Waste Management Strategies for University Campus: A case study on Plant Leaves

A DISSERTATION

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Submitted By

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CANDIDATE'S DECLARATION

I, Neetal Gotra, Roll No. 2K17/THE/07, student of M.Tech (Thermal Engineering), hereby declare that the project Dissertation titled "Waste Management Strategies for University Campus : A case study on Plant Leaves" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology in Thermal Engineering, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Waste Management Strategies for University Campus : A case study on Plant Leaves" which is submitted by Neetal Gotra, Roll No. 2K17/THE/07 [Thermal Engineering], Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

Place: Delhi — Prof. Amit Pal

Date: — SUPERVISOR

ABSTRACT

There is a high density of people in a university campus at any time along with students, faculty members and other individuals living there. So, a very good opportunity arises to properly manage various organic and inorganic waste generated. The end goal is to effectively implement the 3 R's (Reuse, Reduce and Recycle) so that utilization of various resources can be reduced and the amount of waste generated can be reduced. Different types of waste require their corresponding appropriate strategies to properly manage them.

In this experimental study, effects of organic and inorganic wastes on the environment are studied and proper solutions to the various problems are suggested. After that, survey of various sites is done to understand how the waste management is done at a large scale. The survey of DTU campus is done to estimate the amount of waste generated in the campus and to understand various problems associated with waste management. Long-term analysis of the campus biogas plant is done to see how effectively it is being utilized and finding ways to increase its utilization. Usage of fallen leaves as a potential raw material for biogas production is studied and the effect of leaves on the overall biogas production is studied. Initiatives are taken to utilize the kitchen waste from the faculty apartments as a raw material for biogas production. Some unconventional ways of optimizing and improving the biogas production are looked into and their effect is estimated.

Some simple ways for a sustainable living were suggested which are easy to implement in our daily lives. The tree leaves proved to be a very good raw material for the production of biogas. Fallen leaves which are a breeding ground for snakes, insects, fungi and other reptiles and may act as a fire hazard when used as a raw material for biogas production provided many benefits. Using leaves in biogas plant will drastically reduce the waste especially during autumn season when as much as two trolleys of leaves are transported daily from the university campus. Utilization of faculty kitchen waste will act as a very big source of biomass for biogas production.

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ABBREVIATIONS

HDPE = High Density Polyethylene

LDPE = Low Density Polyethylene

LCFA = Long Chain Fatty Acids

VFA = Volatile Fatty Acids

FVW = Fruit and Vegetable Waste

HRT = Hydraulic Retention Time

CM = Cow Manure

TS = Total Solids

VS = Volatile Solids

COD = Chemical Oxygen Demand

OLR = Organic Loading Rate

CHAPTER 1

Introduction

1.1 Preface

The population of humankind has crossed a staggering 7 billion mark.[1] The unsustainable use of resources and non biodegradable materials by such a large number of people results in the production of a lot of waste which is filling up our landfills, polluting our water bodies, floating in the sea and creating garbage everywhere. There is a considerable damage to the earth's ecosystem due to industrialization and deforestation along with discharge of pollutants into the air, water and land. There is an immediate need to manage the different types of wastes which is increasing every year.

There are a lot of ways to deal with the waste. However, tackling the waste at the source is the best way to manage it. This is due to less transportation involved along with less need of segregation. Biodegradable waste like fruits, vegetables, tree leaves can be easily utilized for biogas production, thereby reducing the total volume of waste to be transported further and decreasing the breeding grounds for various disease causing microbes, flies and mosquitoes. Segregated plastic waste is also easier to recycle so total waste going to the landfills is reduced. Different types of waste are generated on the campus and their collection is not a very difficult job as there are well-defined hot spots where the production of waste is maximum so it can be collected easily for further processing. However, a long-term commitment is required on part of the entire campus community. Continuous investigation of quantities of waste generation, recovery and usage of segregation bins is crucial to the sustainability of suck program. Awareness about the matter from time to time is needed. Adoption of universal color-coded dustbins throughout the campus ensures optimal use of a recycling system. By doing so, people will become accustomed to recognizing bins and how to use them. A proper waste management program is an outcome of collaboration of each individual inside a campus which results in a better life for students, teachers and in general all people who are involved in it.

1.2 Waste Management in India:

Over the last few decades, we have used our natural resources at an unprecedented rate with unsustainable cutting of trees, pollution of water bodies and oceans and have filled various landfills with non bio-degradable waste. However, there is now a renewed sense of sustainability all over the globe in which most of the countries are taking appropriate measures to curb our insatiable hunger of consuming resources and producing waste. India has also taken some official steps in this regard recently with the introduction of Solid Waste Management Rules in 2016 which replaced the Municipal Solid Wastes Management and Handling Rules from year 2000.[2] These rules are designed to reduce the waste going to the landfills and use it in some productive manner. Following are the major points of these rules:

1.2.1 Solid Waste Management Rules (2016): [2]

- Waste separation at the origin is made compulsory which means separation of waste according to their types - Organic or Bio-degradable waste, Dry waste and Domestic Hazardous waste. Moreover, infrastructures as hotels, hospitals, restaurants etc. which produce a lot of waste are required to treat organic waste either in-situ or by collaborating with the local authorities.
- Informal waste pickers and rag pickers are required to be included by municipalities into their waste management process. This is the first instance of its kind that any acknowledgement is given to informal sector into the waste management process by a national policy. Over 1.5 million people in India depend on waste picking for their survival and their incorporation into the official waste management system will increase their income security and the local authorities will have a way to improve and streamline their services.
- For Fast-Moving Consumer goods manufacturers who use non-biodegradable packaging material for their products are required to have a system for the collection of waste generated due to their production.
- Bulk waste generators are now required to collect and process their waste and local authorities are given a power to charge them challan if found violating the policy. Also, on-the-spot fining on people burning garbage or tossing it in a public place can be levied.

- Unrecyclable waste with the calorific value of or above 1,500 Kcal/kg cannot be dropped to land-fills. The waste is now meant to be used for energy generation, production of bio-fuels, utilisation in thermal power plants or to be used in co-processing of cement.[2]

1.2.2 India's Waste Data:

Following data is for urban cities of India which hold a population of 377 million.

Table:-1.1 Data of Waste generated in Urban Cities: [2]

Data	Million Tonnes per year
Municipal Solid Waste	62
Waste Collection	43
Waste Treatment	11.9
Waste dumping in landfills	31

Despite having these laws in place, no actual segregation takes place at a lot of places. No company collects the packaging of their products after it is consumed. A lot of untreated waste is thrown into our rivers polluting their water. Landfills are filled with easily recyclable materials due to lack of segregation. Burning of stubble is rampant despite it being suitable for biogas production, mushroom harvesting, power generation in bio-thermal power plants or simply shredding and spreading it in the field to use as a fertiliser.

Amount of waste produced is increasing every year and the market of waste management market in India is estimated to be around USD 14-16 Billion by 2025 and around USD $20 Billion by 2030 with a 6-8% yearly growth rate.[2]

With India's growing economy, increasing urban population and ever increasing consumption of various resources combined with a rise in the purchasing power parity cause a dramatic increase in the amount of waste generation. There is an immediate need to manage this waste as cities like Delhi are drowning with the waste in landfills, rivers and pollution in air. Examination of waste samples collected from academic institutions, hostels, canteens, shopping malls and residential apartments revealed that utilization of organic waste for energy production such as in biogas generation, optimization of resources by 3R concept (reduce, reuse and recycle) of papers, plastic, cloth, glass, metal, etc. is extremely beneficial in adopting suitable waste management strategy.

1.3 Methanization vs Incineration

Besides methanization of organic materials, incineration is also used to produce energy from the combustion of these materials. In India, there are currently 12 incineration plants of which only 4 are operational. The reason for that is the proper segregation of waste. Most of the household waste is of organic nature like fruit and vegetable waste which gets mixed with dirt and sand due to open dumping of waste and lack of door-to-door collection. Household waste also contains a lot of moisture making it unsuitable for burning. This means that incinerator plants have to burn additional fuel so as to properly burn down the waste which drastically increases the price of electricity produced. Despite these problems, Niti Aayog has proposed to increase the Waste-to-energy plants capacity from the existing 65 MW per day to more than 500 MW by the end of 2019 by constructing additional 47 Waste-to-Energy plants of which 5 are under-construction.[3]

Incinerators tend to produce a lot of fly-ash and foul smell during their operation which is not good for the local population. High-tech incinerators are comparatively more efficient as they can recover heat energy from chimneys, cooling circuits and engines etc. They also are less polluting as they use various filtration devices like cyclone filters, electrostatic filters to reduce the fly-ash and foul smell. But they are beneficial only if they are supplied with a good quality dry inorganic non-recyclable raw material. Various countries like France, Sweden and China etc. make very good use of incinerators to produce energy as they specifically import the required raw material for them. However in India, due to lack of proper planning, a lot of money is being wasted on their construction when the existing ones are non-operational. If not properly operated, incinerators produce a lot of dioxins, heavy metals and other harmful gases adding additional pollution to the already choked cities of India.

Incinerators are meant to be served alongside landfills as they can reduce the waste going to landfills but they are not an effective solution to the problem of waste management as they produce too much pollution and their end-products are still harmful to the environment.

1.3.1 Advantages of Incineration:

(a) Reduces waste quantity: If proper waste is incinerated, the end-products are generally 5-30% of the original mass.

(b) Production of energy: They can produce appreciable amounts of heat energy which can be used to produce electricity.

(c) Reduce leaching to groundwater: Landfills are notorious for polluting the ground water as the moisture content present in landfills percolate into the groundwater polluting it with excessive metallic salts, heavy metals and other pollutants.

(d) Reduction in transportation: Due to decreased volume and mass of burnt waste, transportation costs are reduced which indirectly also reduces the pollution from transportation vehicles.

(e) Eliminates microbial growth: Landfills are home to various types of disease causing microbes as they feed on organic material. Incinerating the waste kills the microbes and prevent microbial growth in the future.

(f) Metal recycling: Metals are not burnt during incineration which can be separated from the burnt matter by magnetic separation, gravity separation or hand-picking easily.

1.3.2 Disadvantages of Incineration:

(a) Incineration is expensive: The construction and operation of an incinerator is an expensive task. Besides that, it may not even recover its installation cost during its operating life.

(b) Pollutes the environment: It creates a lot of pollution which forbids its installation near residential areas. Still, damage to the nearby flora and fauna due to fly ash and repulsive smell is too much to consider them as a viable long-term solution to waste-disposal.

(c) Long-term effects: Incineration of waste does not encourage people to reduce and segregate their waste. This also decreases the recycling of waste which can cause accumulation of waste and rise in pollution over a long-term.

So instead of incineration, people should be made aware about composting, recycling, reducing the use of problematic materials. In various developed countries like Japan, people are expected to collect their waste in different bins according to their recyclability and different days are assigned for the collection of the different bins which creates a very effective ecosystem of waste management.

1.4 Dissertation's Topics Layout:

The topics which are discussed in each chapter are listed below:

In Chapter 1, the general introduction about the need of waste management and the current state of waste management in India is discussed.

In Chapter 2, literature review related to organic waste management is done.

In Chapter 3, effects of organic wastes on the environment are studied as organic bio-degradable waste is often considered harmless to the environment.

In Chapter 4, sources of in-organic wastes and their effects on the environment are studied. Some simple solutions are also suggested to reduce these wastes.

In Chapter 5, biogas production process and the physical and chemical requirements of it are studied. Design parameters, commonly used types of biogas plants and methanisation benefits over incineration are also studied.

In Chapter 6, DTU Campus Biogas Plant parameters are studied and the testing of dried leaves as a raw material for the production of biogas is done.

In Chapter 7, testing of green grass and leaves as a raw material for the production of biogas is done

In Chapter 8, survey of some major sites was done to understand how the organic waste management is done at a large scale.

In Chapter 9, some alternative ways which can dramatically improve the yield and composition of biogas of existing biogas plants are studied.

In Chapter 10, conclusion of the study is done and future scope of projects are suggested.

CHAPTER 2

Organic Wastes Problems

2.1 Introduction

Materials that are naturally broken down in the environment by the action of bacteria, fungi, spores or are consumed by big animals and get digested to harmless by-products are called bio-degradable materials and the waste of such nature is called bio-degradable waste. These are naturally created in the environment by nearly every living thing during its life cycle and such waste is then taken by other organisms as their food material which themselves create waste and the cycle continues. The bio-degradable wastes produced naturally are created in a balanced manner and the amount corresponding to the flora and fauna of that ecosystem. But when excess of such waste is added to that ecosystem, that waste acts as a food for a particular species causing its population to grow unsustainably affecting the whole food-web with it. In this chapter, the effects of bio-degradable wastes on our water bodies, environment and general well being are studied.

2.2 Effects of Bio-Degradable wastes

In pursuit of handling non bio-degradable wastes, we often disregard bio-degradable wastes and their impact on the environment. Though these wastes are naturally degraded by the action of fungi, bacteria, spores or other micro-organisms, they still exhibit a great deal of damage to the environment due to the sheer volume they are produced each day and with little management they are handled.

Following are some of the ways in which these wastes impact us and the environment:

(a) Stagnant biodegradable wastes gives off foul smell which is undesirable

(b) A lot of bio-degradable wastes emit greenhouse gases such as methane, carbon dioxide, etc. when they are being broken down which are detrimental to the environment.

(c) They are a breeding ground for mosquitoes, rats, fungi etc.

(d) They pollute nearby water sources due to excess nitrogen and other toxins leaching into the water.

(e) Heaps of bio-degradable waste cause a large number of microbes to grow which cause diseases in humans, plants and animals.

2.3 Bio-Degradable Wastes in Landfills

Bio-degradable products generally let us believe that they are good for the environment but we forget that they need certain conditions to degrade properly like food waste needs soil and water to get properly assimilated in the ground and become organic fertiliser.

But when bio-degradable waste gets dumped in landfills, it breaks down quickly in an unnatural manner causing a rapid release of methane which is a very powerful greenhouse gas. It means that if bio-degradable products are getting dumped in the landfills, then they may cause as much harm to the environment as non bio-degradable waste.

So, the ideal way of dealing with bio-degradable waste is to segregate it from the non bio-degradable waste and use it for composting or methane production. Apart from waste management, we should also consider the environment impact these products cause during manufacturing like energy usage and natural resource usage.

2.4 Bio-degradable Plastics:

There is a growing interest in the bio-degradable plastics worldwide as many people have started to realize the harmful effects of plastics. The general requirement of bio-degradable plastics is that they should be broken down into natural and harmless molecules by the action of micro-organisms within a short period of time. Many plastics in the market fit this criterion with many upcoming plastics promised to even provide other benefits like infinite recycling capability, source of organic manure, cheaper manufacturing costs etc. Some of these plastics are discussed below:

(a) Polyhydroxyalkanoate (PHA): It is naturally formed by certain bacteria in the environment and is completely bio-degradable. The main advantage of PHA is that its production does not require any fossil fuel and its decomposition also does not need any special conditions. It can be easily bio-degraded by burying it in soil within two months. It is insoluble in water and is UV resistant. The only downside of PHA is that it is relatively expensive to produce as it is produced in only small quantities by bacteria but the research is going on to produce PHA from food waste which will have added benefits of waste management also. PHA is currently being used in single-use food wraps, cups, plates, medical sutures etc.

(b) Polylactic Acid (PLA): It is made from lactic acid which is abundantly found in the environment. This makes it cheaper than PHA but there are many downsides to PLA like it is brittle in nature which limits its use cases to mainly rigid objects. It also decomposes relatively slowly in soil and can take up to twelve months to fully decompose. So, there is a concern of PLA being eaten by birds and animals if not properly disposed. It is used in the production of bottles, cups, medical sutures etc.

(c) Polybutylene Adipate Terephthalate (PBAT): It is made from fossil fuels like traditional plastics but it is bio-degradable. It has similar physical properties like elasticity and toughness as that of low density polyethylene and is often used as its alternative. It decomposes easily in soil within 90 days. It is used widely as compostable plastic bags where the whole bag can be buried along with the organic waste in it. The bag provides good anaerobic conditions for bacteria to break down the organic matter.

(d) Starch-based plastics: These are the most widely used bio-plastics as their properties like elasticity, toughness, heat resistance can be altered by the addition of various additives like resins, cellulose or other fossil fuel by-products. Different blends of starch with additives are used according to the required application. Starch is widely available in the environment and is often a waste product of various industries. These plastics are widely used in food packaging, cling sheets, carry bags in big malls, medicine coatings etc.

(e) Polydiketoenamine (PDK): This is the latest type of plastic which has the potential to solve one of the major problems with plastics which is their limited recyclability. The colours and other additives added to the plastics reduce their recyclability and makes the process of recycling harder increasing the price of recycled plastics. But PDK plastic can be broken down to simplest monomers unbinding it from the rest of the additives by just dipping it inside highly acidic solution. These monomers can then again be used to create new materials without any degradation in quality. This process can be repeated over and over making PKD plastics infinitely recyclable. It is being touted as the future of plastics.

Despite the availability of so many bio-degradable plastics, their decomposition needs a proper environment to take place. They should not be mixed with regular plastics whether they are recyclable or not. If they are mixed with regular plastics and sent to landfills, then they are not any better than regular plastics. In landfills, they will not be decomposed and only add to the already existing mountains of plastics. So, special instructions need to be followed for the proper decomposition of the bio-degradable plastics. Thus, it is clear that using bio-degradable plastics alone cannot solve the problem of plastic waste. People have to be made aware about their use and proper disposal practices to have any tangible benefit to the environment. However, the best approach is still reducing the use of all kinds of plastics.

CHAPTER 3

In-Organic Wastes Problems

3.1 Introduction

Plastics are made from naphtha which is a by-product of fractional distillation of crude oil. Plastics are polymers of carbon-based monomers which are chemically inert to most compounds making them suitable for making many items we see around us. But this very nature of plastics makes them a bane for our environment. The first plastic made over a hundred years ago is still around and newer plastics are being added to the environment each day. They are accumulating on our planet day-by-day at every place one can imagine. They are present on tallest peaks of mountains to the deepest waters in our oceans.

3.2 Sources of plastics in the environment

Today mankind has created too much items made up of plastic with enormous oversight over what the effect on environment of it might be. One can look around himself and see how much of things are made up of plastic. Following are some of the most used items made up of plastic:

3.2.1 Food Wrappers: Everything we eat like candies, chips, chocolate, biscuits or some other snacks have a plastic packaging which is thrown away on consuming food. This packaging break down into small pieces from sunlight and is ingested by birds, animals which fills their stomach and they become seriously ill and die a slow and painful death.

3.2.2 Bottle Caps: It may not seem like much but bottle or other container caps are usually thrown away and they escape the usual recycling methods and end up in rivers and ultimately sea. These are easily mistaken as food by bird species which is a major contributor to the decline in the population of many sea-bird species.

3.2.3 Drinking Straws: There is no way to recycle them and they usually end up in oceans. They are a major threat to the marine life as they have the perfect shape to get stuck in their nose, throat or intestines.

3.2.4 Clothes: Various synthetic fabrics are made up of plastics like polyester, nylon, acrylic and polyamide, spandex etc. With each wash, each cloth sheds upto 7 lacs plastic fibres.

3.2.5 Tyres: Styrene- butadiene is a type of plastic used to make synthetic rubber. The heat and friction from driving leads to tyre wear and the resulting plastic dust is blown away and gets mixed with air and water sources.

3.2.6 Laundry Detergents: Polypropylene or polyethylene is used as scrubbing agents in the laundry and dish washing detergents. These are washed down the drain with water.

3.2.7 Diapers: Plastic fibres like nylon, polyester, polyethylene, polypropylene and polylactic acids are used to make diapers. A baby goes through 2-5 diapers a day and worldwide 450 billion disposable diapers are used each year creating 77 million tons of waste to be handled and stored.

3.2.8 Paints: Paints use synthetic binders like alkyds, acrylics, polyurethanes, polyesters etc. which are gradually scrubbed away due to friction from dust particles in air or weathering. Also, some liquid paint is mixed with water during painting, washing of hands, brushes are unpainted areas.

3.2.9 Disposable cups and plates: A lot of urban people are eating outside nowadays using disposable cups and plates made up of plastic. Even paper cups are coated with a plastic film to improve strength and avoid leakage. In case of any event, plastic plates and cups have taken the place of traditionally used biodegradable plates made from banana and lotus leaves.

3.3 Effects of plastics on environment

The amount of time it takes for plastics to decompose is unknown but the general belief is that it takes a few centuries or even a few millennia. During this long period, plastics get accumulated everywhere from landfills, household localities to open seas. The plastic waste effect the environment in many ways which has been enlisted below.

3.2.1 Effect on land: Plastics lead to litter everywhere. They create an unsightly view and get caught on trees, traffic lights and block drains and other water pathways. They decrease the natural beauty of an area and consequently the tourism business suffers. The beaches, mountains, hill stations are some of the major victims of this. If dumped in a landfill, they consume a major portion of land area which could otherwise be used for agriculture, plantations or other infrastructure.

3.2.2 Effect on water-bodies: The ecosystem of water bodies get destroyed as the plastic hinder the natural flow of water and the water becomes stagnant. The stagnation of water provides a breeding ground for dengue and malaria causing mosquitoes. Moreover, the stagnant water also harbours harmful bacteria which further destroy local marine life. Plastics also reduce the natural sunlight reaching the lower depths of the water thereby killing the organisms which need sunlight to survive.

3.2.3 Effect on air: If the plastic is burned, they release dioxins, furans, heavy metals, biphenyls and other chlorinated compounds which travel afar in the air and gets adsorbed on other plastics in sea and absorbed in polar ice caps from where they enter the food-chain. These pollutants cause heart diseases, lung diseases, birth deformities, neurological disorders and decrease in general well-being.

3.2.4 Micro-plastics: Due to exposure to sunlight and moisture, the plastics get brittle and start breaking down into smaller pieces. These small pieces are ingested by birds, fish and other marine creatures. These plastic pieces then move up the food chain and considerably increase in amount due to bio-magnification. Today, most of the drinking water contains micro-plastics whose effect on human body is currently being studied.

3.4 Possible measures to avoid/reduce plastics

We should avoid using multi-layered plastics like in chips packets which have as much as six different layers like inner metallic layer, polypropylene layer and multiple polyethylene layers for printing and joining dissimilar plastic players to each other. These packagings are nearly impossible to recycle as these layers can hardly be separated. Avoid synthetic clothes, just buy natural fabrics like cotton, jute etc. We should not cut the recyclable plastics into smaller pieces like we usually do while pouring milk from packet as these smaller bits will not be collected or recycled. Avoid buying plastic bottles of juices, cold drinks, dairy products etc. and adopt the habit of carrying reusable metallic bottle with you.

3.5 Environmental Impact of Bags

Today, plastic bags form a major portion of the non bio-degradable waste collecting in our environment. The bags which we rarely use twice are very harmful to the environment and their impact largely depends upon the material used to make such bag. There are various types of bags available in the market like paper, plastic, cloth etc.

The environmental impact of such bags can be further divided depending upon our focus such as:

1.) Energy use to make such bag, natural resource use, pollution caused during manufacturing or during transportation.

2.) Impact of product on human health, environment, time taken by bag to degrade naturally.

3.) Cost of recycling, landfill space or incinerating.

3.6 Types of Bags:

We come across various types of bags which are used in our daily lives. Their pros and cons are discussed as below:

3.6.1 Disposable bags:

(a) High Density Polyethylene: This is the most commonly used single use plastic bag.

(b) Paper: These are the first disposable bags to be used. They are less common now but can still be seen in some stores.

(c) Plastic Laminated Paper Bags: These are the stylish bags used by big branded stores like clothes, jewellery or malls etc. These are the worst types of bags as they are nearly impossible to recycle as plastic acts as a contaminant during recycling of paper. These bags are easily ingested by animals. The paper becomes soft and passes through their digestive system as fibre while the plastic film may get stuck in throat or internal organs.

3.6.2 Reusable Bags:

(a) Polypropylene: It has thicker construction than single use bags with handles for easy carrying.

(b) Natural Fibre Bags: These are made from jute or cotton threads woven to create a mesh.

3.7 Impact of Plastic Bags:

One of the most important reason for the adverse effects of plastic bags is their inert nature. Plastics are very stable in the environment and do not have any effect of sun light, rain or pH. Nearly 10 percent of all the oil consumed around the globe each year is used in making plastics. Besides the raw material, the sheer quantity of plastic bags produced each year require a lot of energy which is supplied from the power plants burning fossils fuels. These fossil fuels themselves require transportation and extraction which again consumes more fossil fuels. This again adds up to the overall footprint of the plastic bags. Also, plastic bags when discarded gets collected on ground which could be used for plantation of trees which would absorb carbon. This indirectly acts as a carbon footprint of these bags. So we see that there are a lot of indirect factors which add up to a very huge impact of plastic bags on the environment.

3.7.1 Total Impact Per Bag:

(a) HDPE bags: It has the least global warming potential from manufacturing to use while the pollution after use is high if not recycled.

(b) Paper Bags: These are somewhat higher global warming potential due to added cost of deforestation caused if recycled paper like used newspapers, magazines, office papers etc. is not used.

(c) Polypropylene Bags: These bags have very high global warming potential during production period.

(d) Cotton Bags: These bags have the highest global warming impact as it requires growing of cotton crop which itself needs land, water, storage and transportation.

3.7.2 Breakeven Point:

The number of times one need to use a bag to be more eco-friendly than HDPE bag is as:

(a) Paper Bag needed to use 4 times
(b) Polypropylene Bag needed to use 14 times
(c) Cotton Bag needed to use a massive 173 times

3.8 Alternatives for bags:

It is clear that the first step in being more eco-friendly is to use disposable bags many times. It may also seem that the cotton bags are not that eco-friendly but this data is true only if the bag is made from virgin material so old clothes like curtains, jeans etc. can be used to make stylish bags at home easily. The best practice is to have only a few reusable bags and reusing them again and again till they are unusable.

Everyone should just adopt the habit of carrying reusable bag with them while going for shopping and only use single-use plastic bags when absolutely necessary.

CHAPTER 4

BIOGAS PRODUCTION PROCESS

4.1 Introduction

Biogas is a mixture of gases which can be used for energy production purposes. Major proportions of biogas are methane and carbon dioxide. It is produced using organic compounds by anaerobic bacteria. The biogas produced is the by-product of the respiration of decomposer bacteria and its composition is dependent on the raw material used. If the raw material contains mostly carbohydrates like simple sugars, glucose or other high-molecular polymers such as cellulose and hemicellulose, production of biogas is low. But, if the raw material contains mostly fats, production of biogas is also high. Methane and the leftover hydrogen that forms during anaerobic digestion make up the actual combustible fraction of biogas. Methane is a odourless and colourless gas with a boiling point of -160°C and its flame is bluish in color. The main component (75-90%) of natural gas is also methane. Structurally, methane is a form of alkane and is the simplest possible alkane that can be formed. At normal temperature and pressure, density of methane is around 0.76 kg/m^3. Due to higher molecular weight of carbon dioxide, biogas has a somewhat higher density of around 1.16 kg/m^3. Natural Gas has maximum calorific value of 40-55 MJ/kg equating to 11 kWh/ m3. [4]

Table:-4.1 General Composition of Biogas: [4]

BIOGAS	PERCENTAGE
Methane (CH_4)	50-65
Carbon dioxide (CO_2)	30-45
Hydrogen sulphide (H2S)	1-2
Hydrogen (H_2)	1-2
Ammonia (NH_3)	1-2
Carbon monoxide (CO)	>0.1
Nitrogen (N_2)	>0.1
Oxygen (O_2)	>0.1

4.1.1 Biogas Uses:

Biogas has a moderate calorific value so it can be used to produce energy or in transportation. There is no need for any specialized equipment for its combustion. Biogas has a calorific value which can range between 5.5-6.5 kWh/m^3 according to its composition. So 1m^3 of biogas at 1 atm pressure has the energy value of about 0.5 l diesel. It can be used for following applications:

a) Direct combustion.
b) For heating of houses, buildings, water heaters or brick-kilns.
c) For cooking food.
d) Electricity generation in gas power plants.
e) It can be upgraded to pure methane and transported by pipes.
f) Use in engines after upgradation.

4.1.2 Advantages of Biogas:

1. It is simpler and cheaper to produce than other bio-fuels, therefor it is best suited to small scale applications.

2. No need to recover the biogas as it automatically separates from the solid waste in the drum.

3. Any organic waste material can be used as feed.

4. The raw materials for biogas are often pollutants in the environment and they are used in making useful biogas; this cleanses the environment.

5. Conditions needed in digester are easier to maintain.

6. Even waste with concentration of solids as low as 2-5% can be used.

7. Biogas is nowhere near as explosive as 100% methane.

8. Anaerobic digestion kills harmful microbes so it helps greatly in avoiding the risks of water-borne diseases.

9. It is safer than other fuels in case of a spill as biogas is lighter than air and spreads quickly in the atmosphere.

4.1.3 Disadvantages of Biogas:

1. The yield is often low to justify large scale commercial application.

2. Due to dilute subtrates, a lot of transportation may be involved.

3. Improving the digestion efficiency using Recombinent DNA technologies or specialized bacteria is not possible since the environment inside digester have its own natural selection process.

4. Only way to improve the biogas yield is by tinkering with the digester operating conditions like temperature, pH, substrate quality etc.

5. Certain gases present in biogas such as hydrogen sulphide forms highly corrosive which makes it unsuitable to be used directly in engines.

6. Social stigmas prevent the biogas plants from adoption by the society.

7. The area around biogas plant becomes a breeding ground for insects and flies if proper sanitation is not maintained.

4.2 Chemical Process of Biogas Production:

The bacterial digestion of various organic matters to CH_4 and CO_2 in an oxygen-depleted environment is a multi-step process and is a multi-step reaction process undertaken by different bacterium that play their own unique part in the whole process. The products of digestion of one bacterium becomes a raw material or feed for others, and in this way the bacteria are inter-connected as in an ecosystem. As compared to the aerobic (oxygen-rich) decomposition, energy production by the anaerobic processes is very less. The breakdown of glucose under aerobic conditions produces 38 ATP molecules, whereas anaerobic decomposition produces just 2 ATP molecules. This is due to the fact that the growth rate of anaerobic bacteria is very less as compared to aerobic bacteria. The process of biogas production can be further sub-divided to three processes: Hydrolysis, acidogenesis and methanogenesis, where different types of bacteria undertake a certain chemical reaction to produce biogas as a final product. [5]

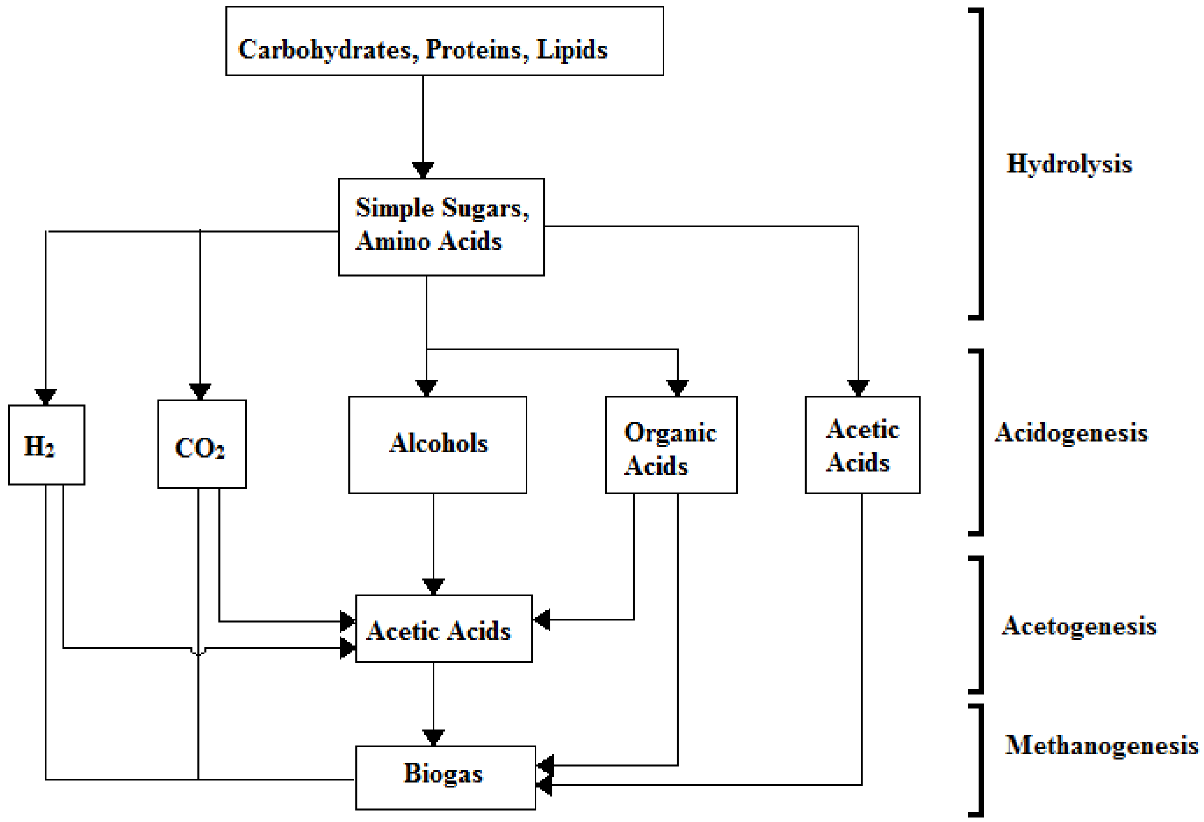


Figure 4.1: Biogas Production Process

4.2.1 Hydrolysis

The process of breaking down long-chain polymers like carbohydrates, proteins and fat molecules into simpler molecules i.e. monomers is called hydrolysis. Various types of bacteria are involved in this process producing enzymes which act as a catalyst for the reactions. Molecules like simple carbohydrates, proteins and other starches can be easily hydrolysed under anaerobic conditions but the complex carbohydrates and other carbon-rich compounds are hydrolysed slowly. Lignin is found in plants which despite being an organic molecule is just not possible to decompose using methanogenic bacteria.

4.2.2 Acidogenesis or Fermentation

The next step in the digestion process is the conversion of monomers to further acids or sone other substances. During acidogenesis, only about half of the monomers are converted to acetic acid. Around twenty percent gets converted to CO_2 and H_2, whereas leftover 30% gets converted to VFAs.

4.2.3 Methanogenesis

This is the last step in the anaerobic digestion of organic matter and it is performed by the methanogenic bacteria called methanogens. The methanogenic bacteria are a type of Archaea which are single-cell micro-organisms having no cell nucleus. Methane production is handled by two separate species of bacteria. One species of bacteria converts acetic acid to methane whereas the other bacteria converts carbon dioxide and hydrogen to methane. If the conditions in the digestion ate optimum then nearly 70% of the methane is produced from the conversion of acetic acid and the other 30% is from carbon dioxide and hydrogen. Both the processes are inter-dependent and inhibition of one also causes other to cease. The methanogenic bacteria have the slowest rate of growth of all the bacteria involved in the digestion process. So these are often the limiting factor for the overall rate of anaerobic digestion and the subsequent biogas production. The rate of growth of other acid-forming bacteria is nearly five times more than that of methanogenic bacteria and the methanogens also produce very less energy during the process. Despite these unfavourable character traits, methanogenic bacteria still manage to survive due to so little oxygen which limits the competition from other bacteria and methanogens get a chance to grow.

4.3 Requirements of a biogas plant

Biogas production process needs some specific conditions to operate and it requires optimization of a lot of factors which effect the rate of digestion. [5]

4.3.1 Anaerobic environment: As mentioned earlier, the methanogens need an oxygen-free environment – they are obligately anaerobic. A biogas reactor therefore has to be airtight. The small amount of oxygen which is dissolved in the raw material fed to the digester is quickly used up by aerobic bacteria that need oxygen for survival, or by some specialised anaerobic bacteria that can use oxygen for their respiration if needed.

4.3.2 Temperature: The rate of biochemical reactions generally increases with temperature. Generally speaking, the rate is doubled for every 10-degree rise in temperature within certain limits. This is true for the chemical reactions involved in biogas production process. In this case, there are several types of bacteria that have evolved to better suit the different temperatures which may occur during anaerobic digestion:

(a) Psychrophiles: 0 – 20°C

(b) Mesophiles: 15 – 45°C

(c) Thermophiles: 40 – 65°C

These are specialized bacteria and they can only work inside their own temperature range. This sensitivity increases with temperature. In real life, biogas plants are either maintained at a temperature of 37°C for mesophilic bacteria where temperature changes of approx. ± 2°C are tolerated, or at a temperature of around 52°C for thermophilic bacteria where temperature changes are stricter and only ± 0.5°C is tolerated.

4.3.3 Acidity (pH): It is very strange to think that although methanogenic bacteria feed on organic acids yet they cannot survive in an acidic environment. The optimum pH for their survival is a value between 6.4 and 8 but the preferred pH is 7.2-7.3. During optimum digestion, the pH level in a digester is nearly 7.1-7.3 and remains at that level till very drastic changes occur. This is due to the fact that various intermediate compounds forming during digestion act as a buffer for the pH value. The digestion process is thus a very stable process. But slurry-based plants often experience a very high pH value of 8-8.3 due to the presence of high levels of ammonium compounds.

4.3.4 Substrate (feedstock): Nearly all organic matter can be decomposed anaerobically, but the degree of decomposition can be increased in various ways. Lignin is, however, indigestible.

4.3.5 Comminution: The finer the material, the larger the relative surface and the easier it is for the bacteria to attack the material.

4.3.6 Dry matter content: For bacteria to be able to degrade the material, the dry matter content must not be higher than around 50%. For best results, it should be about 10-12% to facilitate pumping. Some special reactors with direct feeding lines can work at s somewhat higher dry matter content.

4.3.7 Carbon/nitrogen (C/N) ratio: Like other living things, methanogenic bacteria also need a number of macro and micro-nutrients in order to grow. The most important macronutrients are nitrogen (N), phosphorus (P) and potassium (K). Nitrogen is used by bacteria to produce proteins. Nitrogen is compared with the carbon content of the raw material which suggests whether there is adequate nitrogen available for bacteria or not. The carbon and nitrogen relation is taken as a ratio called carbon to nitrogen ratio (C/N) which 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.

4.3.8 Stirring: There are a number of different plant types, but for the most common type, CSTR, the biomass has to be vigorously agitated to avoid the formation of an impenetrable surface crust.

4.3.9 Organic load: The rate at which organic biomass is fed 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 minimum load for a CSTR reactor is 1-7 kg COD/m3 reactor volume/day. If the rate of feeding is increased beyond what the bacteria can process then the organic matter begins to rot inside the digester resulting in a decrease in pH value. This can kill the methanogenic bacteria and the biogas production will be stopped. The raw material also needs to be fed at an even rate and volume every time, if possible as a continuous feed. If the substrate has to be changed, it must be done gradually over a period of time rather than sudden change so that bacteria can adapt to the new raw material and the digester conditions.

4.4 Biogas process inhibition

The substances which negatively impact on the growth or general working of the bacteria are called inhibitors. They may not necessarily kill the bacteria but rather make the environment unsuitable for their growth making rate of their growth slower. Bacteria can be inhibited by either internal factors or external factors. Inhibition due to internal factors is called endogenous inhibition and it occurs due to conditions or harmful byproducts formed during the digestion process under some specific circumstances. Inhibition due to external reasons is called exogenous inhibition.

4.4.1Nitrogen inhibition:

One of the most significant endogenous inhibitors is NH_3. NH_3 is created during the bacterial degradation of nitrogen-containing substances such as proteins. Nitrogen is essential for bacterial growth and ammonia is an important source of nitrogen. But ammonia at high concentrations acts as a toxin for the bacteria. Thermophilic digesters are more prone than a mesophilic digester to ammonia poisoning as they operate at a higher temperature. Although ammonia can inhibit the bacteria at low concentrations but with time bacteria can adapt to even higher ammonia concentration inside the digester. The longer adaptation period requires constant conditions inside the digester which requires consistent feeding rate and type of raw material. This adaptation is necessary in digesters which use slurry or other high ammonia concentration as feed as typically these bacteria cannot survive such conditions. The whole digestion process can come to a halt if sudden changes in ammonia concentration takes place, so priming of digester with lower ammonia concentration is necessary with gradual shift to higher ammonia substrates.

4.4.2 Acidification:

Another major digestion process inhibitors are the organic acids which are formed during the digestion process. These acids are meant to be removed as soon as they are formed, otherwise the overall pH inside the digester reduces and the digestion ceases.

4.4.3 Antibiotics, etc.:

Antibiotics and other disinfectant agents are some of the obvious inhibitors of the digestion process as these are designed to be toxic to micro-organisms and are commonly used to kill various microorganisms. Antibiotics and other toxic substances are often used in cattle, poultry and other livestock business to treat sick animals and to clean animal shelters. This means that these substances are present in the raw material for biogas plant but are usually at such a low concentration that the digestion process is not affected. Also, bacteria get adapted to these toxic substances slowly over time if they are present in the digester for a long period of time.

4.5 Biogas Plant Design

There are a lot of designs of biogas plants to treat all kinds of organic matter with its own advantages and limitations. However, continuously stirred tank reactor design can process organic matter with higher proportion of dry matter. Organic matter can either be feed to the digester in a continuous way or batch mode. However to make space for new organic matter to be fed, some of the digester slurry is taken out by a pump but the constant stiring of the digester means that some of this newly added organic matter also comes out without proper digestion. This decreases digester efficiency and the biogas production is reduced. In theory, commercial and communial plants have same design and working principle. The only differentiator is the scale on which the plant is meant to be used like the amount of organic matter it is designed to digest. [6]

The system can be effectively divided into two parts:

4.5.1 Biomass System:

(i) Reception tank: Generally, two reception tanks are required: First tank is used for slurry, manure and the other is used for organic industrial waste. The main aim of using reception tank is have a buffer tank so that the biogas plant can be run on off-days and during holidays. All types of organic matter is fed into the reception tank to make sure feed to the digester is homogenous. Reception tanks employed for slurry usually have enough buffer capacity to run for seven days. But industrial reactors employ still larger capacity reception tanks. The tanks are often stirred to avoid crust formation on the walls. They are also heated as the organic matter containing fats can solidify. Reception tanks also have an arrangement to remove sand and grit which settles down and need to be removed periodically.

(ii) Feeder pump: It is used to pump the organic matter from the reception tanks to the reactor tank. The pump is either immersed completely in the reception tank or has its own immersion well. Feeder pump works in conjunction with a comminutor which breaks and shreds the organic matter.

(iii) Reactor tank: It is an airtight tank made up of steel, concrete or masonry with proper insulation. It is the space where actual digestion process by methanogenic bacteria occurs. The digestive slurry is often mixed to ease the migration of bacteria to all parts of the digester and improve the rate of digestion. Various gauges are provided to monitor the operating conditions like temperature, pH and pressure. Pressure release valves are also provided for safety reasons as excessive pressure can lead to leaking of the tank. An outlet is also provided on the top for the removal of biogas so-produced. The reactor tank is designed to have a nominal volume of around 10-20 times the organic matter to be inputted daily for thermophillic type and 15-30 times for the mesophillic type.

4.5.2 Gas system:

(i) Gas condensation: The biogas produced in the main reactor and secondary digester is extracted. This biogas has a lot of water vapor which upon cooling condenses. This water is often pumped to the secondary digester as it is rich in bacteria and also to avoid water wastage.

(ii) Gas purification: Biogas also contains some amounts of H_2S which is directly proportional to the amount of proteins present in the organic matter. H_2S on coming in contact with water and carbon dioxide forms sulphuric acid which is highly corrosive in nature and needs to be removed is biogas is to be used in an engine. The H_2S can be removed using sulphur bacteria which converts H_2S to pure sulphur. The sulphur so-produced is then transferred to the secondary storage tank as an aqueous solution ready to be used on crops in the field.

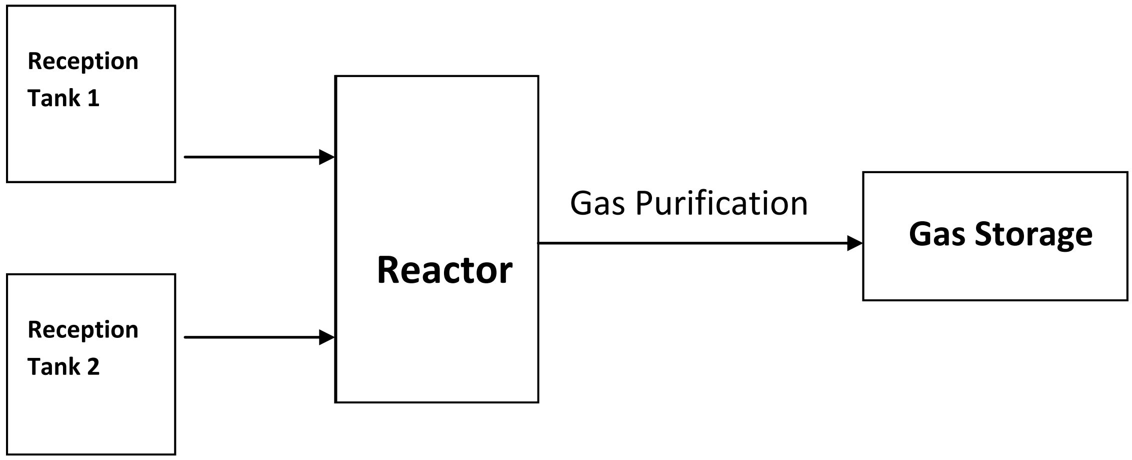


Figure 4.2: Schematic diagram of a communal biogas plant.

4.6 Structure of biogas plants:

4.6.1 Digester:

Biogas plant is generally made using concrete, masonry or steel sheets. It has to be airtight to prevent the escape of biogas and the digestive slurry into the soil which apart from creating a odourous environment can also lead to fire hazard. In case of masonry or concrete plants, cracks are inevitable. There are various ways to predict where the cracks will arise and one can try to reduce them. Cracks always appear at the point of highest tension. Tension arises from tensile forces, flexure, displacements, setteling and temperature fluctuations. Also shrinkage cracks form during mortar setteling. A lot of internal forces act on structure like gravitational, flexural, normal and torsional forces and other external forces like load, dead weight and earth pressure contribute to the stress in the structure. Stresses are highest where the combination of these two forces is largest. For these reasons, curved surfaces are preferred as they distribute forces evenly along the surface and reduce maximum stress points. [7]

4.6.2 Bottom slab:

The bottom slab is used to distribute the weight over a large surface on the ground. The larger the area of foundation of bottom slab, lesser will be the settlement of earth. Larger area of the bottom slab helps to spread the load evenly on the ground which reduces the risk of cracking. The weight of the fermentation slurry in the digester acts as a uniformly distributed load which is pressed against the ground. If the ground is of uneven consistency due to presence of small rocks or boulders in loose soil, then a concentrated force may be applied at the location of rocks or boulder. The bottom slab should be strong enough to bear such type of loads. A well designed bottom slab should spread the load evenly regardless of the soil conditions without cracking. If the slab is made too thin, then it may crumple and the structure will not be water tight anymore. [7]

4.7 Design Parameters for Biogas Plants:

The design of a biogas plants depends on a lot of parameters such as:

(i) Feed per day (kg/day).
(ii) Biogas production per day (m^3/day).
(iii) Volume of the digester (m^3).

(iv) Active slurry volume (m^3).

(v) Height of digester (m).

(vi) Diameter of digester (m).

Some of these can be roughly estimated like biogas rate is equal to the product of average yield of raw material and its weight. Volume of digester can be calculated from its height and diameter.

4.7.1 Calculation for Selecting Design Parameters for a Plant of 100 kg Feed Capacity:

Assuming biogas yield of .04m^3/kg as it is general yield of cow dung and HRT of 50 days.[8]

So, Biogas production rate (B) = .04×100 = 4m^3/day.

Also, Active Slurry Volume (Vs) = $HRT(2\times\frac{F}{1000}) = 50(2\times\frac{100}{1000}) = 10m^3$.

Height of Digester (H) = $(\frac{Vs}{\Pi})^{1/3} = (\frac{10}{3.14})^{0.33} = 1.46$m.

Diameter of Digester (D) = 2×H = 2×1.46 = 2.92m.

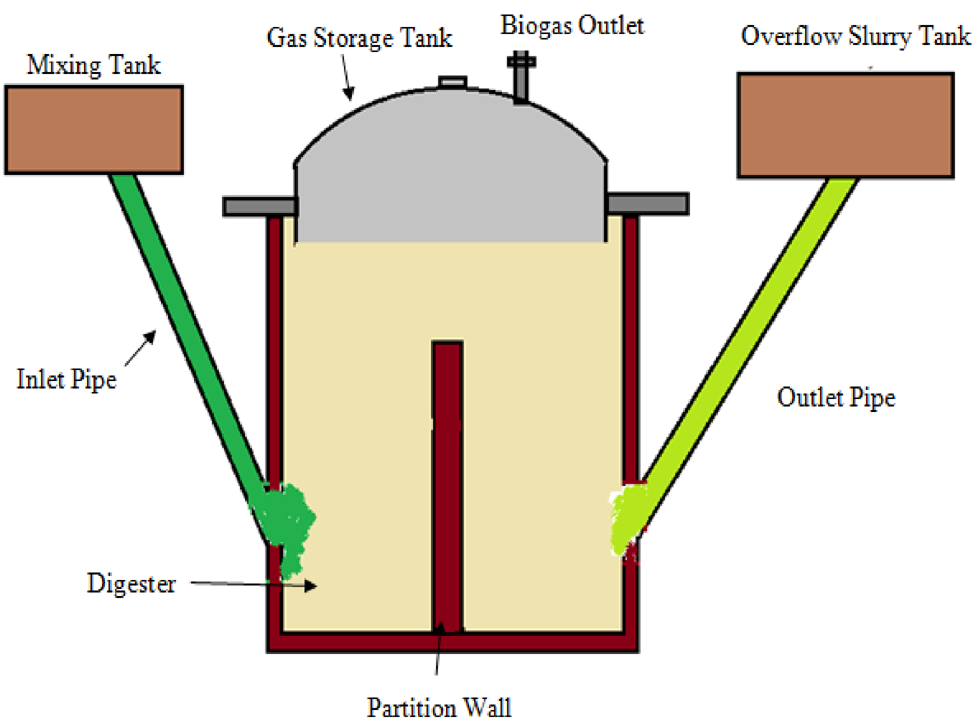
4.8 Types of biogas plants:

4.8.1 Floating gas drum:

This type of drum is usually made from a thin sheet of steel of around 2-3mm thickness. The digester is underground while the biogas holder floats up and down outside the ground along a guide frame. Due to being in contact with water and soil at times, there is a high chance of corrosion of drum which is avoided using coatings. Some commonly used coating products like oil paints, synthetic paints and bitumen paints can be used with correct priming. The drum surface should be properly cleaned and all the corrosion should be scraped off properly. Then after a coat of primer, a minimum of three coats of paint is necessary. Sometimes, plastic sheet stuck to bitumen coating is used but they do not last long and tend to chip off. After painting, periodical repainting is required from time to time. In coastal regions, repainting is required every year but in dry areas it can be done every other year. Besides protection from corrosion, painting serves other purposes also. Dark paints like red or black raise the drum temperature in cold areas due to solar radiation and increase the production of biogas. Internal coating is needed in case of drum constructed from steelwire-meshreinforced concrete or fibrocement. The gas drum should have a slight slope in its roof, otherwise rainwater will be collected on it which can damage the paint and corrode the drum.

4.8.2 Fixed-dome plants:

It has fixed underground digester and a fixed upper dome. It is usually made of concrete or masonary work. The upper dome of such plant has to be gastight so it needs to be painted with an elastic paint like latex por polyster paint as it is the only way to make sure that the cracks in the structure are filled. The dome can also be coated with a layer of hot paraffin coating. It is done by first heating the surface with a blow-torch and then a very hot paraffin is applied which sticks to the concrete. Fixed-dome plants are cheaper to construct than floating-drum types and produce just as much biogas if they are made properly gastight. The problem with them is the gas pressure which changes continuously as the amount of gas changes. An external gas pressure regulator needs to be used if the biogas needs to be immediately used for cooking purposes for the optimum functioning of the burners.



<u>Figure 4.3: Fixed Dome Biogas Plant</u>

4.8.3 Plastic tube digester:

In this case, a cylindrical flexible tube of polyethene plastic is connected to hard PVC pipes at both ends. One PVC pipe acts as an inlet for the raw material and the other outlet for digester slurry. To provide sturdiness to the tube, a semi-cylindrical pit in earth is dug out in which the tube is placed. The lower portion of tube acts as a digester while the upper portion acts as a biogas storage. Due to very low volume available at the top for biogas storage, supplementary storage space for biogas is needed which can be done by installing additional polyethene tanks.

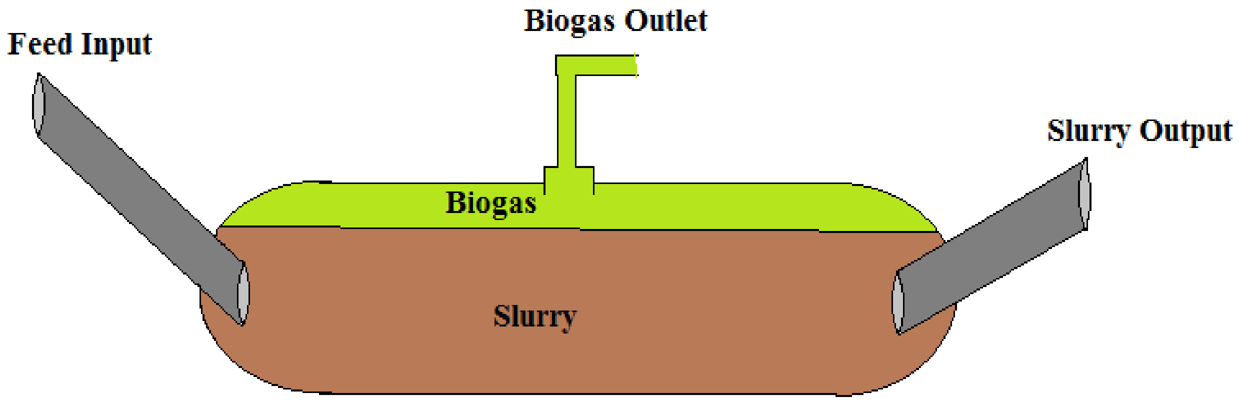


Figure 4.4: Plastic-Tube Digester

4.8.4 Balloon-type digester: It is similar to the tube-type plant except a rubber balloon is used instead of plastic tube. The upper part of balloon acts as a biogas reservoir while the lower part acts as a digester. Inlet pipe and outlet pipe are connected directly to the balloon. Lower part of balloon is placed inside a dug pit to provide support to the digester slurry. Special UV-resistant materials are used for the construction of balloon since there is no extra protection provided for its safety from weather conditions.

Both tube-type and balloon-type digesters are low cost digesters which can be mass-produced in a factory. They are easy to transport, install, clean and operate. Their only downside is that they are not very durable and only suitable for a working period of 2-4 years. They are also prone to puncture from sharp objects and are easily damaged during bad weathers. In India, fixed dome and floating drum type digesters are mostly used

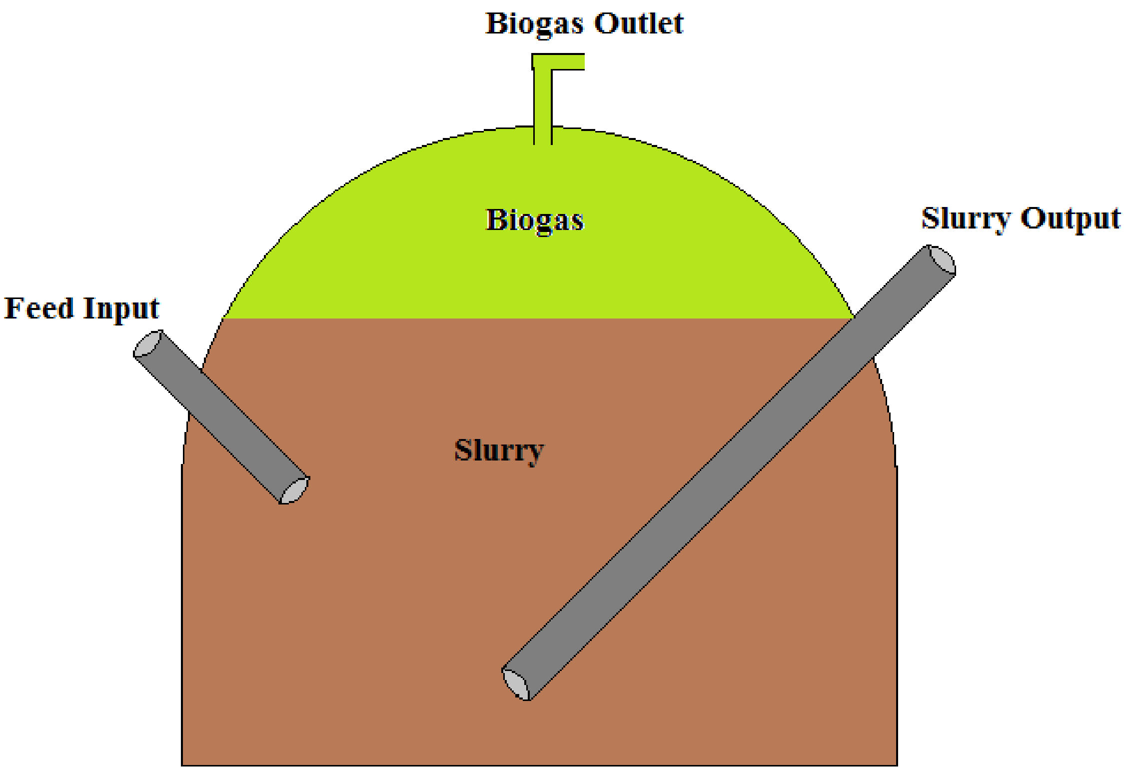


Figure 4.5: Balloon-Type Digester

Table:-4.2 Biogas Plants Comparison: [9]

Factors	Fixed Dome	Floating Drum	Tube-Type	Balloon-Type
Biogas Storage Capacity	High, >20m^3	Medium, >5m^3	Medium, >2m^3	Less, >1m^3
Biogas Production	High	Medium	Low	Low
Biogas Pressure	High, 50-120 mbar	Medium, ~20mbar	Low, ~2mbar	Low, ~2mbar
Durability	Very High, >20 years	High, Drum Fails Early	Medium, 2-5 years	Low, 1-3 years
Agitation	Automatically due to biogas pressure	Manual	Not possible	Not possible
Size	High, 5-125m^3	Medium, >20m^3	Medium, 2-5m^3	Low, 1-2m^3

CHAPTER 5

Improvements to Existing Biogas Production Process

5.1 Introduction

Although Biogas production involves some leeway in the operating parameters but there are some ways which can be utilised to improve the overall biogas production output. Some basic things to consider for maximum biogas production are to increase the input of waste material and to increase the yield from the waste inputted. Following are some suggestions that would address aforementioned key issues and drastically improve the effectiveness and efficiency of biogas plant.

5.2 Using Optimum Ratio of Food and Vegetable in Waste Feed

It was found that methanogenic bacteria can digest carbon nearly 25 times more rapidly than nitrogen. If waste contains less nitrogen, most of the carbon remains unreacted and it contains too much nitrogen, nitrogen will remain unreacted and forms ammonia which increases the pH value. Every fruit and vegetable has a different carbon to nitrogen ratio, so the required carbon to nitrogen ratio in a biogas digester is often not maintained resulting in less than optimum biogas production rate. Proper characterisation of various properties of food waste like pH value, total solids, volatile solids and carbon to nitrogen ratio is essential to achieve maximum efficiency in biogas production process. Also, pH value of 6.8-7.2 is required for the growth of anaerobic microbes and pH value>8.5 is toxic to anaerobic microbes and it can halt the digestion process completely. As carbon to nitrogen ratio of 20:1 to 30:1 is considered optimum for the biogas production, so using ratio of various fruits and vegetables in such a way to achieve that ratio can have a huge positive impact on the yield of biogas produced. Proper ratio of waste can also help in achieving desired pH value of 7 without the need of extra chemical compounds like lime so that the cost of operation of biogas plant can be further reduced.

Following table gives the required data for mostly used fruits and vegetable wastes. These values are calculated as per APHA standards and can be used for the best composition of waste feed to the digester and the biogas production can be increased.

Table 5.1: Properties of Various Foods [10]

Raw Material	pH	Total Solids %	Volatile Solids %	Moisture Content %	C %	N %	H %	S %	O %	C/N
Cabbage Leaves	5.2-5.4	13.3	88	86.7	40	3.1	5	0	0	12.9
Potato Skin	5.6-6	21.3	93	93	40	1.34	5.8	0	0	29.8
Banana Skin	4.5-5.2	10.9	80	89.1	42.2	0.5	5.5	0	36.3	83
Waste Tomato	3.5-4.6	4.85	78.7	94.1	41.6	1.6	6	0	45.6	26.3
Cauliflower Leaves	5.6-6.4	17.8	81.5	80.2	37.4	5.7	5	0.35	39.2	6.57
Lady Finger	6.5-7.5	13.9	90.6	86.1	37.5	0.8	5	0	45.6	47.6
Cucumber Skin	7	12.3	93.6	88	41.5	3.1	5.4	0	38.86	13.4
Spinach	5.5-6.8	10	76.3	90	40	3.1	5.1	0	35.1	12.8
Watermelon Skin	5.8-6.8	6.9	87.5	93	38.7	1.3	5	0	0	29
Sweet Lemon Skin	5.8-6.5	45	-	45	42.4	0.2	5.6	0	45	202.8
Onion Skin	2-2.4	11.7	-	88	43.5	0.45	4.8	0	42.4	6.83
Carrot Skin	7	9	-	-	42.1	0.18	5.7	0	45.1	230
Cluster Beans	7	17	-	-	39.6	2.9	5.5	0	0	13
Mango Skin	>6.8	-	-	-	41	5.9	0	0	0	6.7
Orange Skin	4.2	-	-	-	46.5	0.4	6	0	43.1	115.8

5.3 Using Waste Crushers at Source

In D.T.U. campus, crushing of digester feed is done at the location of plant. This method involves regular transportation of waste from various sources to the digester. The problem with this method is that some waste gets uncollected or the collection gets delayed which begins to rot resulting in decreased yield of biogas.

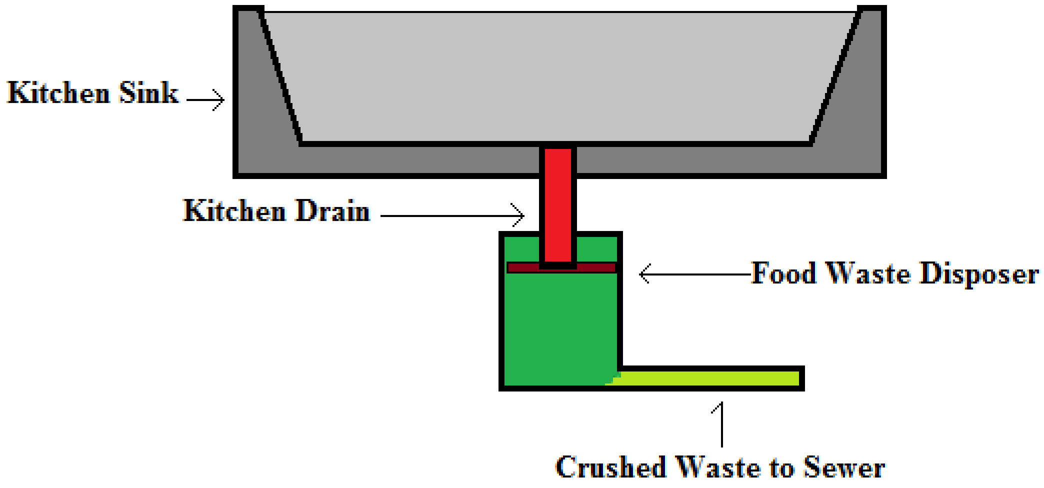
Another method to tackle this problem is installing crushers at various locations inside the campus and pumping the crushed slurry to the biogas plant. This will increase the amount of waste going to the biogas plant and subsequently decrease in the mixing of bio-degradable waste with the non bio-degradable one.

Setting up of crushers at the canteen, hostel mess and near faculty apartments will divert most of their food and vegetable waste to the biogas plant. This project will need pumping stations along with pipes to transfer all the waste.

5.4 Using Food Waste Disposers with Kitchen Sinks

In India, there is a lack of proper waste management system. Most of the kitchen waste is mixed with the plastic waste which is often dumped in landfills, rivers etc. Less than thirty percent of waste is recovered and recycled. In developed countries, waste at home is segregated into recyclable, bio-degradable and non bio-degradable types and then each type of waste is collected individually. However, the sewage system in India is improving and new sewage treatment plants are getting set up. So, if kitchen waste can somehow be transferred to these sewage treatment plants along with human waste, then most of the bio-degradable waste will get automatically handled without the need of segregation from plastic waste. One such way of doing this is the installation of food waste disposer in kitchen sinks. It is a pocket-friendly way of properly kitchen waste. It is installed before the drain pipe of the sink and is connected to the sewage pipe of the house. It is fed the leftover food, vegetable peels or other bio-degradable waste and the disposer shreds it into smaller pieces which are then drained to the sewage pipe. The food waste along with sewage travels to the sewage treatment plant or septic tank where it is treated.

This is by far the best method to utilise maximum amount of bio-degradable waste from households. Nowadays in India, sewage system is gaining traction tremendously and the houses in the urban areas are getting connected to it. If along with sewage, kitchen waste is also transferred, then it will become a lot easier to handle and recycle non bio-degradable waste also due to decrease in volume to be transported, segregated and without the harmful effects of rotting bio-degradable waste. Every house in India connected to sewage system should have a waste food disposer installed in their installed as it is can be done at a fraction of the cost of installing other things in kitchen but have huge positive environmental impacts.



<u>Figure 5.1: Food Waste Disposer</u>

CHAPTER 6

Literature Review

Moezzi et al. [11] studied the green campus concept in Arizona State University (ASU) campus as it is one of the well-known campuses that apply the green campus concept through best practices in waste management. The lessons learned from ASU campus are then proposed for adoption in Universiti Teknologi Malaysia (UTM) Kuala Lumpur Campus with regards to Malaysian unique context. Preliminary study and various field observations that are conducted in UTM Kuala Lumpur Campus clearly indicate that there is a gap between green campus concept and current practices which include a clear lack of facilities and awareness in waste management. It also proposes some general recommendations for UTM Kuala Lumpur campus in order to encourage the practice of the waste management to realise the green campus concept in future.

The study recognises that waste management is becoming one of the key problems of the modern world because the waste issue is intensified by the volume and complexity of domestic and industrial waste discarded by society. The study also highlights various challenges of implementation of green campus like gathering on-site data, identifying waste, devising plans to deal with the waste etc. It uses waste hierarchy which refers to the "3 Rs" i.e. reduce, reuse and recycle, which classify waste management practices according to their feasibility and effectiveness in terms of waste minimization. The concept of waste management has to be individually tailored according to their usage in different countries or areas. Education and awareness in the area of waste and waste management are becoming increasingly important from a global perspective of resource management. It gives utmost importance to the promotion of the economic opportunities of sustainable waste management. Waste Minimization Plan, reducing, reusing, and recycling (compost, recovery, exchange, etc.) could potentially help UTM Campus and the environment by saving energy, money and natural resources. In conclusion, it is worth mentioning that the most effective way to get rid of waste in campus is to not create it in the first place.

Mason et al. [12] studied the implementation of a zero waste program at the Institute of Technology and Engineering, Massey University, New Zealand. The reason for the establishment of a zero waste program was in response to grassroots student concern over environmental management issues. There were some initial discussions with academic ataff and local authorities on a university-run environmental forum which leads to the forming of a team, then a proposal was signed for funding purposes and an externally funded research institute was created. Apart from that, various promotional and educational seminars were held by the staff members for educating about waste management. Senior management supported the team by enacting an environmental policy and a signed commitment to environmental responsibility in tertiary education. Monetary support and funding from the university resulted in the success of the initial funding application. Paid research associates were employed for organising and carrying out projects, which were helped by student volunteers and a program leader from the academic staff was assigned as a supervisor. Facilities management staff informally provided with their support and cooperation. An environmental committee was also setup in the campus to facilitate communication on environmental matters between the School for the Environment, university management, facilities management staff, academic staff and students. However, for maximum effectiveness of the program, a proper link between various entities involved in the program and setting up of a proper environmental management system was needed.

Qingshi Tu et al. [13] studied the implementation of three different waste management projects at the University of Cincinnati. One was conversion of waste cooking oil to biodiesel, second was conversion of waste paper to fuel pellets and third was converting waste food to biogas. Study of various parameters like the amount of raw material to be processed, quality of raw material and type of reactors to be used was done. Already working projects from other universities were studied to get better idea about the project parameters such as yield estimation, project location, setting cost etc.. The implementations of these waste to energy projects would lead to the increased campus sustainability. Various aspects of the project like technical and economical were studied and a clear reduction in green house gases emission, waste management efforts was found.

Early estimates of the projects suggested that together they could convert 3680 litres of waste cooking oil to 3710 litres of biodiesel, produce biogas enough to replace 12770m^3 of natural gas every year from 145 tonnes of food waste and produce 138 tonnes of fuel pellets from 133 tonnes of waste paper and 20.75 tonnes of plastics to replace 121 tonnes of coal.

The payback period was estimated to be 16 months for biodiesel, 155 months for fuel pellets and 74 months for the biogas projects. Reduction in greenhouse gas emissions was estimated to be 9.37 tonnes of CO_2-eq. per year from biodiesel, 260.5 tonnes of CO_2-eq. per year from fuel pellets and 11.36 tonnes of CO_2-eq. per year from biogas.

Hadya et al. [14] studied the influence of inoculants on bio-gas yield from dry and green leaves. Various parameters such as Carbon and Nitrogen ratio, volatile matter, pH content, temperature, retention time and percentage of inoculation affect the efficiency of bio-gas production, were also studied. In this work, it is proposed to pulverize the raw material and inoculants to enhance the fermentation process in the mini bio-gas plant. Inoculation is the active sludge from a working plant from which the solid matter has been filtered out. It is biologically active since it contains the methanogenic bacteria which produced biogas. A mini bio-gas plant with the capacity of 250 litres is used to produce bio-gas from dry and green leaves has been studied.

The addition of inoculants enhances the bio-gas yield in the mini bio-gas plant, the amount of inoculants 5%, 10% and 15 %(by weight of the total slurry) for dry and green leaves. The dry leaves yield higher bio-gas than the green leaves for a given percentage of addition of inoculants. Without addition of inoculants the maximum gas yield for dry leaves and green leaves were found to be 0.55 m3/kg and 0.5 m3/kg respectively. With the addition of inoculants (up to 15%) the maximum gas yields were found to be 0.75 m3/kg for dry leaves and 0.7 m3/kg for green leaves. The inoculants were active during the first period of digestion process only. The amount of yield also depends on the amount cellulose content of leaves. Dry leaves has high cellulose content, hence gas yield is more in dry leaves. Optimum temperature of bio gas plant operation should be 30˚C. Pulverization of leaves increases the bio gas yield.

Wannapokin et al. [15] studied biogas production potential of fallen teak leaves. Chemical formation of leaves suggested C, H, N, S, and O proportions of 48.9, 5.8, 0.56, 0.17, and 30.05 %, respectively. Also by dry weight determination, the leaves were found to have moisture content of 2.83%, ash content of 11.33%, volatile matter content of 83.44% and fixed carbon as 2.4%. Composition of total solids (TS), volatile solids (VS) and chemical oxygen demand in the leaves were calculated and the findings are 982,152.04 mg/kg, 819,413.06 mg/kg and 21,332.83 mg/L, respectively. Biogas from leaves so-formed has CO_2 and CH_4 as 43.6% and 55.46% respectively. Entire biogas production was estimated to be 1.075 m^3/kg and total methane yield to be 0.6 m^3 by theoretical analysis. Preliminary data suggested that the fallen leaves as biogas raw material is a valuable source and should be effectively utilised. In conclusion, this study showed that teak leaves can be reliably used for biogas production as a raw material for production of biogas in industrial-scale reactors. So, it becomes viable to see fallen teak leaves as an energy-rich crop to be used as an alternative energy source.

Rouf et al. [16] studied the production of biogas using fallen leaves and mixing them with cow dung. The leaves used were mainly mixed leaves of mahogany (75%), eucalyptus (10 %) and rain tree (15 %) leaves. Three different batches were tested with whole leaves, crushed leaves and aerobically pretreated leaves. 2 litre glass bottles were used as digesters and the leaves were kept in them for a period of 60 days. Also, different proportions of leaves cow dung were tested for best possible mix for maximum biogas production.

Maximum biogas yield was achieved using 6% of crushed pretreated leaves mixed with 2% cow dung with biogas yield of 0.2 l/g of raw material and the subsequent methane proportion was around 69.2 %. Leaves that were not pretreated had very less biogas yield of 0.0105 l/g.In conclusion, it is seen that using fallen leaves as the raw material for biogas production is feasible. Usage of leaves in such a manner has multi-faceted benefits like clean energy, production of good biofertiliser, avoidance of common hiding spots for reptiles like snakes, fire hazard control and cleanliness.

Tanimu et al. [17] studied the effect of Carbon to Nitrogen Ratio of Food Waste on Biogas Methane Production. The aim of this experiment was to find out the effect of different carbon to nitrogen ratio on the biogas production. For this, mixing of raw materials having different carbon and nitrogen content can be done to get the proper mix of organic matter which is fed to the digester. In this study, food waste having carbon to nitrogen ratio of 17:1 was mixed with meat, fruits and other highly nitrogenous waste materials to increase the carbon to nitrogen ratio. Results confirmed that there was definite improvement in the biogas production as biogas increased from initial 0.353 l/g to 0.45 l/g to a final value of 0.681 l/g with carbon to nitrogen ratio of 17:1, 26:1 and 30:1 respectively. Digestion of food waste was maximum at with efficiency of 85% at C/N ratio of 30. In conclusion, higher C/N ratio is more effective at maintaining optimum pH value and enhancement in the growth of methanogenic bacteria as buffering effect inside the digester increases.

Mane et al. [18] studied the characterisation of fruit and vegetable waste for improvement in the yield of biogas production process. This study deals particularly with characterisation of various fruit and vegetables which are regularly used and are most abundant in the market. The main motive behind this characterisation was to determine the total solids, volatile solids, carbon content and nitrogen content of various raw materials used in the biogas production process. This study was done to study the effects of co-digestion of different materials and the role of characterisation in optimising the the carbon to nitrogen ratio to 25-30. Higher nitrogen content in the digester can raise the pH value and make the environment basic which is unsuitable for methanogenic bacteria. This study can greatly help in the Indian biogas production sector as these were the vegetables and fruits that are most commonly used all over the country and knowing their parameters can help in choosing us the best proportions of their waste so as to increase the biogas production.

Shrimal et al. [19] conducted a study of duration 42 days on vermicomposting various vegetable wastes combined with cow manure and saw dust. The focus of this study was to evaluate optimum carbon to nitrogen ratio for maximum biogas production. It was concluded that the carbon to nitrogen ratio has a pronounced effect on the working of earthworms. The efficiency of vermicomposting was maximum at C/N ratio of 30 but earthworm growth was best at C/N ratio of 40. It was also found that bedding material is essential for the survival of earthworms. Experimental data provides a sound basis that vermicomposting is a better approach to handle decomposable organic waste than conventional ways of composting. The study shows the potential of using indigenous species in agriculture and its waste management.

Deressa et al. [20] studied the production of biogas from the mixture of fruit and vegetable wastes blended with cow dung. Examination of total solids, volatile solids, moisture content and ash content was done for the substrate. The raw organic materials fed to the digester were avocado, papaya, mango, tomato, banana peel, and cow manure. The digester was run at varying volumes of slurry and the biogas so produced was tested for its combustibility. This whole process of using fruit and vegetable wastes mixed with different organic materials to produce biogas took 55 days to achieve complete digestion. Optimum pH of 6.8-7.3 needs to be maintained for the proper functioning and growth of methanogenic bacteria. Apart from above-mentioned factors, temperature also plays a huge role in the overall working of the methanogenic bacteria inside the digester. It was found that if all the factors are carefully controlled and a proper ratio of fruit and vegetable waste and cow manure is used, the biogas plant can be run at maximum efficiency without the need of external chemical additives added to the digester.

It was observed that the biogas production from leftover food waste of students canteens when mixed with cow dung produces higher yield of biogas than using fruit and vegetable wastes mixed with cow dung. Biogas production serves many purposes like management of waste food, organic fertiliser generation along with cheap energy source.

Orhorhoro et al. [21] analysed the impact of varying carbon to nitrogen ratio on the biogas production process. In this study, different raw materials with varying compositions were used. A total of 8 raw materials were chosen for this study and they were used in various combinations and mixtures to understand their effect on biogas yield. Various parameters were examined by varying different factors like hydraulic retention time, biogas production rate, evacuation interval etc.

The low hydraulic retention time of cowdung confirmed that digestion was faster unlike other samples which comprised of organic matter having with higher proportions of carbon. This result proved that the rate of digestion of organic matter is directly linked with the carbon to nitrogen ratio. So, in order to improve the digestion time of other organic raw materials, a mixture of low and high carbon containing materials was used which helped immensely. This was in line with the previous results which showed that upon lowering the carbon content of digestive slurry, the rate of digestion improves. This study can help greatly in improving the efficiency of biogas reactors by decreasing the retention time, thereby more raw materials could be processed during a particular period of time which can reduce rotting of organic matter in the open which decreases the biogas yield.

Bouallagui et al. [22] studied the anaerobic digestion for biogas production from various fruit and vegetable wastes. The raw materials used for the study were analysed for their properties and their effect on the biogas production was studied. Also, different digester designs were studied to determine the best design for a given input of raw material. The raw materials used had a varying total solids from 8-19%, with simple sugars making up 75%, cellulose 8-9% and lignin nearly 5%.

A major limitation of using fruit and vegetable wastes for biogas production is their inherent capacity of lowering the pH value. This is due to rapid rotting of these wastes acidifying the digester volume which can hinder and completely halt the growth of methanogenic bacteria. The advantage of using two-phase system was realised as their innate ability to buffer of the organic loading rate that takes place in the first stage, making feeding rate continuous for the methanogenic second stage. Two-phase systems were extremely efficient of the upwards of 95% conversion efficiency of converting volatile solids to methane. The overall results of biogas production using fruit and vegetable wastes suggest that the two-stage system is a promising process to handle these type of wastes with high efficiency in terms of biogas production rate and decomposition efficiency. This efficiency is possible as bacteria in each reactor are capable of adaptation according to their organic mass. In conclusion aims to increase the biogas conversion efficiency by designing the digesters analogous to animals gasto-intestinal tracts and keeping the processes happening in reactors similar to it. This allows better understanding of the complex working of various bacteria working inside a digester to produce the biogas.

Knol et al. [23] studied mesophilic anaerobic digestion on various fruits and vegetables which are generally sold as a canned product like apples, beans, peas, strawberries etc. in a 90-day experiment at different loading rates from 0.80 to 1.60 kg volatile solids per m^3 per day. Biogas production rate ranged from 0.30 to 0.58 m^3 per kg of volatile solids per day. Carbohydrate-rich raw materials exhibit unbalanced digestion due to their very nature.

The study showed that biogas production is one of the best ways to treat the waste from fruits and vegetables industries. The retention times were kept shorter for this specific study, however if longer retention times in digester were used, more favourable results would have been obtained due to adaptations by methanogenic bacteria to the organic material. Over time these adaptations help methanogenic bacteria to work at higher efficiencies with better growth rates.

Viswanath et al. [24] studied the effect of feeding different fruit and vegetable wastes like apple, mango, banana, strawberry, spinach etc. in a 60-liter biogas digester by replacing the slurry of each raw material after five days. Various characteristics of these digested materials and the corresponding performance of digester such as biogas production were measured at various loading rates and hydraulic retention times. Maximum biogas production rate of 06 m^3/kg volatile solids added was attained at a 20 day hydraulic retention times and 40 kg total solids per m^3 per day loading rate. Biogas production rates were measured every hour for digester operating at 16 and 24 days hydraulic retention times. Maximum biogas of 74.5% was produced after 12 hours of digester feeding at a 16-day hydraulic retention times while at a 24-day hydraulic retention times only 58~92% of the maximum biogas was achievable during that time.

This study determines that fruit wastes like apple, mango, orange etc. and vegetables like tomatoes are suitable as raw material for the production of biogas if they are used in a batch mode reactor with shorter digester retention times like five days without the need of external supplementing with nitrogen compounds. The digester which was being operated at a 16 day hydraulic retention times and at a loading rate of 40 kg total solids per m^3 per day was in a smooth operation for a period of 1.5 years without any problems. During that time, it averaged biogas production rate of 0.5-0.6 m^3 per kg volatile solids added with a methane content of around 50-54%.

Lin et al. [25] studied the effects of mixture ratio on anaerobic digestion of fruit and vegetable waste. For the study, methane producing potential of various fruits and vegetables along with typical food waste was studied. Nominal values of biogas potential were found out to be 0.30 for fruit and vegetable waste, 0.56 m^3 CH^4/kg for leftover food waste were found.

However, food waste was found to be highly bio-degradable as it already broken down and has large surface area which allows better bacterial growth. The food waste could be decomposed as much as 84% with fruits and vegetable wastes at below 60%. Various fruits and vegetables were separately tested with loading rate of 3 kg/m^3 per day in a continuous stirred digester. The digestion of fruits and vegetable waste underwent without any problems with biogas production upwards of 2.2m^3 per day with methane content at 0.42m^3 per kg of volatile solids. But the digestion of food waste was unsuccessful initially due to too much lowering in pH inside digester. To mitigate this, mixing of fruit and vegetable waste with food waste was done at different ratios.

The co-digestion process was done with initial ratio of fruit vegetable waste and food waste as 2:1 to as low as 1:1 without any problems and the whole digestion process was stable without the abnormal rise in ammonium compounds or fatty acids. However, still lower ratios of 1:2 increased the volatile fatty acids to above 1100 mg/l which resulted in the decrease in the growth of methanogenic bacteria and the biogas production process was slightly hindered. The optimum ratio of fruit vegetable waste and food waste was found to be 1:1 which is super easy to maintain as one does not have to do any weighing of separate waste materials. The methane content of biogas was found to be 0.5m^3/kg of volatile solids for mixture ratio of 1:1. In conclusion, it was seen that the co-digestion is an appropriate technique to improve the digester stability and use food waste without the need of additional chemicals like lime to balance pH. This results in proper waste management of fruit and vegetable waste along with reduction in the running cost of digester.

6.1 Summary of Literature Review

The above studied research papers helped in providing the direction as to where to start and what are the problems associated with waste management. The authors have clearly stated that the waste management can only be done by the participation of each individual residing on the campus. It is also made clear that waste management is not a 'set and forget' system, it requires continuous participation and regular monitoring to make sure all the things are working properly. Classification of waste is given major importance along with informing general public about their harmful effects. Adoption of a proper waste management program is easier if people are provided with some alternatives that are just as easy to use. In the above studies waste is characterized, segregated and is utilized for the production of energy. Biogas production is given a lot of importance as it is one of the best ways to handle organic waste. Traditionally, biogas production is linked to the use of cow dung as a raw material in India but studies are done to use the fruit and vegetable wastes in the biogas production process. Various studies are done on the usage of different raw materials for the production of biogas. Numerous ways are being found out to improve the biogas yield and reactor stability for non-conventional organic wastes.

6.2 Gaps in Literature Review

The above literature review provides a lot of information on waste management using various techniques as well production of biogas. But there is little work done on waste management using leaves as a biogas production source. There is also little work done on the integration of household kitchen waste with the sewage waste and their common treatment at the sewage treatment plant. Also, little study on participation of a common citizen in dealing with the problems of rising waste is done.

CHAPTER 7

Research Methodology

The first course of action was to find out the various sources of wastes and to recognize the causes of their rampant use. Then various solutions which are easier to adopt are suggested. Then, biogas production process and its various aspects are studied. It was observed that the leaves on campus are not utilized properly so analysis of both green leaves and dried leaves is done for their viability as a raw material for biogas production. Surveys of some big sites were done to learn how they are handling their waste which led to some peculiar findings. It was noted that the kitchen waste of DTU faculty apartments was just mixed and discarded as garbage. This required some actions in the form of proposal for the issuance of two dustbins for each apartment: one for green waste and other for non bio-degradable waste. Segregation of waste at source is best at it requires least labour intensive, reduces the transportation of waste but produces the most amount of raw material for energy conversion purposes.

7.1 Campus Biogas Plant:

Biogas Plant in DTU campus is the largest of its kind in Educational Institutes of North India. It is made on a project cost of 95 lakhs with the capacity of handling 1 tonnes of raw waste per day producing 200 kgs of organic compost per day. At its peak, it is capable of generating 160 kw of energy per day.

This plant helps immensely in proper waste management of most of the bio-degradable waste produced in the DTU campus. Leftover food waste, raw vegetable and fruit peels, eggs etc. from all the hostel messes, canteen and other campus waste is used to produce biogas and organic compost. This not only provides with a clean energy source but also the waste gets properly handled.

7.1.1 Biogas Plant Running Data:

Over a period of nearly 3 months, daily running data of the plant was studied like total waste received, waste pH, digester pH, compost production, lime addition etc. This data helps in better understanding of the performance of the biogas plant and whether it is being utilised to its full capacity or not.

Table 7.1: Biogas Plant Data

Date (2019)	Waste Received (KG)	Waste pH Value	Digester pH Value	Gas Production (m^3)	Total Energy Generation (kWh)	Compost Generated (KG)	Lime Added
4-3	360	3.8	7.19	0.0	0:00	53	40
5-3	380	3.7	7.1	7.8	4.1	20	40
6-3	250	3.9	6.74	9.7	6.5	75	0
7-3	320	3.9	6.96	7.8	4.6	33	30
8-3	345	4.1	7.1	5.2	4.5	30	20
9-3	290	4.2	7.2	9.3	5.9	48	30
10-3	385	3.3	7.1	8.9	5.6	35	30
11-3	255	3.9	7.0	11.9	6.9	39	20
12-3	340	4.1	6.91	7.1	4.5	46	20
13-3	520	4.8	7.4	12.5	6.3	38	20
14-3	840	4.3	7.1	9.5	4.3	360	30
15-3	260	4.0	7.1	13.8	5.1	16	0
16-3	635	4.1	6.44	18	0	0	30
17-3	420	4.3	6.37	15.3	7.3	240	40
18-3	450	4.2	6.61	13.9	9.0	350	30
19-3	320	4.1	6.17	13.8	7.4	0	30
20-3	630	4.3	6.20	9.3	6.3	0	20
21-3	0	N/A	6.18	10	3.5	0	0
22-3	350	4.2	6.7	12.4	2.3	0	40
23-3	220	4.0	6.40	10	9.1	0	30
1-4	790	5.1	6.42	13.3	10.4	28	60
2-4	620	5.2	6.43	14.4	9.7	30	60
3-4	650	5.2	6.72	19.1	11.3	10	80
4-4	600	4.6	6.75	16.9	12.6	190	80
9-4	760	5.0	6.71	7.1	8.3	110	60
10-4	800	5.1	6.48	17.5	13.2	175	80
16-5	600	5.4	7.3	15.3	1.5	50	40
18-5	500	5.2	7.02	26.4	9.4	70	40
19-5	640	5.1	7.06	30	12.7	20	40
20-5	750	5.6	7.5	35	12.6	50	40
21-5	750	5.2	7.0	26.4	8.6	40	50
22-5	850	5.1	7.1	32.2	9.4	100	40
24-5	900	4.9	7.3	34.7	19.3	65	40
25-5	350	4.8	6.96	28.6	11.6	30	40
28-5	650	5.2	7.03	32.2	5.3	40	50
29-5	350	5.1	7.0	31.2	4.7	50	40
31-5	550	5.2	7.3	29.3	10.4	0	40
1-6	60	4.9	6.98	29.6	11.9	70	30
2-6	280	4.6	6.86	32.4	14.9	100	40
3-6	280	5.1	7.0	29.7	12.4	80	50
4-6	200	4.9	7.1	29.4	14	90	60
5-6	220	5.8	7.05	30.2	14.4	0	40

7.2 Biogas Production from Dry Leaves

The leaves falling from so many trees on the university campus can be a very good resource for the production of biogas. During autumn season this resource increases exponentially, so it is best to utilise the leaves for biogas production as it has multiple benefits like waste management, biogas production, production of fertiliser for soil, prevention of fires as dried leaves are a good fire starter etc.

7.2.1 Preparation: The leaves falling from the trees are often dry and need to be soaked before feeding to facilitate their crushing, and better production of biogas. Soaking makes the leaves softer and leaves become ready for decomposing. Various time frames of soaking were tested and about 10 days seems to be the optimum time but they can be used as early as 3 days. After 10 days, the leaves start decomposing in the water and upon feeding in the digester produces instant biogas.

7.2.2 Feeding: After 10 days, the leaves start decomposing in the water and upon feeding in the digester produce biogas rather quickly. 20 kgs of these pre-treated leaves are mixed with 200 kgs of other raw materials such as cooked food waste, raw vegetable waste, skins etc. This is done so as to maintain the optimum C/N ratio. The density of leaves is very less as compared to food waste so the volume of 20kgs of leaves is nearly equal to the volume of the volume of food waste. The leaves are fed for three days. This is done so as there are leaves in the digester at each stage of digestion. This increases the reliability of the results.

7.2.3 Biogas Composition Analysis: Gas Analyser is used to analyse the composition of the biogas produced with leaves and the data is compared with the biogas without the introduction of leaves in the digester feed. Biogas is analysed first without the addition of leaves to get a baseline value, then 3 readings were taken on consecutive days after 2 days of leaves addition.

Table 7.2: Day-to-day changes in the soaked leaves

Day	Colour	Smell	pH Value	Softness
1	Brown	Natural	5.71	Hard
2	Brown	Natural	5.72	Blade is softer
3	Colour starts changing to black	Slightly pungent	5.74	Veins are softer
4	More leaves are black	Slightly pungent	5.76	Midribs are softer
5	Most of the leaves are black	Pungent	5.78	Midribs are even softer
6	All the leaves are black	More pungent	5.81	Petioles are softer
7	Colour becomes richer	More pungent	5.85	Petioles are even softer
8	Even richer	More pungent	5.88	Petioles are very soft
9	Very dark black	Highly pungent	5.92	Whole leaves are highly Soft
10	Very dark black	Highly pungent	5.97	Whole leaves are highly Soft

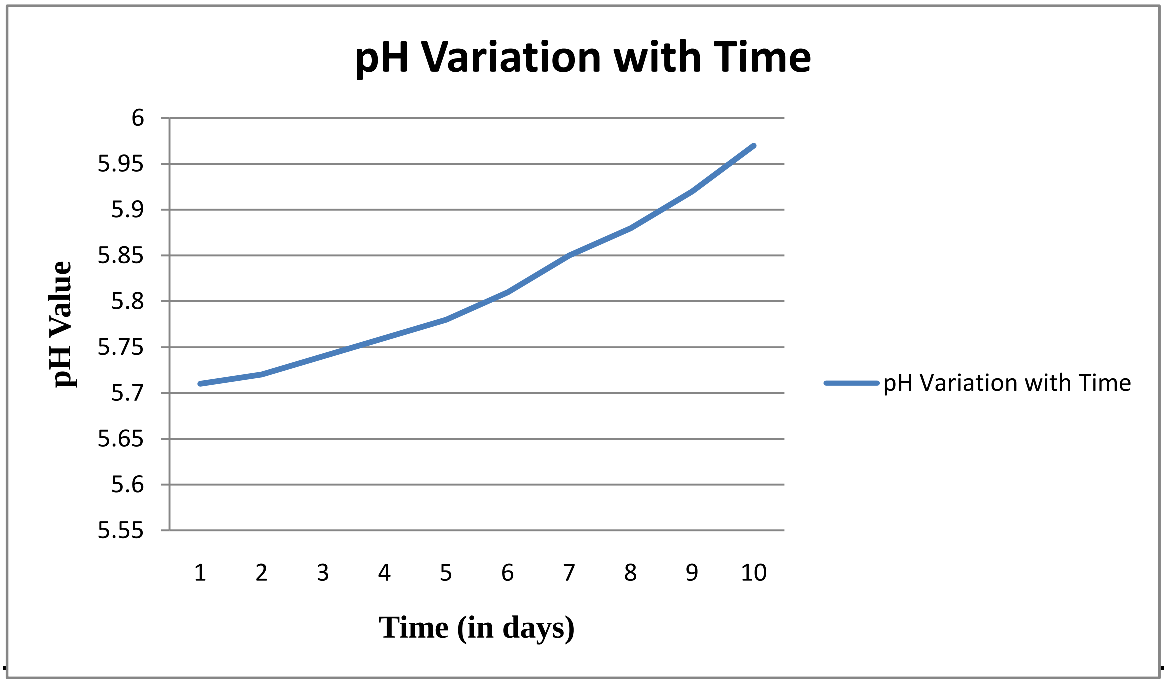


Figure 7.1: pH Variation during Soaking

It is seen from the above graph that soaking of leaves leads to a general increase in the pH of leaves which is a good thing for the reactor.

Table 7.3: Biogas Composition w/dry leaves

	Methane (V/V)	Carbon Dioxide (V/V)	Oxygen (V/V)	Hydrogen Sulphide (PPM)
No Leaves	38.2	37.1	0.4	845
Day 1 With Leaves	36.0	34.1	6.2	373
Day 2 With Leaves	36.4	35.3	6.1	360
Day 3 With Leaves	37.5	36.2	4.6	350

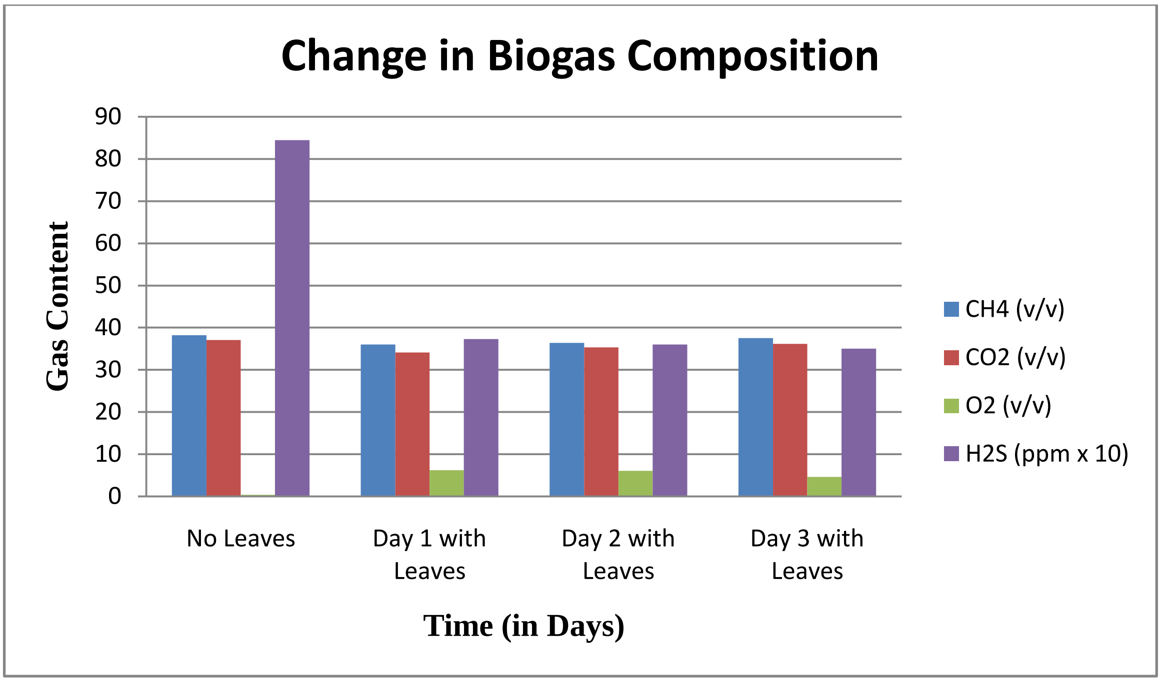


Figure 7.2: Biogas Composition Variation with Time

As can be seen from the graph, methane production starts slower in case of leaves as compared to food waste. Also, leaves produce appreciably less hydrogen sulphide which is useful for using biogas in engines. The carbon dioxide content is similar to the biogas without leaves but the oxygen content is appreciably more which can help in the burning of biogas.

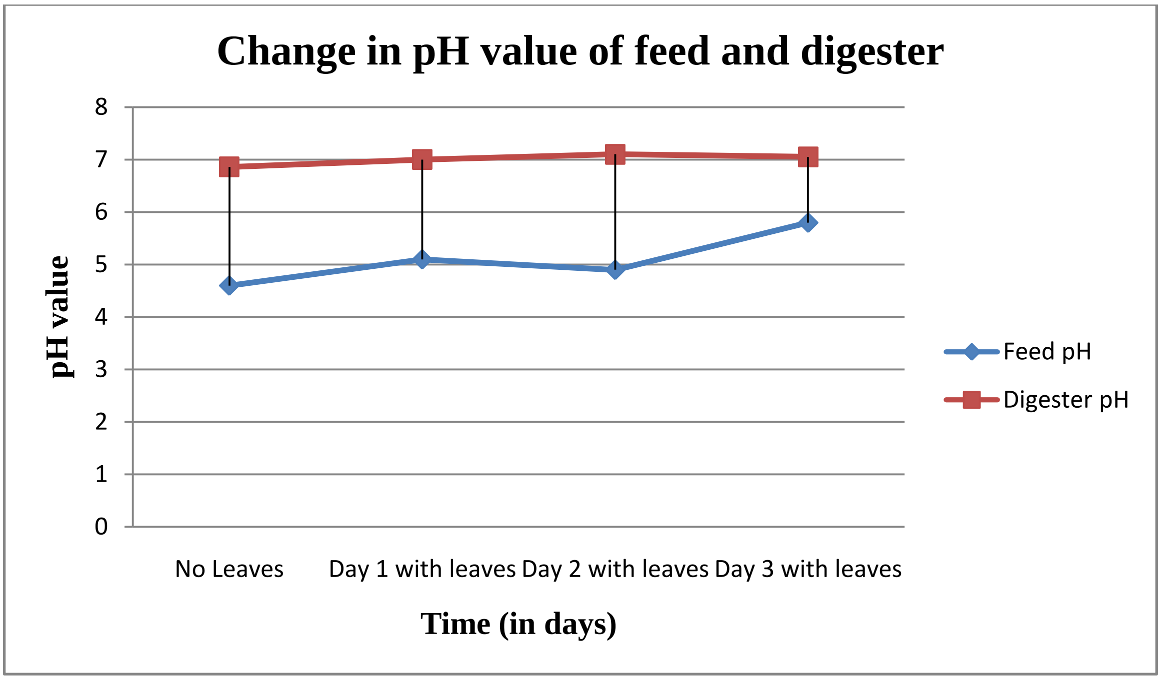


Figure 7.3: pH Variation with Leaves

Soaked Leaves have relatively higher pH resulting in less need of lime to be added to increase the pH. This acts as a good cost saving measure as well.

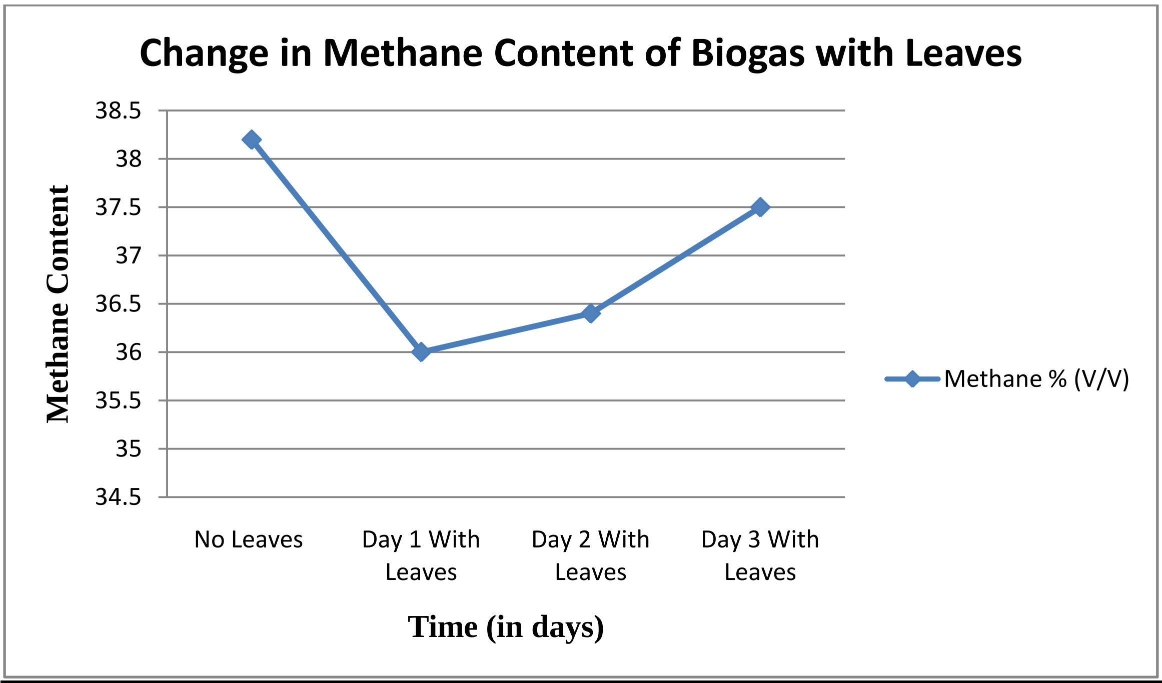


Figure 7.4: Methane Variation with Leaves

It is clear from the graph that the biogas production rate is slower in the beginning but it gradually increases to a normal value.

Figure 7.5: Dry Leaves

Figure 7.6: Soaked Leaves

Figure 7.7: Leaves After 10 Days of Soaking

Figure 7.8: Crushing of Leaves

Figure 7.9: Crushed Leaves

Figure 7.10: Biogas Storage

7.3 Biogas Production from Green Leaves

Apart from the fallen leaves, green leaves are also cut from the trees during their regular cutting, cleaning of parks, trimming of lawns etc. These leaves can also be utilized as a raw material for biogas production which also generates organic fertiliser for soil.

7.3.1 Preparation: Green grass of various types and leaves of many kinds of trees found in university campus were collected and transported to the biogas plant. Green leaves require no extra preparation as can be directly sent to the crusher from which they are transferred to the digester with the help of pump.

7.3.2 Feeding: Green leaves are fed directly to the crusher without any pretreatment. As green leaves are high in nitrogen, so they need mixing with brown matter like waste fruit and vegetable waste to keep carbon to nitrogen ratio within optimum range of 25:1 to 30:1. 40kgs of these mixed green leaves are mixed with 300 kgs of fruit waste like pomegranate skins, lime fruit and orange skins etc and uncooked vegetable waste like green leafy vegetables cuttings, rotten tomatoes etc. The volume of leaves was nearly equal to the volume of other waste.

7.3.3 Biogas Composition Analysis: Gas Analyser is used to analyse the composition of the resulting biogas. Biogas is analysed after a period of one and two days to see the change in the composition in the biogas, if any.

Table 7.4: Biogas Composition w/ green leaves

	Methane (V/V)	Carbon Dioxide (V/V)	Oxygen (V/V)	Hydrogen Sulphide (PPM)
Day 1 Without Leaves	34.3	37.7	5.8	365
Day 2 With Leaves	46.2	58.3	0.3	956
Day 3 With Leaves	45.8	56.3	0.4	915

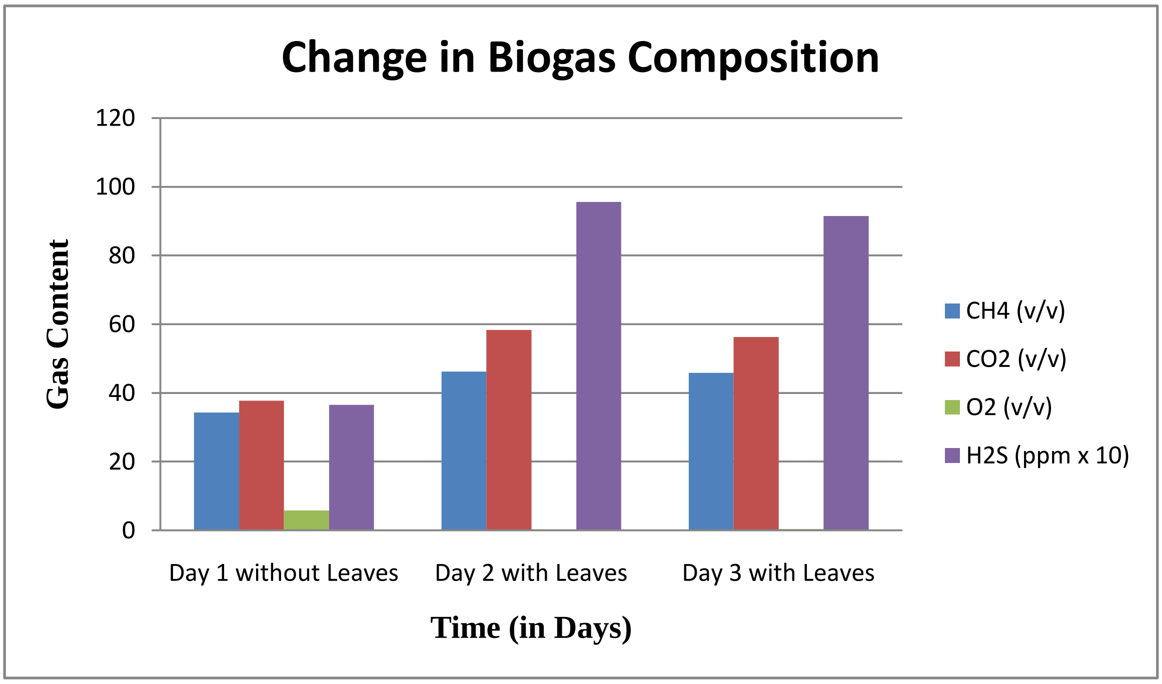


Figure 7.11: Biogas Composition Variation with Time

Thus, it can be seen that using green leaves dramatically increases the methane content in biogas along with carbon dioxide. So, it becomes clear that green leaves are a very good source for biogas production and should be utilized as much as possible.

Figure 7.12: Green Grass

Figure 7.13: Green Leaves

Figure 7.14: Grass Feeding

Figure 7.15: Leaves Feeding

CHAPTER 8

Bio-degradable waste management in some major sites in Delhi: A Survey

8.1 Introduction

Indian products have to face tough competition in export markets due to strict restrictions on quality standards implemented by developed countries. This makes the Indian products tougher to export due to various quality issues like excessive pesticide use which leaves small amounts on the product, shorter shelf life due to poor storage and handling etc. About 40% of the fruit and vegetable produce gets wasted because of poor handling and management practices. Agricultural products in India are still grown using traditional methods while there are better techniques like vertical stacking, climate controlled chambers, automatic water sprinklers etc. India faces a rampant use of pesticides and synthetic fertilisers without actually testing the soil for the proper requirement of nutrients. Even post harvesting, due to lack of proper storage and transport facilities, nearly 30 percent of harvest is wasted. Lack of proper storage leads to more than 10 percent of grains to be eaten by rats. India needs at least 10 million tonnes of additional cold storage facilities. Most of the agricultural produce of India remains unprocessed which drastically decreases its shelf life, increases perishability and needs larger area to be stored. Only 7 percent of Indian produce is processed which way less than international standards. This leads to a massive loss to the Indian economy as well as a production of waste material. Recycling of fruit and agricultural waste can solve at least one of the major problems of Indian agriculture with many benefits like electricity generation, cooking gas, organic fertiliser, disease prevention due to microbes and insects etc.

In view of aforementioned points, the survey is meant to study the existing methods of managing the agricultural and bio-waste. Survey of some major bio-degradable waste producing sites in Delhi like Azadpur Mandi, Shree Krishna Gaushala and Grameen Gaushala (Bhawana) is done to study their waste management practices. This survey helps in better understanding the ways how waste in large quantities is handled.

8.2 Azadpur Mandi:

Delhi's famous Fruit and Vegetable Market at Azadpur has experienced great strides in progression in the last few decades. Better management, facilities and efforts of participation in achieving goals by the market committee and officials have increased the credibility of the organization. In 5^{th} of November ,1976, Delhi Agricultural Produce Marketing Regulation Act was in Delhi for regulating the agricultural produce marketing. This act is replaced with the new act called Delhi Agricultural Marketing Regulation Act in year 1998. On 7^{th} of January 2004, Fruit & Vegetable Market Azadpur is acknowledged as Market of National importance. There are 118 products that are imported and exported in the Azadpur Mandi of which 50 are fruits and 68 are vegetables. Azadpur Mandi is the largest Fruit and Vegetable Market in the Asia today.

8.2.1 Statistics About Azadpur Mandi:

Area: 160 acres

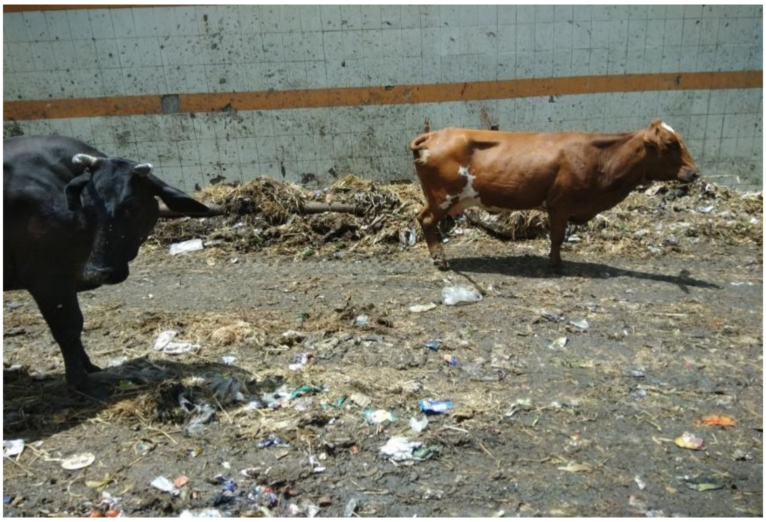
Yearly Arrivals of Fruits: ~2.5 million tonnes

Yearly Arrivals of Vegetables: ~3 million tonnes

Waste Generated Daily: ~220 tonnes daily

Each block in the Azadpur Mandi has its own dump-yard where the waste is collected. JCBs are used to collect the waste and load it into trucks which transfer the waste to various nearby power plants for power generation.

<u>Figure 8.1: Azadpur Mandi Dump Yard</u>



<u>Figure 8.2: Azadpur Mandi Dump Yard</u>

<u>Figure 8.3: Azadpur Mandi Dump Yard</u>

8.3 Gaushalas:

Gaushalas are home to cows in India where wandering cows are kept. Due to urbanisation, natural habitat of cows called range-lands are destroyed to create buildings, roads or other structures. This causes cows to roam on streets where they can block public roads or cause accidents. So, Gaushalas act as a safe shelter for cows. Gaushalas produce huge amounts of bio-degradable waste as cow dung so it provides with a good opportunity for proper usage of cow-dung so that it can be utilised in fields as fertilisers or to produce biogas etc.

8.3.1 Shri Krishna Gaushala:

It is the largest Gaushala in Delhi-NCR area situated in Bhawana. It has area of 37 acres and is home to 8500 cows. It can hold five thousand tonnes of animal feed in its warehouse. There are two water pools with clean drinking water. Regular cleaning is done by 8 Tractors, 75 Ox-pulled buggie and, 1 JCB. Solar panels are used for electricity generation. 10 tonnes of green fodder is produced every day by the hydroponic method for weak and ill cattle.

Nearly 80 tonnes of cow-dung is produced every day which is fed into biogas plant. The resulting biogas is used to make food for 300 people.

Besides waste handling, there were many other fascinating things to be learnt about this Gaushala. The ways of handling such a large number of cows, taking care of their feeding, drinking requirements, medical care, process of salvaging cows from roadsides were shockingly good.

<u>Figure 8.4: Shri Krishna Gaushala Cow Shed</u>

<u>Figure 8.5: Shri Krishna Gaushala Cow Shed</u>

<u>Figure 8.6: Shri Krishna Gaushala Cow Shed</u>

Figure 8.7: Shri Krishna Gaushala Biogas Plant Digester

Figure 8.8: Shri Krishna Gaushala Biogas Plant Slurry Outlet

8.3.2 Grameen Gaushala:

This Gaushala is near Shri Krishna Gaushala in Bhawana. The cows are a lot more congested here with inadequate roofing to save them from sunlight. It is home to 3500 cows producing 30 tonnes of cow-dung each day. Nearly all the grass for cows is donated by the local people. The cow-dung is taken by the grass donors which is used as a manure in their fields.

Figure 8.9: Grameen Gaushala Shed

Figure 8.10: Grameen Gaushala Shed

8.4 DTU Campus:

Delhi Technological University Campus has an area of 164 acres with apartments for faculties and hostels for boys and girls. Currently, there are about 10,000 students studying here. There are 8 hostels for boys and 6 hostels for girls and a hostel for married couples. The capacity of hostels for boys is 1284 students and for girls is 334 students. The students of hostels have their own respective mess for food facilities and the leftover food waste is properly managed by converting to biogas.

Students living in hostels reveal that due to no market place inside the hostel area, there is little to no packaging waste entering hostels. Also, most of their eating is done in their mess which further reduces the organic waste in hostels. Only a small amount of plastic waste is, therefore, expelled from the hostels which can be confirmed by checking their dust bins. Despite each hostel being the size of a colony, only a small amount of waste is produced by hostels. DTU campus produces on average 100-120 kgs of plastic waste everyday which is mostly segregated and it is transferred to recycling facilities everyday.

8.4.1 Faculty Apartments Initiatives: DTU has a total of 5 residential apartment buildings faculty members and their respective number of apartments are as:

Type 1: 60

Type 2: 105

Type 3: 45

Type 4: 60

Type 5: 56

So, in total there are 326 apartments where faculty members live with their families. Their average kitchen waste per day is around 1.5-2 kgs. This waste is currently being mixed with the other non bio-degradable waste and is not being utilised or managed properly. The major reason for this is lack of segregation of household waste at the source. To tackle this issue, a proposal has been filed regarding issuance of separate dustbins in each faculty apartment for organic and inorganic waste. If all the organic waste from these apartments gets collected and used for biogas production, it will be more than 400 kgs of additional raw material for campus biogas plant. It will also reduce the organic waste mixing with the plastic waste which will make recycling of the latter easier.

8.4.2 Canteen and other small shops waste: Due to a large number of students coming to campus everyday, a lot of waste in the form of cups and plates is formed. The major causes of this waste are the cups used for tea, shakes, juices and the plates used for snacks. Although, at first glance they seem to be perfectly recyclable as they look to be made up of paper. While they may be made up of paper, they have a thin coating of plastic on the inside to make them leakproof in case of cups and to avoid oil seepage from snacks in case of plates. This plastic film is nearly impossible to remove. So the cups and plates can neither be recycled as paper or as plastic which means they will end up in landfills.

Solutions:

If all the cups and plates are replaced with stainless steel ones, then a lot of waste will automatically be reduced as not producing the waste is the best type of waste management. Also, reusable glass jars can be used for shakes and juices. This will also decrease the transportation involved with their procurement and disposal.

CHAPTER 9

CONCLUSION AND FUTURE SCOPE

9.1 Conclusion

This study shows that even eco-friendly or biodegradable products are just as bad for the environment if they are not disposed properly. Talking about plastics, there are simple ways to reduce their amount in our environment.

The campus biogas plant is currently not being utilised to its maximum potential. Inclusion of waste from apartments will help in this regard. Utilisation of fallen leaves for biogas production will decrease the waste as well as act as a great source of biogas.

Survey of some major sites reveal interesting things about the present scenario of waste management and it shows that people and the government are becoming more aware every day to tackle the waste problem. It also shows the utilisation of waste for non-conventional energy sources which is a major step towards a clean and pollution-free environment in the future.

As India's urban population is increasing day by day and new housing buildings are being made along with the advent of smart cities. If waste disposer system is installed in all the houses of urban India that are linked to sewage treatment plants, then a lot of waste will be automatically handled. This will greatly reduce transportation of waste and the segregation involved. This will indirectly also increase the recyclability of plastics in our waste.

In Conclusion, there are a lot of opportunities in the future which can lead us towards a true net zero waste India.

9.2 Future Scope

1. Biogas generation from leaves using batch type system can be studied for a longer retention time.

2. Reduction in hydrogen sulphide in the biogas from dried leaves can be further studied.

3. Biogas generation from wheat stubble can be done as it is one of the major culprits of particulate matter pollution.

4. Addition of various chemicals to break down the leaves faster can be studied.

5. Surveys of different sites around the nation need to be done to see how they have improved over the years.

6. Analysis of DTU campus biogas plant should be done again after the waste from faculties starts to be used there.

7. Replacement of all the cups and plates used in canteens with steel ones and again calculate the reduction in campus waste and overall effect on environment.

REFERENCES:

[1] World Bank.World development indicators. Retrieved on 15,5,2019, from http://databank. worldbank.org/data/reports.aspx?source=worlddevelopment-indicators (2019)

[2] *Press Information Bureau, Ministry of Environment, Forest and Climate Change, GOI.* Retrieved on 16,5,2019, from http://pib.nic.in/newsite/PrintRelease.aspx?relid=138591. (2016)

[3] Sambyal S.S., Agarwal R. NITI Aayog's solution to India's solid waste management. Retrieved on 17,5,2019, from https://www.downtoearth.org.in/news/waste/burn-it-all-58827 (2017)

[4] Amon T., Hackl E., Jeremic D., Amon B. & Boxberger J. Biogas production from animal wastes, energy plants and organic wastes. *Applied Microbiology and Biotechnology*, (2001), 850-857.

[5] Bagi Z., Ács N., Bálint, B., Horváth L., Dobó K. & Perei K. R. Biotechnological intensification of biogas production. *Applied Microbioligy and Biotechnology Vol 76*, (2007). 473-482.

[6] Sasse L. Biogas Plants. *German Appropriate Technology Exchange*, Deutsches Zentrum fur Entwicklungstechnologien (1988), 28-35.

[7] Aziz N. I., M.Hanafiah M., Yasreen M., & Ali M. Sustainable biogas production from agrowaste and effluents – A promising step for small-scale industry income. *Renewable Energy* (2018), 363-369.

[8] Bachmann N., Erep S.A. Design and engineering of biogas plants. *The biogas handbook.* Switzerland: Woodhead Publishing Series in Energy (2013), 191-211.

[9] Saleh A. Comparison among different models of biogas plants. *Department of Chemical Engineering*, COMSATS Institute of Information Technology, Lahore. (2015).

[11] Moezzi E., Muhammad A. M., Kamarudin K. H. & Wahab M. H. Realising “Green Campus” through Waste Management. *1st Regional Conference on Campus Sustainability*. Kota Kinabalu, Sabah, Malaysia (2014)

[12] Mason I. G., Brooking A. K., Oberender A., Harford J. M. & Horsley P. G. Implementation of a zero waste program at a university campus. *Resources, Conservation and Recycling 3(8)* (2002), 257-26.

[13] Qingshi Tu, Chao Zhu & Drew C. McAvoy. Converting campus waste into renewable energy – A case study for the University of Cincinnati. *Waste Management* (2015), *39*.

[14] Hadya B. & Jaipalreddy P. Enhancement of Bio-Gas Yield from Dry and Green Leaves by Inoculation. *International Journal of Latest Engineering and Management Research Vol. 2(10),* (2017), 07-12.

[15] Wannapokin A., Ramaraj R., Unpaprom Y. An investigation of biogas production potential from fallen teak leaves. *Emergent Life Sciences Research 3* (2017), 1-10

[16] Rouf M. A., Islam M. S., Rabeya T. & Mondal A. K. Anaerobic digestion of mixed dried fallen leaves by mixing with cow dung. *Bangladesh Journal of Scientific and Industrial Research*, *50*(3) (2015), 163-168.

[17] Tanimu M. I., Tinia I., Ghazi M., Harun R. M. & Idris A. Effect of Carbon to Nitrogen Ratio of Food Waste on Biogas Methane Production in a Batch Mesophilic Anaerobic Digester. *International Journal of Innovation, Management and Technology* Vol. 5(2), (2014), 116-119.

[18] Mane A. B., Rao B., & Rao A. B. Characterisation of fruit and vegetable waste for maximizing the biogas yield. *2nd International Conference on Science and Technology*, (2015), 1892-1900.

[19] Shrimal S. & Khwairakpam M. Effect of C/N ratio on Vermicomposting of Vegetable Waste. *Global Science Book,* (2010), 123-126.

[20] Deressa L., Libsu S., Chavan R. B., Manaye. & Dabassa A. Production of Biogas from Fruit and Vegetable Wastes Mixed with Different Wastes. *Environment and Ecology Research* 3(3), (2015), 65-71.

[21] Orhorhoro O. W., Orhorhoro E. K. & Ebunilo P. O. Analysis of the Effect of Carbon/Nitrogen (C/N) Ratio on the Performance of Biogas Yields For Non-Uniform Multiple Feed Stock Availability and Composition in Nigeria. *International Journal of Innovative Science, Engineering & Technology, Vol.3(5),* (2016), 119-126.

[22] Bouallagui H., Touhami Y., Cheikh R. B. & Hamdi M. Bioreactor performance in anaerobic digestion of fruit and vegetable wastes. *Process Biochemistry 40*, (2005), 989-995.

[23] Knol W., Most M. & Waart J. Biogas Production by Anaerobic Digestion of Fruit and Vegetable Waste. A Preliminary Study. *J.Sci.Fd Agric.*, (1978), 822-830.

[24] Viswanath P., Sumithra Devi S. & Krishna N. Anaerobic digestion of fruit and vegetable processing wastes for biogas production. *Bioresource Technology 40*, (1992),43–8.

[25] Lin J., Zuo J., Li P., Liu., Wang K., Chen L. & Gan H. Effects of mixture ratio on anaerobic co-digestion with fruit and vegetable waste and food waste of China. *Journal of Environmental Sciences* 23(8), (2011), 1403-1408.