thanks to the biomass produced from Opuntia ficus indica a huge energy potential but almost completely overlooked today. Discover the great possibilities of sustainable development of some arid regions with the simple installation of extensive cultivation of Opuntia**.** The versatility and the thousands of Opuntia’**s** uses were already known, but anyone had not ever thought to the possibility of using its tissues as a source of renewable energy so far. A study, bounced through the portal Agrinotizie, begun in the '80s at the Polytechnic University of Madrid and followed-up again in these days, shows that if this cactus is grown extensively, it could provide a significant production of energy in the form of bioethanol, biodiesel and bio methane**.** Widespread in Central America and in the Mediterranean countries, the Opuntia is a hardy plant, easily adaptable to many different environmental conditions. The officially registered species are about 300 (107 only in Mexico), but the difficulties of identification caused by hybridization and polyploidies make this number quite uncertain. The most widespread species in the world is very well known Opuntia ficus indica**,** which is able to withstand prolonged periods of drought and, with the little water available**,** produces large amounts of biomass **(**fruit, blades and tissues, all parts of the plant that spontaneously fall and begin to biodegrade)**.** If it has the right amount of water and nutrients**,** Opuntia can get to produce more than 150 tons of fresh biomass per hectare of cultivation**:** a huge asset.

Figure 3. Cultivated Opuntia (prickly pear cactus)

Sources; renewable energy world.com

2.6.1. Biogas production process from cactus.

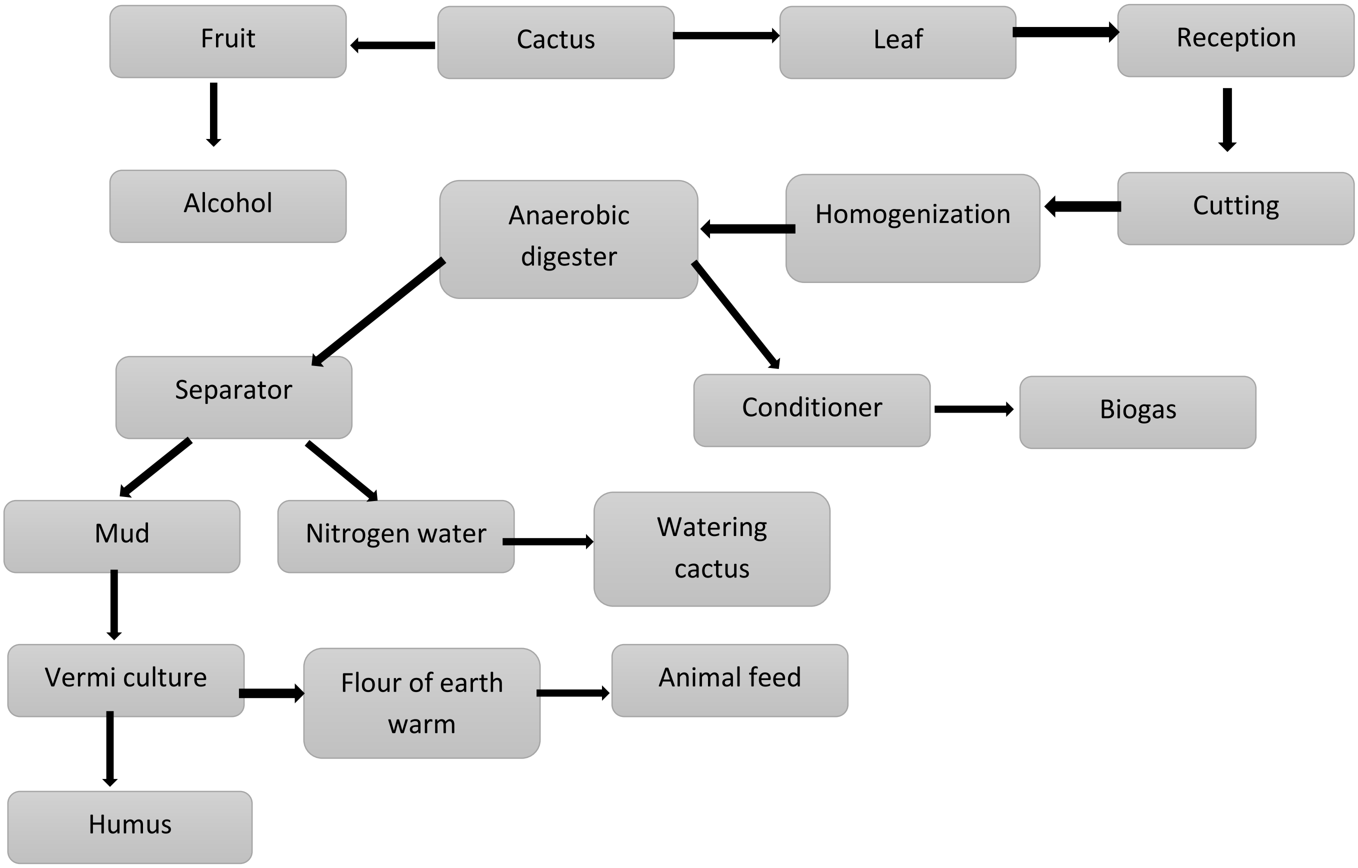

Figure 4. Utilization of cactus Source: Wayland 2010

3. Materials and Methods

3.1. Description of cactus (opuntia ficus indica)

Opuntia ficus-indica and its fruit are commonly called “Prickly Pear,” but the more attractive name “Cactus Pear” is now generally applied commercially. This is a fleshy bush or small tree, 3–5 m (10–16 feet) tall, native to the desert zones of northwestern Mexico and southwestern United States, with dozens of cultivated varieties available. The species was brought to Europe from Mexico by the first Spanish colonists and it has been cultivated along the Mediterranean coast since the late 17th century. Cactus pear was introduced to Ethiopia between 1848 and 1920 (Neumann 1997; Habtu 2005). The plant is widely distributed in the arid and semi-arid regions of the country; especially in eastern and southern zones of Tigray Region of Ethiopia. One or more attractive, reddish (sometimes white, pink or yellow) flowers occur on the upper edge of the highly flattened segments (pads). The genus of Prickly Pears, Opuntia, contains at least 300 species, and several are cultivated (Scheinvar in Barbera et al. 1995). Classification and identification of the group is very complex and requires much more study. Opuntia ficus-indica is distinguished by a lack of hair and spines, the presence of widely open flowers (pollinated by insects instead of tubular flowers pollinated by hummingbirds), and by the pear-shaped (instead of rounded) pads (Armada Rodiguez-Felix and Cantwell, 1987).

3.2. Feed stock

The substrates used as feed stock materials for the generation of biogas in the laboratory were samples of cactus Cladodes (flat green, plate-like sections of O. ficus-indica called cladodes (pads).The Cladodes were found from O. ficus indica producing community in Adigrat (East Tigray).Cladodes were collect with its age group that is <1, 1, 2, and 3 years old and the age was determined by asking the cactus farmer Mr.Gebremeskel Gidey. and according to him the age of the cactus plant was known by the tip of the leaf, freshness of the leaf and by the planting age. The collected cactus was cut manually into small pieces and homogenize used for digestion as reported by Wayland (2010).

3.3. General Procedure

The total solid (TS), volatile solid (VS), fixed solid (FS) and the C:N ratio of the feed stock (cactus) had been determined before the anaerobic digestion process began, and the sample of the plant (cactus) was then cut, purified from spin and homogenized each sample. The process of anaerobic digestion for the generation of biogas was then conducted by varying the temperature and the maturity of cactus in eight treatments as, T1 (<1 year at 27^oC), T2 (<1 year at 37^oC), T3 (1 year at 27^oC), T4 (1 year at 37^oC), T5 (2 year at 27^oC), T6 (2 year at 37^oC), T7 (3 year at 27^oC) and T8 (3 year at 37^oC). In the laboratory each the water content for each sample was determined using the recommendation for better biogas production as reported by Mazumdar 1982; Nijaguna (2002). That is, a total solid (TS) of 9% in the fermentation slurry.

3.4. Determination of the Physico-Chemical properties of the Feed stocks

3.4.1. Total Solid

10g of freshly collected samples of each of cactus age were weighed using electrical balance (digital weight measuring device) and placed inside an electric hot air-oven maintained at 105 °C using a crucible. The crucible was allowed to stay in the oven for 24 hours, then taken out, cooled in a desiccator and weighed. Then the percentage of the TS was calculated.

$$\%\mathrm{Ts} = \frac{\mathrm{A} - \mathrm{B}}{\text{mass of fresh sample}} * 100$$

Where: % Ts = percentage of total solid

A = total mass of dried sample (mass of dry sample +mass of dish)

B = mass of dish

3.4.2. Volatile and Fixed Solids

The TS obtained was ignited at 650°C in furnace for three hours as indicated in Elias Jigar et al. (2011) to determine the volatile and fixed solid content of the sample . Then the following formula was employed to calculate the percentage of volatile solid content of the TS

$$\%\mathrm{Vs} = \frac{\mathrm{A} - \mathrm{C}}{\mathrm{A}} * 100$$

Where: % Vs = percentage of volatile solid

A = total mass of dried sample

C = total mass of fixed solid (mass of ash + mass of dish)

m(ash)= remaining mass after ignition which is called fixed solid i.e. %Ts = %Vs + Fs

3.4.3. Carbon to Nitrogen Ratio (C/N)

3.4.3.1. Carbon (C) determination

The carbon content of the feed stock is measured by considering the volatile solids content that was expressed as a percentage and the total carbon content was obtained from volatile solids data using an empirical equation as reported by Haug (1993) and Badger et al. (1979) cited in Elias Jigar et al. (2011).

$$\text{Carbon \%} = \mathrm{VS}(\%)/1.8$$

3.4.3.2. Nitrogen determination

The Kjeldahl method was employed to determine the total nitrogen content of the feedstocks. Weigh the sample in a tactor tube. Place in the rack, add 6ml of concentrated sulfuric acid from a bird or oxford pipette. Immidetly mix the sample and acid carefully, add step by step 3.5 ml of hydrogen peroxide. Watch out for violent reactions. As soon as the most violent reaction has ceased shake the tube a few times by hand and put it back in to the rack, add 3g of the catalyst mixture. Let stand for 5-15 min. before digestion.

Digestion takes about 4-5 hours for the digester to reach working tempreture with the tempreture of the digester at 370^{o} C lower the tubes (in the rack) into the digester and continue the digestion until a clear solution is obtained, about four hours. Put the rack in to the fume hood for cooling add 50ml of water shack to avoid preciptation of sulfur in the solution. Distilation, add 25ml of the 40% sodium haydroxide solution into the digested and dilute solution, place a 250ml conical flask contanning 25ml of the boric acid 25ml of disteled water and indicator solution under the condeser of the disteller with its tip immeresed in to the solution, continue the distillation until a total volume become between 200ml and 250ml. rinse the tip with a few ml of water before the recevier is removed. Titration, titrate with 0.1N hydrochloric acid to a reddish color. Finally, the amount of nitrogen present was calculated using the formula:

$$\%\mathrm{N} = \frac{\mathrm{VHCL\ in\ L} * \mathrm{NHCL(ca.0.1.)} * 14.0 * 100}{\mathrm{Wo}}$$

Where : %N = percentage of nitrogen

N = normality of HCL (used often is 0.1N)

V = volume of HCLin L consumed to the end point of titration,

Wo = sample weight of dry matter basis and

14.0 = the molecular weight of nitrogen

Finally, the ratio of carbon to nitrogen was calculated as:

$$\frac{\%\mathrm{Carbon}}{\%\mathrm{Nitrogen}}$$

3.5. Digester Composition

3.5.1. Feed stock content

For the purpose of this study the amount of cactus in digesters was fixed to be 500 g (taking the digesters volume in to consideration) and the wet cactus was added to 3 L of plastic bottle digesters. To prepare the cactus for anaerobic digestion first the cactus plant cut manualy by knife and crushed by 2mm sized crusher in Addis Ababa institute of Technology School of Chemical and Bio Engineering Chemical Engineering Department mechnical unit operation laboratory.

3.5.2. Water content

According to Sasse (1988); Nijaguna (2002). A wet anaerobic digestion process have an optimal total solid (TS) content of 5 to 10%. When the TS values were above the optimal value water was add to obtain the optimum concentration of 9% TS, according to Mazumdar (1982); Nijaguna (2002). For this study the water content were adjusted according to the indicated optimal condition. The amount of water added was then determined by the formula and added after determining the moisture content and the total solid of cactus.

$$\frac{\mathrm{mTs}}{\mathrm{A + B}} * 100 = 9\%$$

Where mTs = mass of total solid

A= mass of sample

B= mass of water

3.5.3. Inoculation

To initiate or start up the digestion process 10% of inoculem was added for all treatments. The inoculem comes from Addis Ababa zenebework area kebele 04 raey trade union resturant cow dung digestre. The digestate contain methanogenic bacteria. The content of each digester were summarized in table 1.

Table 1. Composition of each digester

Treatment	Condtions	Cactus amount (g)	Water added (g)	Inoculem in g. 10% of amount of cactus	Total mass (g)
T1	<1year at 27^{o}C	500	-	50	550
T2	<1year at 37^{o}C	500	-	50	550
T3	1year at 27^{o}C	500	-	50	550
T4	1year at 37^{o}C	500	-	50	550
T5	2year at 27^{o}C	500	27.7	50	577.7
T6	2year at 37^{o}C	500	27.7	50	577.7
T7	3year at 27^{o}C	500	222.2	50	772.2
T8	3year at 37^{o}C	500	222.2	50	772.2

3.6. Set up

The experimental set up for the study on batch digestion consists of plastic bottle with a plastic stopper. All the eight anaerobic digesters were constructed in bench-scale experiments at which the degradation of the substrate was accomplished in sealed plastic bottles with a capacity of 3 liters in AAiT Environmental Engineering laboratory. Each bottle was sealed with a rubber stopper having one outlets. The outlet was attached to the branched connector one branch connect to plastic air bag and the other one is closed and it is used to measure collected gas by using gas syringe. Manual agitation was take place by shacking the digester by hand in each day.

Figure 5. Experimental setup

3.7. Controlling conditions

The digesters' internal working temperature was maintained at 27^oC for the sample <1, 1, 2 and 3 years old cactus and 37^oC for the other <1, 1, 2 and 3 years old cactus samples and PH was adjusted at 6.8 once for all treatments.

3.8. Temperature

Samples cactus <1, 1, 2, 3 years old were treated 27^oC and 37^oC. 27^oC is taken to be the average room tempreture for tropical area (Kolla) of Ethiopia as reported in Ethiopian National Metrological Services Agency (2015). And 37^oC is used as an optimum tempreture for mesophilic condition. This tempreture were constant througout the process time. This tempreture were controled by using the water bath (model:HWS-24,voltage 220V,50Hz,power 1000w, date 2010.07). The actual inside temperature of the digester is not measured directly but it is determined by the outside temperature (temperature of water bath).

3.9.pH

pH is another factor that affects digestion of substrates in reactors. The natural pH of cactus was 4.6 to 5.5 (4.6, 4.8, 5.2, 5.5) for <1, 1, 2 and 3 years old cactus. Thus, the pH of all the treatments was adjusted once at 6.8. This is in agreement with a pH range of 6.25 to 7.5 which is conducive for methanogenic bacteria to function properly as indicated by Rai (2004).

3.10. Biogas yield and its quality

The volume of gas produced in the anaerobic reactors was measured by using 100ml calibrated gas syringe. And methane content of the gas was measured by using gas analyzer (Geotech).

Figure 6. Biogas quantity measurement setup

3.11. Data Analysis

The mean for average biogas yield and methane percentage of the eight treatments, respectively were carried out using simple mean and average mean calculation equations. T-test and F-test as well as correlation statistics at 5% significant level, respectively were carried out using Statistical Package for Social Science (SPSS) software In addition, the biogas yield, the percentage of methane and the energy equivalent of each treatment were manuplated in line graph, bar chart and table using Microsoft Office Excel.

4. Results and Discussion

4.1. Characterization of feed stocks

The Characteristics of feed stock (% moisture content, %TS, %VS, %C, %N and % C/N between the samples (values are mean and SE, n=4)) were determined. Each test were conducted two times and the average values are shown in Table 2.

Table 2. Characteristics of feed stock (% moisture content, %TS, %VS, %C, %N and % C/N between the samples (values are mean and SE, n=4))

Parametres	S1 (%)	S2 (%)	S3(%)	S4(%)	Mean	SE
Moisture content	95.3	93	90.5	87	91.45	1.78
TS	4.7	7.0	9.5	13	8.55	1.78
VS as percentage of TS	80.8	74.3	73.7	69.2	74.5	2.39
Ash as percentage of TS	19.1	25.7	26.3	30.8	25.47	2.41
C	44.9	41.3	40.9	38.4	41.37	1.34
N	1.3	0.92	0.83	0.72	0.94	0.12
C/N	34.5	44.9	49.3	53.3	45.5	4.0

The mean moisture content of sample 1 (cactus <1 year old), sample 2 (cactus 1 year old), sample 3 (cactus 2 year old) and sample 4 (cactus 3 year old) were 95.3, 93, 90.5 and 87, respectively. and standard error of the mean was 1.78 (Appendix F). This result shows that the moisture content of cactus less than one year old was higher than other cactus samples, less than one year old cactus have more water content than 1 and above years old cactus, as a result increasing the degree of digestion as bacteria can easily access liquid substrate for relevant reactions to take place easily. There was significant difference in moisture content values between samples. The total solids and volatile solids were determined for all substrates before AD (Table 2). When determining TS and VS, it is important to understand that high content of volatile fatty acids (VFAs) in the substrates can produce misleading results since they may volatilize from the substrate when they are first heated and thus give total solids and volatile solids values that are too low. This in turn can produce incorrect estimates of biogas production, which depend on volatile solids (Anna, 2010). The maximum TS (sample 4) was measured in 3 year old cactus, where as the minimum TS were measured from <1 year old cactus (Table 2). This may show that 3 year old cactus contain more total solids compared to other samples, but the biodegradiabilty of the sample were determined by analyzing the volatile content of substrates. The total solid content of all sample before AD was between 4.7% (i.e., 4.7 gram of TS from 100 gram sample) and 13.0%. From Table 2, the total solid content (TS) of each sample cactus (<1, 1, 2 and 3 years old) were 4.7, 7.0, 9.5 and 13%. And the standard error of the mean was 1.78 (Appendix F). According to Sasse, (1988) and Nijaguna (2002) biogas digesters generally follow a wet anaerobic condition process with an optimal total solid (TS) content of 5 to 10%. Except the last sample (TS=13%) all sampleas were allmost under optimal condition. And Out of the total solid the volatile solid (VS) were 80.8, 74.3, 73.7, 69.2, respectively. And the standard error of the mean was 2.39 (Appendix F). This indicated that large fraction of cactus is biodegradable and thus it can serve as an important feedstock for biogas production. The carbon to nitrogen ratio of the feed stocks is another factor that affects the anaerobic digestion process. Methane yield and its production rates are highly influenced by the balance of carbon and nitrogen in the feeding material. The percent degradation of organic carbon for <1 year old cactus (44.9) was higher than all (from 38.4 to 41.37) (Table 2).

The results also revealed that there are differences in percentage organic carbon between samples. Comparison of %C showed that %C significantly decreased when the age of cactus increases. And the standard error of the mean was 1.34 (Appendix F). The nitrogen content of treatment were 1.3, 0.92, 0.83 and 0.72% And the standard error of the mean was 0.12 (Appendix F). And the C/N were 34.5, 44.9, 49.3 and 53.3 for Sample 1, 2, 3 and 4. And the standard error of the mean was 4.0 (Appendix F). The C/N of all samples does not agree with the sugessted value 20:1 to 30:1 as reported by Dahlman and Forst (2001) cited in Yitayal Addis (2011), This indicates that cactus needs additional substrate to minimize its C/N ratio to the optimum level. From table 2, the standard error of the mean were 1.78, 1.78, 2.39, 1.34, 0.12 and 4.0 (Appendix F). For moisture content (MC), total solid (TS), volatile solid (VS), carbon (C), nitrogen (N) and carbon to nitrogen ratio (C/N), respectivly. This indicated that C/N ratio and volatile solid content (4.0 and 2.39 SE) were relativly higher difference between means and nitrogen content (0.12 SE) was the lowest stsndard error between means this indicated that there was a minimum difference between means of each sample.

4.2. Characteristics of digesters (Tempreture and pH)

Temperature and pH are the main factors that affect bio-digestion. Consequently, the temperature were adjusted at 27^{o}C for the treatments T1, T3, T5,T7 and 37^{o}C for the treatments T2, T4, T6, T8. From the expermental result treatments those treated in 37^{o}C (T2 (49% CH4), T4 (45% CH4), T6(40% CH4) and T8 (40% CH4)) produced higher amount methane when compered to other corrosponding treatments T1, T3,T5 and T7 those treated in 27^{o}C. Producing biogas in a tempreture of 37^{o}C was much better than producing in 27^{o}C but it need more energy to heat the digester. The pH of each digester were also adjusted 6.8 at the beginning of the digestion process as indicated in sub topic 3.9. The pH of all the treatments came down at the end of the digestion period. This may be due to the formation of acids by acidogenic bacteria, the pH of the treatments were adjusted once before starting the digestion at 6.8 and after digestion the pH of the treatment were T1=5.1, T2=5.5, T3=4.7, T4=5.4, T5=4.2, T6=4.6, T7=4.5, T8=4.8. The relative higest value of the out put pH was the indication of the digestion of volatile acid and nitrogen compounds, and more methane was produced.

4.3. Amount and Quality of biogas production

Biogas production and its methane content were measured for about 45 days of digestion period until gas production was stopped. It was found that treatment T4 produced the highest (900 ml) of gas in the first 20 days of digestion, the methane% is zero for all treatments for the first 15 days, But the other gases were produced in the first five days those are CO_2, O_2, H_2S (<10ppm) and the balance were atmospheric nitrogen. This indicates that feed stock (cactus) were not satble for biogas production until day 20.

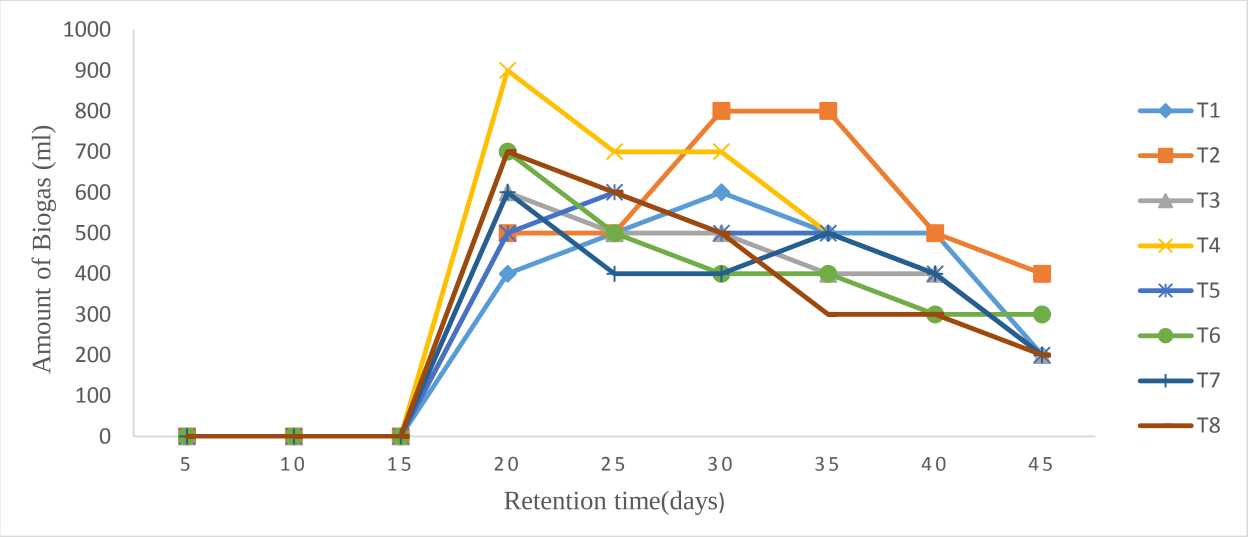

Figure 7. Biogas production comparisim between treatments

Figure 7 shows the amount of biogas (ml) produced in the whole digestion period. 2700ml, 3500ml, 2600ml, 3400ml, 2700ml, 2600ml, 2500ml and 2600ml of the total biogas produced in T1, T2, T3, T4, T5, T6, T7, and T8, respectively in the whole fermentation period. The standard diviation were 137.84, 172.24, 136.62, 250.33, 137.84, 150.55, 132.91, 196.63 (Appendix F) for T1, T2, T3, T4, T5, T6, T7 and T8, respectivly. From the result the highest standrd diviation scored in T4 (250.33 Std. Diviation) which means there were the highest volume variation between measured days in test four. The amount of biogas with in six treatment (T1, T3, T5, T6 , T7 and T8) were 2500ml to 2700ml, these indecated that the volume of biogas of the treatments were not highely affected by the controled parameters (age and temperature), but the two treatments T2 and T4 gives the higher amounts of bio gas (3500ml and 3400ml) than other treatments. And also T2 (<1 year cactus at 37^{o}C) produced the maximum of average methane percentage 49% and T4

(1 year cactus at $37^{o}C$) was 45%. The maximum methane percentage were measured at day 30 for treatmets T1 up to T4 and day 35 for the remainnig four treatments. This indicated that <1 and 1years old cactus were stable early. The lag phase was observed at the beginning of the experiment, because the cactus need time for stablization , the digester starts producing methane at day 20 but it was very small (31.5%-47.8%) and it increased and reached its maximum value in day 30 to 35 and then decreased (29.9%) at day 45. The biogas production was stopped at day 45. The low methane content suggests a higher hydrolytic-acidogenic activity than methanogenic activity in the reactors. In such cases different mechanisms were used to improve the quality of biogas. Absorbing (scrubbing) the CO_2 by basic substances: lime, sodium hydroxide or potassium hydroxide was the mechanisim that maximized the gas quality and the gas burn easily.

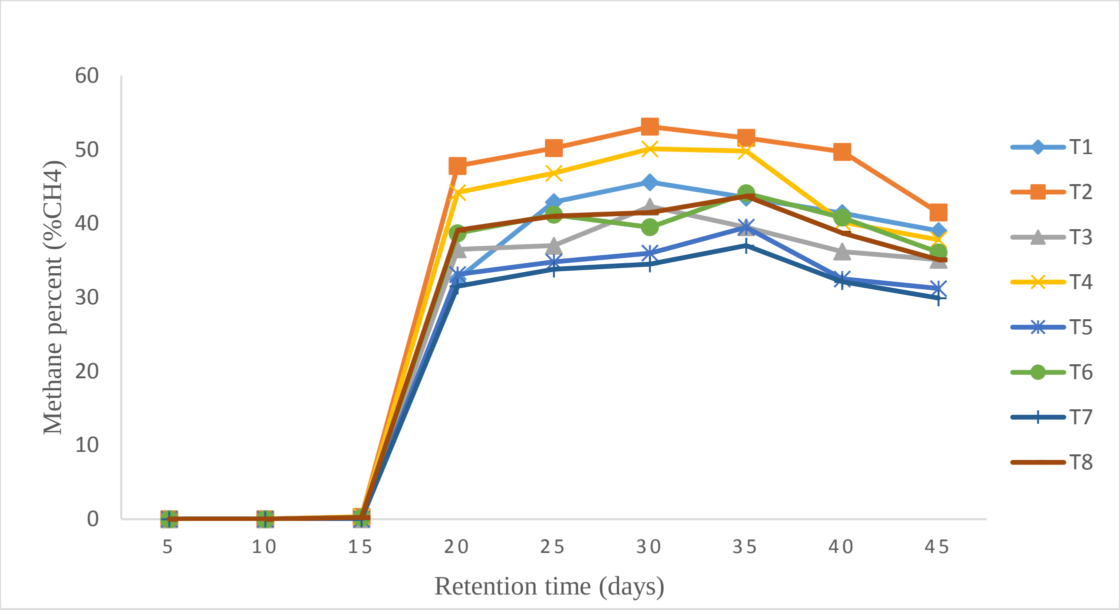

Figure 8. Percentage of methane in each treatment

The percentage methane was between 33% to 49% (Figure 8). T2 scored total higest overall average percentage of methane (49%) the other tretments were 41%, 38%, 45%, 35%, 40%, 33% and 40% for T1, T3, T4, T5, T6, T7 and T8. And the standared eroor of the mean and standard diviation were 1.89, 1.66, 1.08, 2.06, 1.21, 1.09, 1.02, 1.2 and 4.63, 4.07, 2.65, 5.05, 2.97, 2.68, 2.50 and 2.94 (Appendix F) for T1, T2, T3, T4, T5, T6, T7 and T8, respectivly. From the above standard error of the mean and standard diviation 2.06 and 1.8 for T4 and T2 were the highest standard error this shows that this two treatments (T4 and T2) were the highest methane percentage when comperd to the other treatments. This variation also showed in standard diviation of the treatments 5.05 and 4.63 (T4 and T2) were the highest. The overall methane percentage was between 33% to 49% during the whole digestion period. The Value of the percentage of methane of five treatments (T1, T2, T4, T6 and T8) in this experiment is almost similar to the value (40 to 80) suggested by Stewart et al. (1984) Cited in Elias jigar et al.(2011).

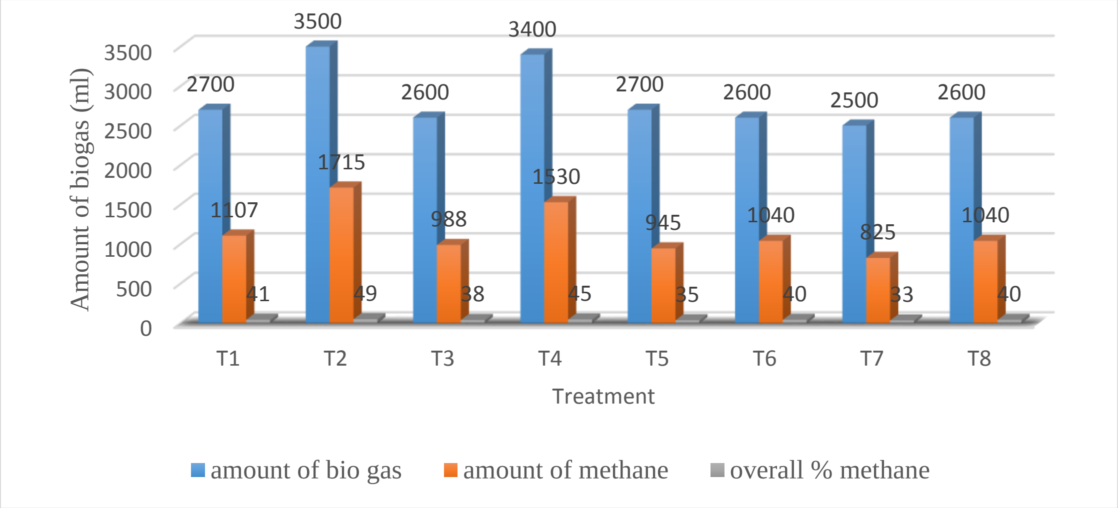

Figure 9. The total biogas, methane and its overall percentage of treatments

4.4. Comparison of treatments

Figure 9 indicate that the total gas production and the percentage of methane of treatments (T2 and T4) were greater than those of the corresponding treatments. For the first 15 days of fermentation period all treatments produced gas that have no methane and it containes CO_2, O_2, <10ppm H_2S and the balance atmospheric nitrogen (Appendix A), after 15 days of lage phase the digester starts producing methane. T2 produced more than other treatments in day 20. The average methane quality was high in T2 (49%) and T4 (45%). The other treatments it is between 33 to 41%. These significant variations in the amount, quality and rate of biogas production may be due to the feedstock difference (different concentration and amount of volatile solid) and difference in tempreture.

In this experiment the average temperature of tropical area of the country that was 27°C was possible to produce biogas, but it needs optimization for better methane yield, there are different techniques that can be used to increase the quality of biogas, controling the tempreture fluctuation was one method as reported by D. Fulford, (2001) and B.T. Nijaguna. (2002), insulation was the method that used to control the temprature fluctuation, when the digester was worked on at atmosheric temprature or the heating system was inside the digester, insulation of the batch biogas digester was required to achieve mesophilic temperature for maximum biogas production as reported by Patrick Mukumba, Golden Makaka and Chipo Shonhiwa (2015). To provide good insulation of the reactor constracting underground digester was one alternatives becouse the temperature 1 meter below the ground is almost constant according to philp and itodo (2007). And also in order to increase the biogas quality and quantity, co-digestion with other feed stock (cow dung for example) Stated by (elias jigar et al, 2011) was an alternative.

4.5. Energy Determination

Pure methane has an upper calorific values of 39.8 MJ/m^3, which corresponds to 11.06 kWh/m^3. From the data the amount of pure methane were calculated by multiplying the bio gas volume by methane percentage and the value were 0.012KWh, 0.018KWh, 0.011KWh, 0.017KWh, 0.01KWh, 0.012KWh, 0.009KWh and 0.012KWh for T1, T2, T3, T4, T5, T6, T7 and T8 as indicated in Figure 11. Figure shows that T2 produced the higher amount of energy when comparing to other treatments which was 0.018 KWh from 0.001715m^3 (1.715liter) of pure methane.

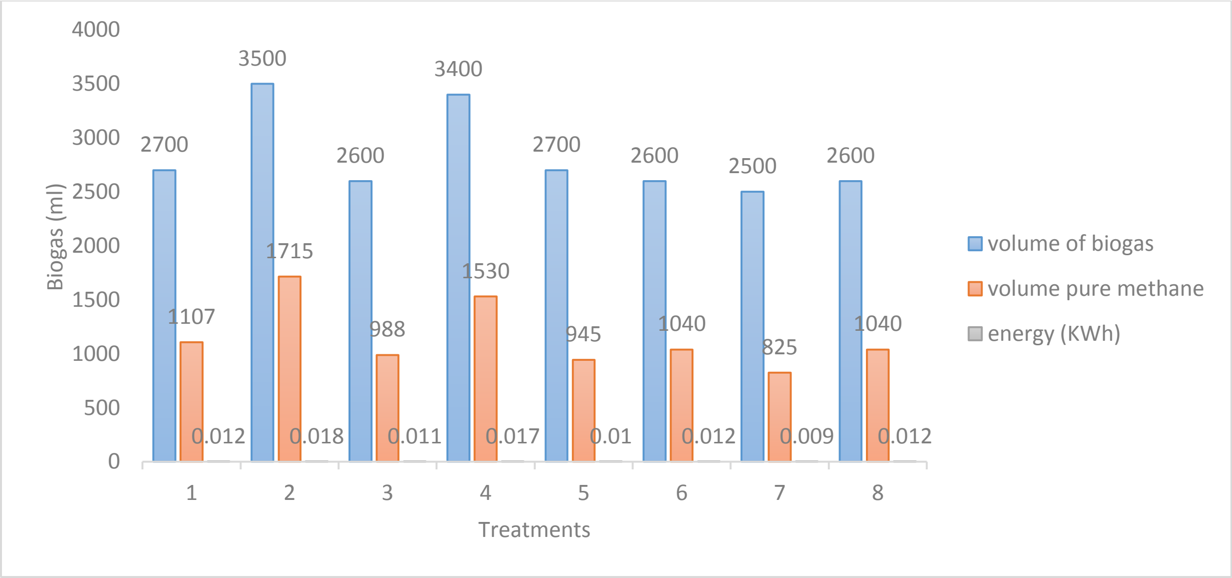

Figure 10. Volume of gas, volume of pure methane and equivalent energy

4.6. Characterization of Digestate (slurry)

One advantage of anaerobic digestion is the use of the digestate (slurry). To characterize the digestate tests were done two times and the mean values were indicated, total solid (TS) were 2.3%, 2.1%, 3.6%, 3.2%, 5.1%, 4.3%, 5.4 and 6.8% and volatile solid (VS) were 6.1%, 5.2%,12.5%, 11.3%, 13.2%, 12.4%, 15.1% and 14.7% for treatment T1, T2, T3, T4, T5, T6, T7 and T8. According to Joenssen et al (2004) anaerobic digestion only removes organics and the main mineral material and almost all nutrients remain in the bottom sludge, the result indicated that organics are decomposed. After digestion , the PH of the slurry were 5.5, 5.1, 5.4, 4.7, 4.2, 4.6, 4.5, 4.3. for T1, T2, T3, T4, T5, T6, T7 and T8 respectively. The pH of the slurry of T1-T4 were higher than other treatments that revealed the four treatments (T1-T4) were better in methanoginesis procees (had high in conversion of acetic acid to methane). According to Rodrigo Morales (2010) the slurry was water nitrogen and can be used for watering the cactus. And the solid digestate can be used for forage by mixing with flour of earth warms.

5. Conclusion and Recommendations

5.1. Conclusion

According to a study conducted 15 years ago, Ethiopia has 120,000 hectare of wild cactus potential (FOTUNE weekly newspaper (2007)), In Tigray region it is estimated that there is over 49,552 ha covered with cactus trees and total annual production is estimated at around 342,136.4 tons of cactus pear. This shows that Cactus is well adapted to arid and semi-arid zones of the country. From the results it can be realized that cactus could be used as a substrate for biogas production at a controled temperature of 27°C and 37°C. the pH of the cactus was acidic. In this regard, the pH of all the digesters of treatments were not in the range of optimal level 6.25 to7.5, suitable for most methanogenic bacteria to function for biogas production so it has to be adjusted at optimum level. The total solid content (TS) of each cactus were between 4.7 to 13%. sampleas were allmost under optimal except one total solid (TS) content of 5 to 10% According to Sasse, (1988); Nijaguna (2002). And Out of the total solid the volatile solid (VS) were between 69.2% to 80.8%. This indicated that large fraction of cactus is biodegradable and thus it can serve as an important feedstock for biogas production. The cactus biomass is highly organic having less nitrogen, therefore it might need feed stocks which are rich in nitrogen if used as substrate for biogas production. Less than one year Cactus at 37°C gaves highest volume of biogas with quality relative to other treatments. Before starting methane production the digester waits for 20 days. This indicates that the cactus need at least 20 days for stabilization (start to produce methane).

5.2. Recommendations

- The codigestion of cactus in different proportions with other feed stock, especialy the feed stock those have less C:N ratio need to be studied.
- The fertilizing value (mineral and micro-nutrient content) of cactus slurry should be studied.
- The biogas production from cactus need additional studies to improve thae gas yield.
- Awareness and skill development training on the sustainable use of cactus as additonal substrate for biogas production for users and organizations is essential.
- The stabilization time of cactus in different geographical and climatic areas should be studied.
- The production of biogas from cactus should be studed in Thermophilic (>45°C) condition.

6. Reference

Ann C. Wilkie (2008), bio methane from bio mass, bio waste and biofuel, J.Well et al. Washington DC.

Armada Rodiguez-Felix and Cantwell (1987), developmental change in composition and quality of prickly pear cactus cladodes (nopalitos), center for food research and development, Hermosillo, Mexico,

B.T. Nijaguna (2002), Biogas Technology (New Age International (P) Limited, Publishers, New Delhi.

Bruce Dorminey (2014), Prickly Pear Cactus: Nuisance or Bioenergy Opportunity, renewable energy world.com

Cantwell, M., A. Rodriguez-Felix, and Robels-Contreras.1992.Postharvest Physiology of prikly pear cactus stem. Sci hort.50:1-9

Dahlman J, Forst C. (2001) Technologies demonstrated at echo. Floating drum biogas digester; echo, 17391 Durance Rd, North Ft. Myers FL 33917, USA.

Davis, S.C., Hay, W. & Pierce, J. (2014), Biomass in the energy industry: an introduction.

D. Fulford (2001), Running a Biogas Program, (ITDG Publishing, UK.

Ethiopian National Biogas Program (2007).

Ethiopian National Energy Policy (2012).

Elias Jigar et al. (2011), Study on Renewable Biogas Energy Production from Cladodes of Opuntia ficus-indica. ISABB Journal of Food and Agriculture Science Vol. 1(3), pp. 44-48,

Fesseha Yaye Dulume (2010), cactus based development In Tigray and experience from Mexico, Tigray Bureau of Agriculture and Rural Development, cactusnet newsletter

Gebremeskel Gebretsadik et al. (2013), Assessment of the potential of cactus pear (Opuntia ficus indica) as livestock feed in Northern Ethiopia, School of Animal and Range Sciences, Haramaya University, livestock research for rural development 25(2)2013.

Gutterer, B. (Editor) (2009): Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries. Loughborough University (UK): Water Engineering and Development Centre (WEDC).

Habtu L 2005 Cactus in southern Tigray: Current status, potential uses, utilization and threat. M.Sc. Thesis, Addis Ababa University

Joensson, H.; Richert, A.; Vinneraas, B.; Salomon, E. (2004): Guidelines on the Use of Urine and Faeces in Crop Production. (Ecosanres Publications Series, 2004). Stockholm:

Jenssen, P.D.; Greatorex, J.M.; Warner, W. S. (Editor) (2004): Sustainable Wastewater Management in Urban Areas (=Kapitel 4. Kurs WH33, Konzeptionen dezentralisierter Abwasserreinigung und Stoffstrom management). Hannover: University of Hannover.

Karekezi, Lata and Coelho 2004, traditional biomass energy improving its use and moving to modern energy use, international conference for energies, Bonn

Ljupka Arsova (2010), anaerobic digestion of food waste Current status, problems and an alternative product, Department of Earth and Environmental Engineering Fu Foundation of Engineering and Applied Science Columbia University.

Lucy F. R. Montgomery and Günther bochmann (2014), Pretreatment of feedstock for enhanced biogas production, IEA Bioenergy

Mazumdar, A. (1982): Biogas Handbook. Consolidation of Information. Paris: United Nation Educational, Scientific and Cultural Organization (UNESCO).

Nijaguna, B. T. (2002): Biogas Technology. New Delhi: New Age International (P) Ltd.

Neumann L (1997) Opening speech. In: Proceedings of the International Workshop on "*Opuntia* in Ethiopia: State of Knowledge in *Opuntia* Research" February 23-27, 1997, Mekelle University, Ethiopia and Wiesbaden Polytechnic, Germany, pp 5-9

Patrick Mukumba, Golden Makaka and Chipo Shonhiwa (2015), An assessment of the performance of a biogas digester when insulated with sawdust, International Journal of Energy and Power Engineering 2015; 4(2): 24-31

Peter Jacob Jørgensen (2009), Plan Energy and Researcher for a Day, 2nd edition, Faculty of Agricultural Sciences, Aarhus University.

Rai GD. (2004), Non-conventional energy resources, 2nd edn, Khpu Khanna, India.pp331-337,369.

Rogner H, Popescu A. (2004) World Energy Assessment. Energy and the Challenge of Sustainability. An Introduction to Energy, part I,

Rose Chiteva and Norman Wairag (2013), Chemical and nutritional content of Opuntiaficus-indica(L.), kenya forestry research institute (kefri), forest products research center, karura,nairobi, Kenya

Sasse, L. (1988): Biogas Plants. German Appropriate Technology Exchange (GATE) and German Agency for Technical Cooperation (GTZ) gmbh.

Sameer Maithel (2009), Biomass Energy Resource Assessment Handbook, Prepared for APCTT,

Sari Luostarinen, Argo Normak & Mats Edströmm (2011), knowledge report, Overview of Biogas Technology, WP6 Energy potentials.

Sundar Bajgain and Indira (Sthapit) Shakya (2005), the Nepal biogas support program: a successful model of public private partnership for rural household energy supply, Ministry of Foreign Affairs. The Netherlands, SNV-Netherlands Development Organization, Biogas Sector Partnership Nepal.

Teame Gebrekidan, Meseret C. Egigu and manikandan Muthuswamy (2014), Efficiency of biogas production from cactus fruit peel co- digestion with cow dung, Department of biology, Haremaya University, Haramaya, Ethiopia, international journal of advanced research.

UNDP (2000), world energy assessment, United Nations Development Program Bureau for Development policy one United Nations Plaza New York, NY 10017.

Yitayal Addis (2011), study on biogas energy production from leaves of justicia schimperiana (hochst.ex a. Nees) t. Anders. MSc. Thesis, Addis Ababa University, unpublished.

Website sources

www.biodiesel.org/pdf_files/fuelfactsheets/Production.

www.elquiglobalenergy.com

www.epa.gov/chp/basic/catalog.html#biomasscat

www.epa.gov/agstar/operational.html.

www.nrel.gov/biomass/pdfs/40742.pdf.

www.nrel.gov/news/press/2007

7. Appendix

Appendix A. Amount and Quality of biogas in every measured day.

Day	<1		1		2		3	
	27^{o}c	37^{o}c	27^{o}c	37^{o}c	27^{o}c	37^{o}c	27^{o}c	37^{o}c
5 24-02-2016	CH_4=0.0 CO_2=9.5 O_2=12.7 500ml	CH_4=0.0 CO_2=20.6 O_2=18.7 700ml	CH_4=0.0 CO_2=33.9 O_2=6.0 500ml	CH_4=0.0 CO_2=18.7 O_2=11.7 800ml	CH_4=0.0 CO_2=28 O_2=6.5 700ml	CH_4=0.0 CO_2=20.7 O_2=11.5 800ml	CH_4=0.0 CO_2=21.5 O_2=10.3 600ml	CH_4=0.0 CO_2=11.9 O_2=14.5 500ml
10 29-02-2016	CH_4=0.0 CO_2=20.2 O_2 = 6.9 800ml	CH_4=0.0 CO_2=18.4 O_2=7.7 600ml	CH_4=0.0 CO_2=20.6 O_2=9.0 900ml	CH_4=0.0 CO_2=22.5 O_2=6.2 900ml	CH_4=0.0 CO_2=28.9 O_2=5.3 400ml	CH_4=0.0 CO_2=17.3 O_2=7.3 500ml	CH_4=0.0 CO_2=30.5 O_2=7.8 600ml	CH_4=0.0 CO_2=36.2 O_2=8.3 800ml
15 05-03-2016	CH_4=0.2 CO_2=23.1 O_2=13 600ml	CH_4=0.3 CO_2=25.1 O_2=10.2 700ml	CH_4=0.0 CO_2=14.1 O_2=8.8 800ml	CH_4=0.3 CO_2=53.1 O_2=1.5 600ml	CH_4=0.0 CO_2=29.0 O_2=6.1 400ml	CH_4=0.2 CO_2=16.3 O_2=12.8 700ml	CH_4=0.0 CO_2=30.5 O_2=18.0 400ml	CH_4=0.2 CO_2=38.2 O_2=6.8 500ml
20 10-03-2016	CH_4=32.5 CO_2=27.1 O_2=6.2 400ml	CH_4=47.8 CO_2=30.0 O_2=5.4 500ml	CH_4=36.5 CO_2=27.3 O_2=6.5 600ml	CH_4=44.2 CO_2=32.2 O_2=7.5 900ml	CH_4=33.1 CO_2=29.4 O_2=8.3 500ml	CH_4=38.7 CO_2=28.6 O_2=9.2 700ml	CH_4=31.5 CO_2=32.1 O_2=15.2 600ml	CH_4=39.1 CO_2=26.9 O_2=13.2 700ml

25 15-03-2016	$CH_4=42.9$ $CO_2=28.2$ $O_2=7.5$ 500ml	$CH_4=50.2$ $CO_2=28.5$ $O_2=3.2$ 500ml	$CH_4=37$ $CO_2=24.2$ $O_2=7.2$ 500ml	$CH_4=46.8$ $CO_2=28.2$ $O_2=5.5$ 700ml	$CH_4=34.8$ $CO_2=32.1$ $O_2=5.8$ 600ml	$CH_4=41.2$ $CO_2=29.7$ $O_2=6.2$ 500ml	$CH_4=33.8$ $CO_2=27.3$ $O_2=7.5$ 400ml	$CH_4=41$ $CO_2=29.4$ $O_2=6.8$ 600ml
30 20-03-2016	$CH_4=45.6$ $CO_2=29.5$ $O_2=3.2$ 600ml	$CH_4=53.1$ $CO_2=19.6$ $O_2=5.3$ 800ml	$CH_4=42.3$ $CO_2=35.2$ $O_2=6.5$ 500ml	$CH_4=50.1$ $CO_2=28.7$ $O_2=6.4$ 700ml	$CH_4=36$ $CO_2=24.5$ $O_2=6.8$ 500ml	$CH_4=39.5$ $CO_2=25.1$ $O_2=6.2$ 400ml	$CH_4=34.5$ $CO_2=29.3$ $O_2=7.2$ 400ml	$CH_4=41.5$ $CO_2=28.4$ $O_2=5.8$ 500ml
35 25-03-2016	$CH_4=43.5$ $CO_2=27.1$ $O_2=4.2$ 500ml	$CH_4=51.6$ $CO_2=29.8$ $O_2=8.3$ 800ml	$CH_4=39.5$ $CO_2=28.5$ $O_2=7.1$ 400ml	$CH_4=49.8$ $CO_2=21.2$ $O_2=5.5$ 500ml	$CH_4=39.5$ $CO_2=29.4$ $O_2=7.3$ 500ml	$CH_4=44.1$ $CO_2=27.5$ $O_2=6.2$ 400ml	$CH_4=37$ $CO_2=28.9$ $O_2=5.4$ 500ml	$CH_4=43.7$ $CO_2=28.7$ $O_2=6.1$ 300ml
40 30-03-2016	$CH_4=41.4$ $CO_2=32.4$ $O_2=3.5$ 500ml	$CH_4=49.7$ $CO_2=35.8$ $O_2=9.2$ 500ml	$CH_4=36.2$ $CO_2=29.6$ $O_2=6.8$ 400ml	$CH_4=40.2$ $CO_2=29.5$ $O_2=6.1$ 400ml	$CH_4=32.5$ $CO_2=28.4$ $O_2=5.1$ 400ml	$CH_4=40.8$ $CO_2=28.1$ $O_2=6.0$ 300ml	$CH_4=32.1$ $CO_2=29.8$ $O_2=6.2$ 400ml	$CH_4=38.7$ $CO_2=28.0$ $O_2=7.1$ 300ml
45 05-04-2016	$CH_4=39$ $CO_2=30.4$ $O_2=4.2$ 200ml	$CH_4=41.5$ $CO_2=28.7$ $O_2=6.5$ 400ml	$CH_4=35.1$ $CO_2=30.4$ $O_2=5.6$ 200ml	$CH_4=37.8$ $CO_2=27.6$ $O_2=4.7$ 200ml	$CH_4=31.2$ $CO_2=30.4$ $O_2=3.8$ 200ml	$CH_4=36.1$ $CO_2=32.7$ $O_2=5.4$ 300ml	$CH_4=29.9$ $CO_2=36.2$ $O_2=4.9$ 200ml	$CH_4=35.1$ $CO_2=31.1$ $O_2=6.5$ 200ml

Appendix B. Amount of biogas after day 20.

Amount of bio gas (ml)								
Days	Treatments							
	T1	T2	T3	T4	T5	T6	T7	T8
20	400	500	600	900	500	700	600	700
25	500	500	500	700	600	500	400	600
30	600	800	500	700	500	400	400	500
35	500	800	400	500	500	400	500	300
40	500	500	400	400	400	300	400	300
45	200	400	200	200	200	300	200	200
Total	2700	3500	2600	3400	2700	2600	2500	2600

Appendix C. Quality of methane (%)

Quality of methane (%)								
Days	Treatments							
	T1	T2	T3	T4	T5	T6	T7	T8
20	32.5	47.8	36.5	44.2	33.1	38.7	31.5	39.1
25	42.9	50.2	37	46.8	34.8	41.2	33.8	41
30	45.6*	53.1*	42.3*	50.1*	36	39.5	34.5	41.5
35	43.5	51.6	39.5	49.8	39.5*	44.1*	37*	43.7*
40	41.4	49.7	36.2	40.2	32.5	40.8	32.1	38.7
45	39	41.5	35.1	37.8	31.2	36.1	29.9	35.1
Average	41	49	38	45	35	40	33	40

*. The peak value

Appendix D. Methane value (ml) each of 5 days.

	day (20)	day (25)	day (30)	day (35)	day (40)	day (45)	Average methane (ml)
T1	130	214.5	273.6	217.5	207	78	186.7666667
T2	239	251	424.8	412.8	248.5	166	290.35
T3	219	185	211.5	158	144.8	70.2	164.75
T4	397.8	327.6	350.7	249	160.8	75.6	260.25
T5	165.5	208.8	180	197.5	130	62.4	157.3666667
T6	270.9	206	158	176.4	122.4	108.3	173.6666667
T7	189	135.2	138	185	128.4	59.8	139.2333333
T8	273.7	246	207.5	131.1	116.1	70.2	174.1

Appendix E. Energy Equivalent

Total bio gas produced (ml)	Methane (ml)	Methane (m^3)	Conversion factor (KWh/m^3)	Energy (KWh)
2700	1107	0.001107	11.06	0.01224342
3500	1715	0.001715	11.06	0.0189679
2600	988	0.000988	11.06	0.01092728
3400	1530	0.00153	11.06	0.0169218
2700	945	0.000945	11.06	0.0104517
2600	1040	0.00104	11.06	0.0115024
2500	825	0.000825	11.06	0.0091245
2600	1040	0.00104	11.06	0.0115024

Appendix F. Statistical output

Statistical output of feed stock characteristics

		Moisture content	Total solid	Volatile solid	Ash content	Carbon content	Nitrogen content	Carbon to Nitrogen ratio
N	Valid	4	4	4	4	4	4	4
	Missing	0	0	0	0	0	0	0
Mean		91.4500	8.5500	74.5000	25.4750	41.3750	.9425	45.5000
Std. Error of Mean		1.77787	1.77787	2.38851	2.41052	1.33876	.12599	4.04804

Statistical output between treatments (comparison by volume of biogas)

Treatment	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
T1	6	200.00	600.00	450.0000	56.27314	137.84049	19000.000
T2	6	400.00	800.00	583.3333	70.31674	172.24014	29666.667
T3	6	200.00	600.00	433.3333	55.77734	136.62601	18666.667
T4	6	200.00	900.00	566.6667	102.19806	250.33311	62666.667
T5	6	200.00	600.00	450.0000	56.27314	137.84049	19000.000
T6	6	300.00	700.00	433.3333	61.46363	150.55453	22666.667
T7	6	200.00	600.00	416.6667	54.26274	132.91601	17666.667
T8	6	200.00	700.00	433.3333	80.27730	196.63842	38666.667
Valid N (list wise)	6						

Statistical output between treatments (comparison by percentage of methane of biogas)

Treatments	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
T1	6	32.50	45.60	40.8167	1.89058	4.63095
T2	6	41.50	53.10	48.9833	1.66522	4.07893
T3	6	35.10	42.30	37.7667	1.08495	2.65757
T4	6	37.80	50.10	44.8167	2.06243	5.05190
T5	6	31.20	39.50	34.5167	1.21365	2.97282
T6	6	36.10	44.10	40.0667	1.09565	2.68378
T7	6	29.90	37.00	33.1333	1.02394	2.50812
T8	6	35.10	43.70	39.8500	1.20160	2.94330
Valid N (list wise)	6					