# JIMMA UNIVERSITY

## JIMMA INSTITUTE OF TECHNOLOGY

## SCHOOL MECHANICAL ENGINEERING

## SUSTAINABLE ENERGY ENGINEERING POST-GRADUATE PROGRAM

**MSc. Thesis**
**On**

# Potential assessment, design and implementation of biogas system from dining hall and kitchen wastes at Kito Furdisa Campus

**By**

**Fikiru Tafase**

**Thesis submitted to the school of graduate studies of Jimma institute of Technology, in partial fulfillment of the degree of masters of Science in *Sustainable Energy Engineering***

**Advisor: Professor Dr. A. Venkata Ramayya**

**Co-Advisor: Dr.-Ingr Getachew Shunki**

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Jimma, Ethiopia

**JIMMA UNIVERSITY**

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# Declaration

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been acknowledged.

| | | |
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The thesis entitled, '**Potential assessment, design and implementation of biogas system from dining hall and kitchen wastes at Kito Furdisa Campus**' submitted by **Fikiru Tafase** to Jimma institute of Technology in partial fulfillments for the degree of Master of Science in Sustainable Energy Engineering is here by recommended for final evaluation and examination.

| | | |
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## Acronyms

| | |
|---|---|
| AD | Anaerobic Digestion |
| HRT | Hydraulic Retention Time |
| WEC | Waste to Energy Conversion |
| JiT | Jimma Institute Technology |
| SEE | Sustainable Energy Engineering |
| ETB | Ethiopian Birr |
| VFA | Volatile Fatty Acids |
| VS | Volatile Solid |
| OLR | Organic Loading Rate |
| T | Temperature |
| CHP | Combined Heat and Power |
| V | Volume |
| CV | Calorific Value |
| EUC | European Union Commission |
| USEPA | United States Environmental Protection Agency |
| GC | Gas Chromatography |
| OFMSW | Organic fraction of municipal solid waste |
| MSW | Municipal solid waste |
| PH | Hydrogen ion concentration |
| SCOD | Soluble Chemical Oxygen Demand |
| DD | Degree of Disintegration |
| WAS | Waste Activated Sludge |
| NPV | Net Present Value |
| PB | Pay Back |

## Summary

Energy from waste is about taking waste and turning it into a useable form of energy. This can include electricity, heat and methane from waste source. Waste to Energy Conversion (WEC) technology provides an alternative source of renewable energy in a world with limited or challenged fossil reserves. The most common conversion method is through biological treatment method via anaerobic digestion. Anaerobic digestion is a waste-to-fuel application that waste can be converted into purified biogas which can then be used to power and to create heat or electricity.

Food wastes and kitchen wastes reduction is the first step to food waste management. As long as proper food safety and handling practices are followed, reusing leftover food can save money and reduce waste. Creatively repurpose leftovers and trimmings to efficiently use excess food for other meals. Flexibility in menu planning to accommodate the use of excess food from previous meals is a good way to extract energy from those wastes. Also, diverting wasted food to anaerobic digestion can generate renewable energy (biogas) and create a valuable soil amendment.

Jimma University, JiT, Kito Furdisa Campus currently generates approximately 33,902 Kg/month of food waste and kitchen waste by the on-campus dining halls. Production of dining hall wastes is seasonal, as food preparation needs decrease significantly in mid of July and August. While dining hall and kitchen wastes provides a significant potential source for feedstock energy and in anaerobic digestion processes. These wastes should be an acceptable feedstock for the anaerobic digestion process.

From food and kitchen wastes of Kito Furdisa Campus of Jimma Institute Technology about 33,902 kg of wastes is assessed within a month and biogas plant of 322m$^3$ volumes is designed and also total biogas produced is calculated 113m$^3$ / day. This gas produced using energy conversion gives us 722kwh of power per day. Based on biogas produced it diverted to combined heat and power (CHP) system to generate electricity and heat that recovered to produce hot water using stove for cafeteria of Kito Furdisa and its kitchen itself. Energy consumption of this anaerobic digestion of system in dining hall & kitchen wastes give us 41.03 kwhr and the net energy used is 681 kWh which used for CHP. This means the production of electricity will be 75.42MWh/y and the production of heat will be 138.27MWh/y.

When we generate the biogas from food and kitchen wastes, we have to use like addition of bacteria from other biogas generating wastes, fresh cow dung and availing digester surrounding temperature which can quickly give up bacteria that start up the process of acidogenesis. Cleaning unusable and dirty oil is also speeding up our work progress easily.

General objective of this thesis is that to extract energy from Dining Hall and kitchen wastes of Kito Furdisa Campus, through Anaerobic Digestion process at Jimma University, Institute Technology.

The methodology to work this project is that; collecting data of Food Waste and kitchen wastes, analyzing by experimentally both dining hall and kitchen wastes using small scale set up constructed digestor and lastly designing biogas plant using amount of waste assessed. From economic cost analysis the pay back of this project takes about 5 years to replace its overall cost work.

# 1. Introduction

## 1.1 Background

As the demand for energy increases worldwide, it is surprising to learn that a seemingly insignificant part of everyone's life could lead to technology with the potential to produce Electricity. Energy can be recovered from waste by various (very different) technologies. It is important that recyclable material is removed first, and that energy is recovered from what remains, i.e. from the residual waste. The fact that humans eat and throw away food is inevitable. Likewise, it is obvious that we need a source of energy to cook food, heat homes, etc. The production of biogas from waste is admittedly a complicated process on the microbial level. However, it is beneficial for universities and industries to take advantage of the high yield process [2].

Biogas, produced during anaerobic digestion of biodegradable organic solids, typically contains about 60–65% methane, which is a valuable resource and can be used to offset part of the energy requirements for in-plant use. With rising electricity and natural gas costs, there is an incentive for utilization of biogas as an energy source. Biogas collection and utilization technologies have steadily improved over the years, and energy recovery from biogas is developing into a successful "waste/residues-to-bioenergy" technology [3].

Typical biogas yield values for an anaerobic digester treating primary and waste activated solids range from 0.8 to 1.0$m^3$/kg of volatile solids (VS) destroyed at mesophillic conditions. The amount of gas produced, however, depends on several factors such as temperature, pH and alkalinity, hydraulic and organic loading rates, toxic compounds, substrate type, and total solids (TS)/volatile solids (VS) content.

**Table1.1 Theoretical methane percent for different waste streams.**

| Waste type | Reaction | $CH_4$ in Biogas (%) |
|---|---|---|
| Carbohydrate | $(C_6H_{10}O_5)n + nH_2O \rightarrow 3nCH_4 + 3nCO_2$ | 50 |
| Protein | $4C_{11}H_{24}O_5N_4 + 58H_2O \rightarrow 33CH_4 + 15CO_2 + 19NH+_4 + 16HCO-_3$ | 69 |
| Lipids | $4C_{15}H_{90}O_6 + 98H_2O \rightarrow 139CH_4 + 61CO_2$ | 70 |

(Source: Anaerobic Biotechnology for Bioenergy Production Principles and Applications)

Biogas is a clean-burning, "green" fuel used for heating and cooking, transport and power generation. Biogas usually contains about 55-65% methane, 30-35% carbon dioxide, and traces of hydrogen, nitrogen and other impurities. It's typically refers to a gas produced by the biological breakdown of organic matter such as dead plant, animal material, animal feces, and kitchen waste in the absence of oxygen. Biogas can be used as a fuel in any country for any heating purpose, such as cooking, electricity and when compressed like natural gas can be used as vehicle fuel to power motor vehicles. Biogas is a renewable fuel, so it qualifies for sustainable energy subsidies in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio methane [4].

Kitchen waste with its high water content is an ideal carrier of disease and odor but these problems can be solved by converting food waste to energy in the form of biogas. According to [27], food waste produces two clean energy gases hydrogen and methane (other waste materials just produces methane gas), which can be burned to produce electricity and heat, or to propel vehicles.

Once the economy is in a better state, these decisions can be made on an informed and educated basis. Whenever these technologies are implemented, they will bring about more than just economic benefits; renewable technologies benefit society through the economically intangible ways of environmental improvements, appeal to ethics and social benefits.

This paper explores the results from designed and implementation of anaerobic digesters aimed to assess biogas production of wastes from the Kito Furdisa Campus Students' Dining Hall and kitchen at Jimma Institute Technology. Based on a review of the scientific literature concerning the project, it seemed that the experimental digesters would be able to produce a substantial amount of biogas. This level of biogas production would in turn mean that this technology could be a viable investment for Jimma Institute Technology to make further development of the project included small scale up implementation, design and to evaluate the economic and social benefits of the system.

Jimma University, JiT, Kito Furdisa Campus currently generates approximately 33,902 Kg/month of food waste and kitchen waste by the on-campus dining halls. Production of dining hall and kitchen wastes are seasonal, as food preparation needs decrease significantly in mid of July and August. This waste provides a significant potential source for feedstock energy and in anaerobic digestion processes. These wastes also should be an acceptable feedstock for the anaerobic digestion process.

Anaerobic digestion of organic waste provides many benefits. This includes the generation of renewable energy, a reduction of greenhouse gases, a reduced dependency on fossil fuels, job creation and closing of the nutrient cycle. It transforms organic waste material into valuable resources while at the same time reducing solid waste volumes and consequently waste disposal costs. Biogas as a renewable energy source not only improves the energy balance of a country but also contributes to the preservation of the natural resources by reducing deforestation and to environmental protection by reducing pollution from waste and use of fossil fuels.

This project helps to create an organic processing facility to create biogas which will be more cost effective, eco-friendly, cut down on landfill waste, generate a high-quality renewable fuel, and reduce carbon dioxide & methane emissions. Overall by creating a biogas reactor on campus of our food wastes from dining hall and kitchen will be beneficial.

**Easily Biodegradable:** Food waste is highly biodegradable and has a much higher volatile solids (VS) destruction rate (86-90%) than biosolids. This means that even though additional material is added to the digesters, the end residual will only increase by a small amount [6].

**Renewable Energy Generation:** Arguably, the most important reason that food waste should be anaerobically digested is for capturing the energy content. Unlike biosolids and animal manures, post-consumer food scraps have had no means of prior energy capture. In fact, in a study done by East Bay Municipal Utility District it was revealed that food waste has up to three times as much energy potential of methane production as biosolids. That means [6].

- Cattle manure= 25m³ gas/ton
- Biosolids= 120 m³ gas/ton
- Food waste= 376 m³ gas/ton

As energy prices continue to climb and our nation looks towards renewable energy generation and energy independence, capturing the energy from food and kitchen wastes become more important. When facilities start digesting food waste, the increased energy production allows them to offset the amount of energy they are using and potentially sell excess energy back to the grid.

**Fig 1.1 Post-consumer food waste will produce energy and a soil amendment when anaerobically digested and then composted [6].**

### 1.1.1 Biochemical Processes

In recent years, anaerobic digestion technology has seen rapid growth. Biogas plants around the world have experienced a 20 to 30 percent increase each year with most experienced and well-developed markets being in Germany, Denmark, and Austria. As of 2007, Germany has 3,700 biogas plants in operation [1], Denmark has 20 centralized plants and 35 farm scale plants in operation [9], and Austria has 323 plants with an electrical capacity of 81MW.

In other parts of the world, AD technology also flourishes as a waste-to-energy solution but on a smaller scale and in a decentralized manner. In 2007, China had an estimated 18 million biogas digesters and in India there are currently over 5 million small-scale biogas plants in operation. The volumes of the digesters range from $2m^3$ to $20m^3$ and they are usually fed household and agricultural wastes. The biogas is predominantly used for personal cooking and lighting purposes [1].

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**Description of Process**

Anaerobic digestion is a complicated biochemical process. Based on temperature and input substrate, different strains of bacteria digest complex chains of carbohydrates, fats, and proteins into their component parts, then again into intermediate, simpler molecules, and eventually into a biogas which is rich in methane and can be burned as fuel in the place of natural gas.

**Digestion**

Digestion refers to various reactions and interactions that take place among the methanogens, nonmethanogens and substrates fed into the digester. This is a complex bio-chemical process involving different factors and stages of change.

The main stages in the biochemical process of AD: hydrolysis, acidogenesis and methanogenesis which are shown in Figure below.

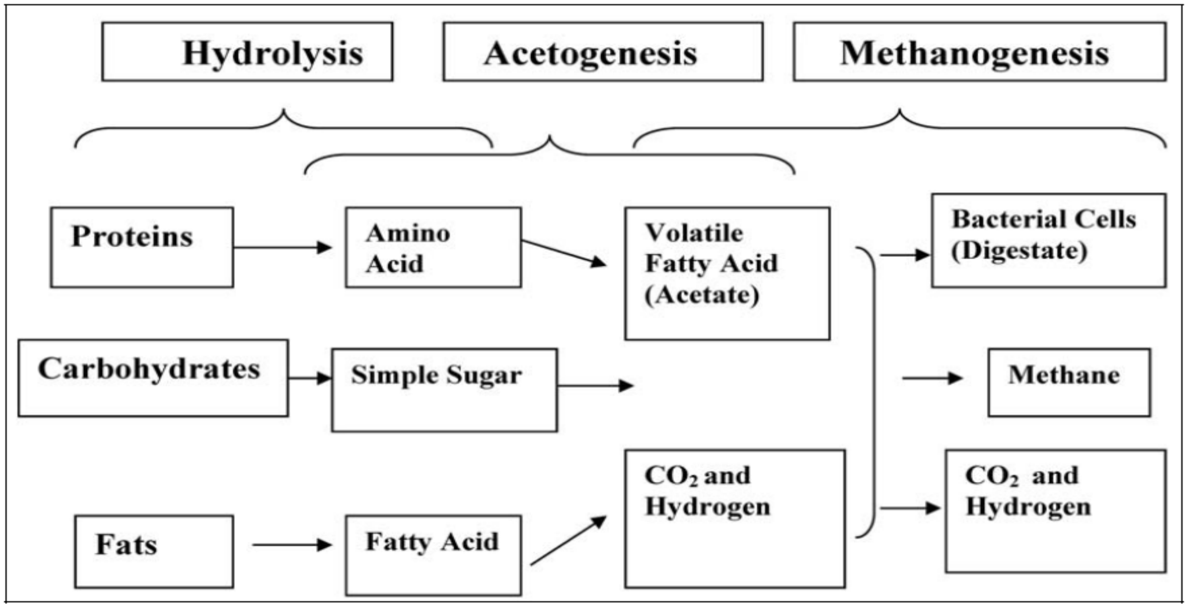


**Fig 1.2 Biological process of anaerobic digestion [9].**

### *Hydrolysis*

Certain hydrolytic microorganisms secrete extracellular enzymes that play a crucial role in hydrolysis of the substrate. This is considered to be the very first step in the AD process in which the complex substrate molecules like fat, protein and carbohydrates are converted/hydrolyses to their respective simpler forms like fatty acid, amino acid and simple sugar. These simpler molecules are then exposed to the process of acitogenesis [1].

$$\begin{aligned} &\text{Lipid} \longrightarrow \text{Fatty Acid} \\ &\text{Polysaccharide} \longrightarrow \text{Monosaccharide} \\ &\text{Proteins} \longrightarrow \text{Amino acids} \end{aligned} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

### *Acetogenesis*

It is a biological reaction where simple monomers are converted into volatile fatty acids (VFA). This is the second stage of the anaerobic digestion process in which $H_2$ gas is also generated as a byproduct along with VFA and alcohol.

This stage is also known as the acidogenic or fermentative stage in an anaerobic digestion process. The activity of microorganisms during the start-up of acidogenic anaerobic reactors at mesophillic and thermophillic temperature ranges has been studied.

### *Methanogenesis*

The third stage produces $CH_4$ by methanogenic bacteria that utilize/decompose the products of the acetogenic stage. A certain group of acidophilic microorganisms called acidotrophic bacteria generate around 70% of $CH_4$ from volatile fatty acids while the rest 30% is generated by hydrogenotrophic microorganisms from carbon dioxide and hydrogen. A rise in hydrogen level disturbs the reaction stability in an AD process resulting in a decline in the activity of the acedogenic microorganisms. Thus, there is a fall in the biogas production rate. Therefore, the role of hydrogenotrophic microorganisms is crucial in maintaining a low level of hydrogen in the reactor. Methanogenic microorganisms are very sensitive to change in reaction parameters hence it is essential to maintain the reactor in steady state for stable $CH_4$ production [1].

$CH_3COOH$ (acetate) $\longrightarrow$ $CH_4 + CO_2$

$2C_2H_5OH$ (ethanol) + $CO_2$ $\longrightarrow$ $CH_4 + 2CH_3OOH$

$CO_2$ $4H_2$ (hydrogen) $\longrightarrow$ $CH_4 + 2H_2O$ …………………… (2)

Biogas, specifically $CH_4$, is a renewable energy source which has become the need of the day. However, $CO_2$ and $CH_4$ being greenhouse gases are a cause of concern for the entire mankind. $CH_4$ can be collected through anaerobic digestion of various wastes, stored and used as a source of energy. The purpose of using $CH_4$ is to generate energy and to reduce the greenhouse gases from the atmosphere [2].

Possible aims of using AD are it can be used either to treat biodegradable wastes or produce saleable products (heat/electricity, soil amendment). Energy crops can be grown and then used for AD. In this case, the aim is to produce as much biogas as possible. A good quality soil amendment is another byproduct. Especially for waste management, it is unlikely that AD will be a viable treatment without using the biogas and the digestate as both of these are potential pollutants. The biogas is a greenhouse gas and the digestate might contain pathogenic microorganisms and other undesirable byproducts; however, their qualities will vary depending on the feedstock and its contamination [7].

### 1.1.2 Important parameters in anaerobic digestion

**1) PH**

The pH of the digester is an important indicator of the performance and the stability of an anaerobic digester. The pH level changes in response to biological conversions during the different processes of anaerobic digestion. A stable pH indicates system equilibrium and digester stability. Many aspects of the complex microbial metabolism are greatly influenced by pH variations in the digester. The pH in an anaerobic digester initially will decrease with the production of volatile acids. However, as methane-forming bacteria consume the volatile acids and alkalinity is produced, the pH of the digester increases and then stabilizes.

The pH of an anaerobic digester is significantly affected by the carbon dioxide content of the biogas. Digester stability is enhanced by a high alkalinity concentration. The composition and concentration of the feed sludge directly influence the alkalinity of the digester. For example, large quantities of proteinaceous wastes transferred to the anaerobic digester are associated with relatively high concentrations of alkalinity. PH values ranges 6.8 to 7.2 for Mesophillic.

**2) Substrate characteristics**

The characterization of substrate is a key factor for the design and optimization of waste treatment and disposal methods. The physical and chemical characteristics of the organic wastes are important information for designing and operating anaerobic digesters, because they effect biogas production and process stability during anaerobic digestion.

**3) Temperature**

Temperature is one of the most important factors affecting microbial activity in anaerobic digester and methane production is strongly temperature dependent. Temperature determines the rate of an anaerobic degradation processes particularly the rates of hydrolysis and methanogenesis. There are three widely known and established temperature ranges of operation:

I) Psychrophilic (15-20$^{o}$C)

II) Mesophillic (30-40$^{o}$C) and

III) Thermophillic (50-60$^{o}$C).

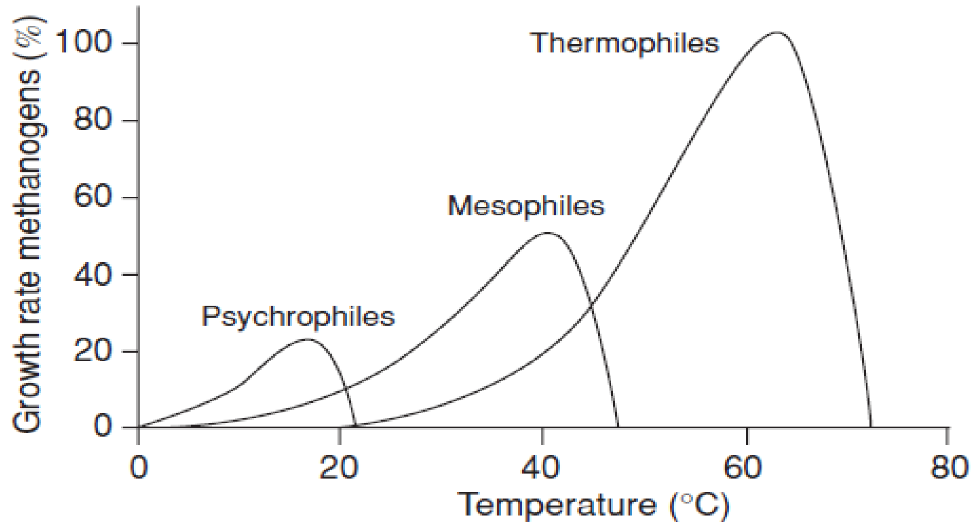


**Fig 1.3 Relative growth rate of psychrophilic, mesophillic, and thermophillic methanogens.**

**4) Mixing**

Mixing facilitates the contact between bacteria/enzymes and substrates preventing the accumulation of substrates and intermediates and guarantee homogenous conditions in the assays vessels [23]. It also prevents the thermal stratification and the formation of a surface crust/scum build up in an anaerobic reactor [13]; [21] Furthermore, mixing ensures that solids remain in suspension avoiding formation of dead zones by sedimentation of sand or heavy solid particles. Mixing also enables the particle size reduction as digestion progresses and the release of produced biogas from the digester contents [3]. The effect of mixing duration and intensity on the performance of anaerobic digestion varies considerably.

**5) Inhibitions**

Inhibition is usually indicated by a decrease in the microbial population and methane production. A wide variety of substances have been reported to be inhibitory to the anaerobic digestion processes. These kinds of substances can be found as components of the feeding substrate or as by-products of the metabolic activities of bacterial consortium in the digester. A material may be judged as inhibitory when it causes an adverse shift in the microbial population or inhibition of bacterial growth.

**6) Hydraulic Retention Time and Organic Loading Rate**

Retention time, in the anaerobic reactors, refers to the time that a certain substrate resides in a digester. It is determined by the average time needed for decomposition of the organic material, as measured by the chemical oxygen demand of the influent and the effluent material. The longer the substrate is kept under proper reaction conditions, the more complete will be its degradation.

Furthermore retention time in the anaerobic digestion system depends on process temperature. Mesophillic digesters have longer retention time than thermophillic digesters. Commonly used method for shortening the residence time in anaerobic reactors is mixing the digesters.

The organic loading rate (OLR) is defined as the amount of organic matter expressed in terms of volatile solids or chemical oxygen demand that must be treated by a certain volume of anaerobic digester in a certain period of time. The potential danger of a rapid increase in the organic loading rate would be that the hydrolysis and acidogenic bacteria would produce intermediary products rapidly. Since the multiplication time of methanogenic bacteria is slower, they would not be able to consume the fatty acids at the same rate. The accumulation of fatty acids will lead to a pH drop and affect the activity of methanogenic bacteria, causing the digester failure.

7**) Composition of the food waste**

The composition of food waste is variable depending on the time of the year, cultural habits, region etc. It is important to know the composition of the food waste in order to be able to predict both the bio-methanization potential and the most efficient AD facility design.

The bio-methanization potential of the waste depends on the concentration of four main components: proteins, lipids, carbohydrates, and cellulose. This is due to the different bio chemical characteristics of these components [14].

The highest methane yields have systems with excess of lipids but with longest retention time. The methanization is fastest in systems with excess of proteins followed by the reactors with excess of cellulose and carbohydrates respectively. However, there are also inhibitory effects observed due to the VFA accumulation and ammonium nitrogen respectively. The lowest rates of the hydrolysis are the assays with an excess of lipids and cellulose, indicating that when these are in excess, a slower hydrolysis is induced [14].

**Types of anaerobic reactors**

Anaerobic reactors or processes of solid waste can be distinguished into several types, based on the feeding mode (batch mode and continuous mode: single stage, two stages) and based on the moisture content of the substrate (wet or dry digestion). Furthermore with those basic types, the anaerobic reactors can be arranged according to the digestion process temperature (mesophillic or thermophillic) and the shape of the reactors (vertical or horizontal).

In the batch system, digesters are filled once with fresh feedstock, with or without addition of inoculum, and sealed for the complete retention time, after which it is opened and the effluent is removed. In the continuous system, fresh feedstock is continuously fed to the digester and an equal amount of digested material is withdrawn.

Anaerobic digestion processes can be termed as “wet” and “dry” digestions depending on the total solids concentration of the feed substrate. Anaerobic digestion is defined as a wet process if the total solids concentration of the substrate is less than 15% and as a dry process if the concentration reaches 20-40% [8]. In wet digestion processes, the solid waste has to be conditioned to the appropriate solids concentration by adding process water either by recirculation of the liquid effluent fraction or by co-digestion with a liquid waste.

### 1.1.3 Advantages of Biogas Technology

- The generated biogas can replace traditional energy sources like firewood and animal dung, thus contributing to combat deforestation and soil depletion.
- Biogas can contribute to replace fossil fuels, thus reducing the emission of greenhouse gases and other harmful emissions.
- By tapping biogas in a biogas plant and using it as a source of energy, harmful effects of methane on the biosphere are reduced.
- By keeping waste material and dung in a confined space, surface and groundwater contamination as well as toxic effects on human populations can be minimized.
- By conversion of waste material and dung into a more convenient and high-value fertilizer, organic matter is more readily available for agricultural purposes, thus protecting soils from depletion and erosion.
- Production of energy (heat, light, electricity).
- Transformation of organic waste into high quality fertilizer.
- Improvement of hygienic conditions through reduction of pathogens, worm eggs and Flies.
- Reduction of workload, mainly for women, in firewood collection and cooking.
- Environmental advantages through protection of soil, water, air and woody vegetation.

- Micro-economical benefits through energy and fertilizer substitution, additional income sources and increasing yields of animal husbandry and agriculture.

Research on biogas is having a lot of significance and can be understood from its advantages:

- Reduced greenhouse gas emissions and mitigation of global warming
- Reduced dependency on imported fossil fuels
- Waste management

**ADVANTAGES OF BIOGAS AS A FUEL**

- It mixes easily with the air.
- It is light fuel gas.
- High calorific value.
- It is highly knocked resistant.
- Due to uniform distribution thermal efficiency is higher.
- Biogas has a high octane number.
- It reduces pollution
- Plants capital cost is low.
- Domestic fuels for burners used in kitchen.
- No toxic to skin.
- Clean fuel.
- No residue produced.
- Economical.
- None polluting.
- Can be supplied through pipe lines.
- Burns readily - has a convenient ignition temperature.
- Uses of biogas for street lighting.
- Generation of electricity.

**Advantagees and Disadvantages of anaerobic digestion**

**Advantages**

AD Contributes to reducing the greenhouse gases. A well-managed AD system will aim to maximise methane production.but not release any gases to the atmosphere.thereby reducing overall emissions. also provides a source of energy with no net increase in atmospheric carbon which contributes to climate change.

The feedstock for AD is arenewable sourse,and therefore does not deplete finite fossil fuels.Energy generated through this process can help reducing the demand for fossil fuels.The use of the digestate also participates to this reduction by decreasing synthetic fuels use in fertiliser manufacturing,which is an energy intensive process. AD creates an integrated management system which reduces the likelihood of soil and water pollution to happen,compared to disposal of untreated animal manure /slurries.The treatment can also lead to a reduction up to 80% of the odour and it destroys virtually all weed seeds, thus reducing the need for herbicide and other weed control measures.

On a financial aspect, the advantage of AD is to convert residues into potentially saleable products: biogas,soil conditioner,liquid fertilizer. It can also contribute to the economic viability of farmes by keeping costs and benefits within the farm if the products are used on-site [5].

**Disadvantages**

AD projects as with many developments will create some risks and have some potential negative environmental impact. These need to be removed wherever possible or at least minimized.

AD has significant capital and operational costs. It is unlikely that AD will be viable as an energy source alone and therefore must be seen as an integrated system. It is likely to be cost effective for those who can use the other products of AD: better waste management, fertiliser.

All waste management systems create traffic movement. This can become a problem in plants and alternative methods of transport should be investigated as transport greatly influences costs and emissions. The location of the plant should be chosen carefully so that distances travelled are minimized between the production feedstock, the storage tanks and the digester. Nuisance for then neighborhood has also to be taken in to account. About health and safety, there may be some risks to human health with the pathogenic content of the feedstock but it can be avoid with an appropriate plant design and feedstock handling procedures. There may also be some risks of fire and expiosion, although no greater than for natural gas installation. Larger plants may have some visual impact, although the digester can partially be sunk into the ground to reduce visual impact, although the digester can partially be sunk in to the ground to reduce visual impact and make it easier to load [5].

## 1.2 Problem Statement

Due to scarcity of petroleum and coal it threatens supply of fuel throughout the world. Also problem of to get access the new sources of energy, like renewable energy resources and access to energy resources, economic development and environmental pollution, which in turn threatens human health, is major challenges facing developing countries like our country Ethiopia today. Economically feasible and efficient designed Biogas plant could be the answer of solving some of these problems and needs.

Jimma Institute Technology, Kito Furdisa Dining Hall and kitchen wastes are producing between 240 – 300 $m^3$ of wastes per year. That means kitchen wastes and food wastes left from the students' cafeteria after their breakfast, Lunch and dinner. Considering typical waste disposal fees, JiT have paid high amount of money per academic year on disposal of food waste. In addition to the disposal costs, organic waste in a landfill contributes significantly to greenhouse gas emissions as it is converted to methane gas. The Biogas system designed from Kito Furdisa Dining Hall waste and kitchen waste in our Jimma Institute Technology will be avail for the highest share.

The food waste from dining hall and kitchen wastes are extremely polluting the environment people living in the vicinity of the campus are always complaining as it is bringing about health problem to them. Therefore, the construction of biogas plant has the advantage of clean energy generation, environmental protection and bio fertilizer production.

### 1.2.1 Present Study

Food wastes and kitchen wastes reduction is the first step to food waste management. As long as proper food safety and handling practices are followed, reusing leftover food can save money and reduce waste. Creatively repurpose leftovers and trimmings to efficiently use excess food for other meals. Flexibility in menu planning to accommodate the use of excess food from previous meals is a good way to extract energy from those wastes. Also, diverting wasted food to anaerobic digestion can generate renewable energy (biogas) and create a valuable soil amendment.

The main target of this thesis is that to extract Energy for Jimma University, Institute Technology, Kito Furdisa Campus, using Students' Dining Hall and kitchen wastes through Anaerobic Digestion process.

The methodology to work this project is that; Collecting datum of Food Waste and kitchen wastes, designing biogas plant and analyzing and by experimentally analyzing dining hall and kitchen wastes using small scale set up constructed Digestor.

### 1.2.2. Objectives

**General Objectives:**

General objective of this thesis is that to extract energy from Dining Hall and kitchen wastes of Kito Furdisa Campus, through Anaerobic Digestion process at Jimma University, Institute Technology.

**Specific Objectives:**

- To determine amount of food wastes and kitchen wastes from Kito Furdisa Student's Cafeteria and calculating amount of energy extracted from those wastes.
- To design biogas plant
- To analyze with experimentally the effect of different parameters like;

  I) Temperature

  II) PH
- To analyze the effluent quality

To assess potential amount of food and kitchen wastes, design and implementation of biogas system.

# 2. Literature Review

## 2.1 History of Anaerobic Digestion

Anaerobic digestion is historically one of the oldest processing technologies used by mankind. In modern age, after the discovery of methane emissions from natural anaerobic habitats by Volta in 1776, people started to collect the natural biogas and used it as a fuel, basically for lighting. In 1808, Sir Humphry Davy demonstrated the production of methane by the anaerobic digestion of cattle manure [1]. The first anaerobic digestion plant was reported to have been built at a leper colony in Bombay, India in 1859. Anaerobic digestion reached England in 1895, when biogas was recovered from sewage treatment facility to fuel street lamps in Exeter [2]. The development of microbiology as a science led to research by Buswell and others in 1930‟s to identify anaerobic bacteria and conditions that promote methane production. The primary aim of waste stabilization in due course of time led to the basic municipal sludge digester. However, it took until the end of the 19th century when anaerobic digestion was applied for the treatment of wastewater and solid waste [3]. In developing countries such as India and China there was a gradual increase in small-scale AD systems used mostly for energy generation and sanitation purpose.

Food wastes are generally biodegraded in the process of anaerobic digestion to produce biogases. Anaerobic digestion (AD) is a biological process in which biodegradable organic matter is broken down by microorganisms in the absence of oxygen into biogas which consists of methane ($CH_4$), carbon dioxide ($CO_2$), and trace amounts of other gases [21]. AD is advantageous because it is a renewable source of energy and reduces the emission of landfill gases. The nutrient rich solids left after digestion can also be used as an organic soil amendment [22].

It has been reported that anaerobic digestion has been used as a major technique for management of waste produced from municipal as well as industrial sources since many years [23] Only in the past decade has the technology become a recognized method for processing solid organic waste from residential and commercial sources. The benefit of an AD process is that it is a net generator of energy which can be sold in the form of heat, steam or electricity.

Wastewater from multiple sources like, municipal, food processing industries, leather industries, and animal husbandry are exposed to treatment through the anaerobic digestion technique. Many European countries like Denmark, France, and Germany are now leaders in organic waste-management, using the AD technique [24]. The biogas produced usually consists of around 60% methane ($CH_4$), followed by carbon dioxide and trace amount of ammonia [25]. Methane can be used to fuel a Combined Heat and Power (CHP) system for electricity and heat generation, refined for addition to existing gas supply networks, used as a vehicle gas, or used in conventional gas boilers or engines for separate heat or electricity generation. Methane has approximately 21 times the greenhouse gas effect of $CO_2$ [26]. Decomposition of food waste in open space results in release of methane gas to the atmosphere. Therefore, implementation of AD process not only displaces conventional generation it also helps to reduce natural greenhouse gas emissions. The nutrient rich product of the AD process can be applied in soils to improve soil fertility [15].

The same can also be used as compost in horticulture and other agricultural practices. In case of Chico State this can be used at the University Farms. Thus, the best use of AD is to combine both waste management and its by-products use [17].

Food waste is “any food substance, raw or cooked, which is discarded, or intended or required to be discarded,” according to the legal definition of waste by the European Union Commission (EUC) (topics/documents/ [14]. Food waste is further divided into many categories depending on the norm through which it is processed, used, and then discarded. According to the survey of United States Environmental Protection Agency (USEPA), components of food waste happen to be one of the largest parts of the overall Municipal Sewage waste generated in the entire USA [3].

One of the methods that Purdue University is currently using for food waste disposal is an anaerobic digester. An anaerobic digester is a machine that takes ground up organic material and is able to turn that organic material into methane gas. The methane gas can then be turned into electricity. While most organic material can be used a study conducted by Zhang, El- Mashad, Hartman, Wang, Liu, Choate, and Gamble showed that food waste is a great material for an anaerobic digester. After twenty-eight days of digestion the anaerobic digester produced an average of 435 mL/gVS (volatile solids) of methane gas [3].

The main sustainable food production goals for universities revolve around being more socially and environmentally responsible. Two ways in which universities are tackling these issues are by buying locally produced food and Fairtrade products. Purchasing regionally significantly reduces the impact of food sourcing on the environment, while buying locally also has an abundance of positive consequences. The journal „Building Local Food Programs on College Campuses" (The Community Alliance with Family Farmers 2008) highlights this: "supporting local farmers offers both environmental and social benefits since it reduces carbon emissions by shortening distance travelled while also returning a greater percentage of the food dollar directly to local farmers ... for every dollar spent in the conventional retail system only 20% makes it back to the farmer". In contrast, institutions buying directly from farmers or non-profit entities send 60% - 100% of each dollar to local food growers (The Community Alliance with Family Farmers 2008).

## 2.2 International status

An important fraction of the municipal solid waste stream can be defined as organic fraction of municipal solid waste (OFMSW). The food waste which includes both cooked and uncooked leftovers constitutes the largest component of waste coming from the restaurants and fruit/vegetables markets, residences, cafeterias etc. At present, the world wide municipal solid waste generation is about two billion tons per year, which is predicted to increase to three billions tons by 2025 [21].

A study of global food waste published in 2011 by the Food and agriculture organization (FAO) of the UN found that one third of all food produced for human consumption each year goes to waste which amounts to 1.3 billion tons. This waste is distributed fairly evenly between developing and industrialized nations with 40% of the food waste in the developing nations occurring in the production and processing phases of consumption while in the industrialized nations, 40% occurs at the retail and consumer levels of consumption. In 2009, USA generated 243 million tonnes of municipal solid waste (MSW) comprising mainly of food scraps, yard waste, plastic packaging, furniture, tyres, appliances, paper, and cardboard. The discarded MSW came from two main sources: residential (55-65%) and commercial/institutional (35-45%). Nearly half of this waste was recycled or reclaimed with 132 million tonnes (54%) going to landfill [5].

The per capita food waste in Europe and North America is 95-115 kg/year (Global, 2011). The average solid waste generation rate in 23 developing countries is 0.77 kg/person/day [6]. The municipal solid waste from urban areas of Asia would rise from 760,000 tonnes/day in 1999 to 1.8 million tonnes/day in 2025 [7]. These organic wastes requires to be managed in a sustainable way to avoid depletion of natural resources, minimise risk to human health reduce environmental burdens and maintain an overall balance in the ecosystem [8]. Anaerobic digestion could be an appealing option for converting solid organic waste into useful product like biogas, which will play an important role in meeting the world's ever increasing energy demand in the future. In addition, where anaerobic digestion technology is applied, food waste would not be sent to landfills reducing transportation costs and greenhouse gas emissions [9]. As a global measure of the expected impacts, if present waste management trends are maintained, landfilled food waste is predicted to increase the landfill share of global anthropogenic emissions from 8 to 10.5%.

A comparison between aerobic and anaerobic treatment methods show that with anaerobic treatment, 80% of the organic load can be reduced to $CH_4$ and $CO_2$ with a very small amount of surplus sludge production. In the aerobic treatment, 45% of the organic load is mineralized to $CO_2$ while 50% is transformed into biomass [10]. Studies carried out [11] indicate that food waste is a highly desirable substrate for anaerobic digesters with regards to its high biodegradability and methane yield. Anaerobic digestion of different types of food waste has been studied extensively. [11] investigated digestion of kitchen refuse with a total solid concentration of 7-8% VS. With OLR 6.0 gVSl-1d 1 and HRT 11d, the maximum VS reduction under steady state conditions reached 72% at mesophillic and 80% at thermophillic conditions. At 55°C the yield of gas, were about 830L gas/kg/VS, whereas at mesophillic conditions only about 800L gas kg/VS were generated. They conducted the digestion in a two stage plant with a concentration unit between the two stages. Under these optimized process conditions a turnover of the organic matter of 90% with low retention time could be realized.

Food waste has high ratios of volatile solids/total solids (80-90%) and has a very interesting methane potential. [12] Conducted batch digestion tests of food wastes at 37$^{o}$C and 28 days retention time. The methane yields were 0.48, 0.29, 0.28 and 0.47 L/g VS for cooked meat, boiled rice, fresh cabbage and mixed food wastes, respectively. Evaluated the biodegradability of a traditional Korean food waste consisting of boiled rice (10%-15%), vegetables (65%-70%), meat and eggs (15%-20%) and showed a methane yield of 0.49 L/g VS at 35℃ after 40 days retention time. [13] analyzed the nutrient content of food waste from a restaurant, showing that the food waste contained appropriate nutrients for anaerobic microorganisms, as well as reported a methane yield of 0.44L/g VS of food waste in batch digestion test under thermophillic conditions (50℃) after 28 days. Anaerobic digestion of food waste is achievable, however different types of food waste result in varying degrees of methane yields, and thus the effects of mixing various types of food waste and their proportions should be determined.

[14] Reported that the low hydrolysis rate constants were obtained in the assays fed with kitchen waste that contained an excess of lipids.

Indian urban dwellers generate 0.2-0.6 kg per person per day of solid waste resulting into a total generation of nearly 105,000 metric tons of solid waste per day nationally [15]. The per capita waste generation is increasing by about 1.33% annually [16] had reported that annual contribution per fixed dome biogas plant (capacity $2m^3$) to the global methane budget in plain region of northern India was 53.2kg as compared to 22.3 kg of hilly area due to the difference in the ambient temperature under the two climatic conditions of hills and plain regions affects $CH_4$ flux. [17] Had made qualitative assessment of the methane emission data at Okhla landfill site in Delhi, India.

About 135.5 million tonnes per year of municipal solid waste is generated in India and food waste alone constitutes of about 30-40 % [18]. Anaerobic digestion of food waste has the potential to generate 367m3 of biogas per dry ton at about 65% methane with energy content of 6.25 kWh/m3 of biogas yielding 894 TWh annually [12].

## 2.3 At National our country Ethiopia Status

Now a day biogas production is one of the most promising renewable energy sources in Ethiopia. Anaerobic digestion is one of the effective ways of generating biogas. It is also a reliable method for treating food wastes such as cafeteria wastes, vegetable wastes etc. and cow dung and the digested slurry can be used as fertilizer to enhance the fertility of the soil. Co-digestion of food waste with cow dung or other feed stocks with low carbon content can improve process stability and methane production. Anaerobic co-digestion of food waste with cow dung is needed to enhance biogas production and very useful to treat these waste [19].

Organic Waste is undesirable matter, which is most frequently generated by human activity that causes environmental pollution. Therefore, domestic biogas production is one of the most promising method of biomass wastes treatment because it provides a source of energy while simultaneously resolving ecological, environmental and agrochemical issues. The provision of bioenergy tackles both energy poverty and the reliance on polluting and Non Renewable fuels as a result matured biogas production technology has led to the development of a number of biogas appliances for lighting, power generation, and cooking. The most promising among them is the biogas energy in order to meet the energy requirement for cooking application at domestic and community level. In this paper, an attempt has been made to design and develop a cylindrical torpispherical fixed dome bio digester for cooking application in the condominium houses at Debiza site in Debre Markos, East Gojjam in Amhara Region. The size of biogas plant is $53m^3$ and the input materials are different wastes such as kitchens, food waste and the human excreta from a total of 357 people living in four building of 120 residence. The gas production rating of the developed biogas plant is $25.36m^3$/day, which accounts 60.73% of the energy consumption that covers all the energy demand of firewood, charcoal and animal dung cakes that used for baking Injera and bread. The amount of gas obtained averagely, $0.211m^3$/ per household per day for cooking purpose [20].

## 2.4 Recommendation by Past Researchers

It can be recommended that operators require induction courses for the digesters to be operated more efficiently. Technical problems of the digesters include a lack of trained operators, poor equipment design and failure to feed the digester regularly. The school should have ready information on operation of digesters and in addition operators should be kept updated with relevant information on biogas digesters. Furthermore, the opening and closing of the gas outlet and main gate valves must not be cumbersome and the feedstock should be fed into the digester when correct amount of water is mixed with it. The most favorable total solids (TS) value desired for better biogas production is 8%. The pH changes in the digester would affect methane formation process and therefore, pH fluctuation would be controlled by the addition of wooden ash at zero cost. However, temperature fluctuations in the digesters would be minimal since the digesters would be constructed underground [32].

Kitchen waste will be the best alternative under a community level biogas production. Here our research was just under a proto type biogas plant but if we will made this at a big level, it will generate more biogas production and increase their utilization under multiple role [33].

Further research is necessary to collect additional data on the use of the Anaerobic Digester using kitchen wastes. In addition, technical and economic feasibility studies of the environmental and economic aspects of the industrial application of this process alternative should be carried out [34].

### 2.4.1 Knowledge gaps still to be addressed

Many researchers studied for about generating of biogas from either food wastes (post-consumer) or kitchen wastes (pre-consumer). This means they have done an experiment from post-consumer alone or from pre-consumer alone. In this thesis we have done the mixed food wastes (post-consumer) and kitchen wastes (pre-consumer) at once. Even we have done the design of biogas plant from food and kitchen wastes.

### 2.4.2 Scope of the Present Study

The scope this project is that as the following progress; Data should be gathered and analyzed from Dining Hall and Kitchen wastes, Calculating amount of energy extracted from those wastes, Designing biogas plant, finding necessary material for small scale set up constructing Digestor, testing food and kitchen wastes using small scale set up constructed Digestor and analyzing the result and writing Conclusion.

# 3. Research Methodology and Design

## 3.1 Materials and Methods

### 3.1.1 Materials

Materials we have used to collect data of food and kitchen wastes are as the followings;

- Weighing balance
- Different types of buckets


**Fig. 3.1 During measuring wastes from both dining hall and kitchen of JiT students' cafeteria**

### 3.1.2 Method

The method we have used to collect data of food and kitchen wastes is first we weigh in (Kg) of bucket alone we have used; at the second weighing in (Kg) bucket with wastes (food or kitchen) and lastly we have subtracted amount of bucket (kg) and put the net values of wastes on our data.

The methodology to work this thesis is as the following;

**Collecting data of Food Waste and kitchen wastes and Analyzing.**

This means both post-consumer foods, like food left after breakfast, lounge and dinner of student's cafeteria as well as pre-consumer food from the kitchen wastes are collected and assessed.

Measuring wastes from both dining hall and kitchen of JiT students' cafeteria is done; in the morning, afternoon and at the dinner. Measuring system is done independently from both the dining hall and kitchen.

I) **collecting data of Food Waste**

- Data collected from April 27,205 to May 26, 2015 ( for a month) total amount of food wastes in the afternoon (lunch) 12,944 Kg, in the evening (dinner) 11,691 Kg and in the morning (breakfast) 3,939 Kg were collected from largest to smallest respectively.

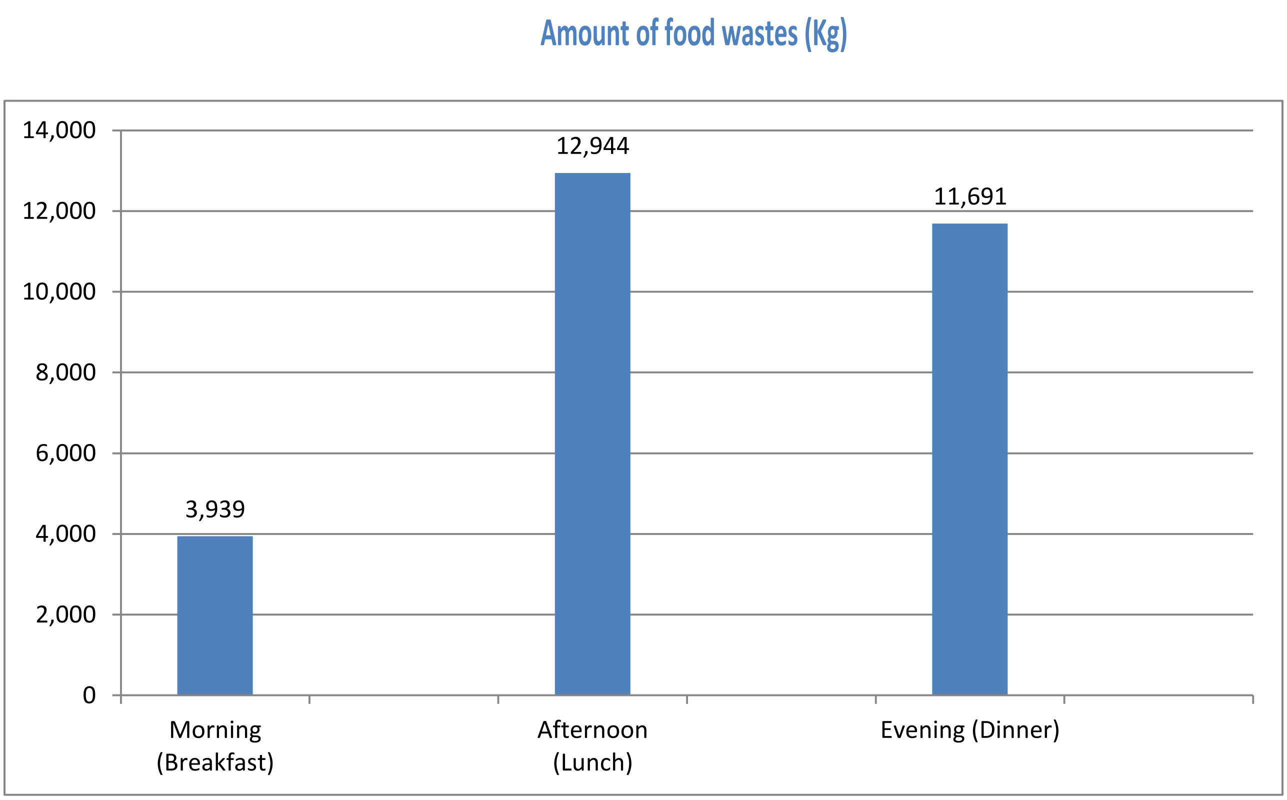


**Fig 3.2 Graph of Forms of collecting datum of Food Wastes from Dining hall, at Jimma Institute Technology (JiT), Kito Furdisa Campus**

II) **Collecting data of kitchen Waste**

- Data collected from April 27,205 to May 26, 2015 ( for a month) total amount of kitchen wastes in the afternoon (lunch) 4,623Kg, in the evening (dinner) 527Kg and in the morning (breakfast) 178Kg were collected from largest to smallest respectively.

Amount of Kitchen wastes (kg)

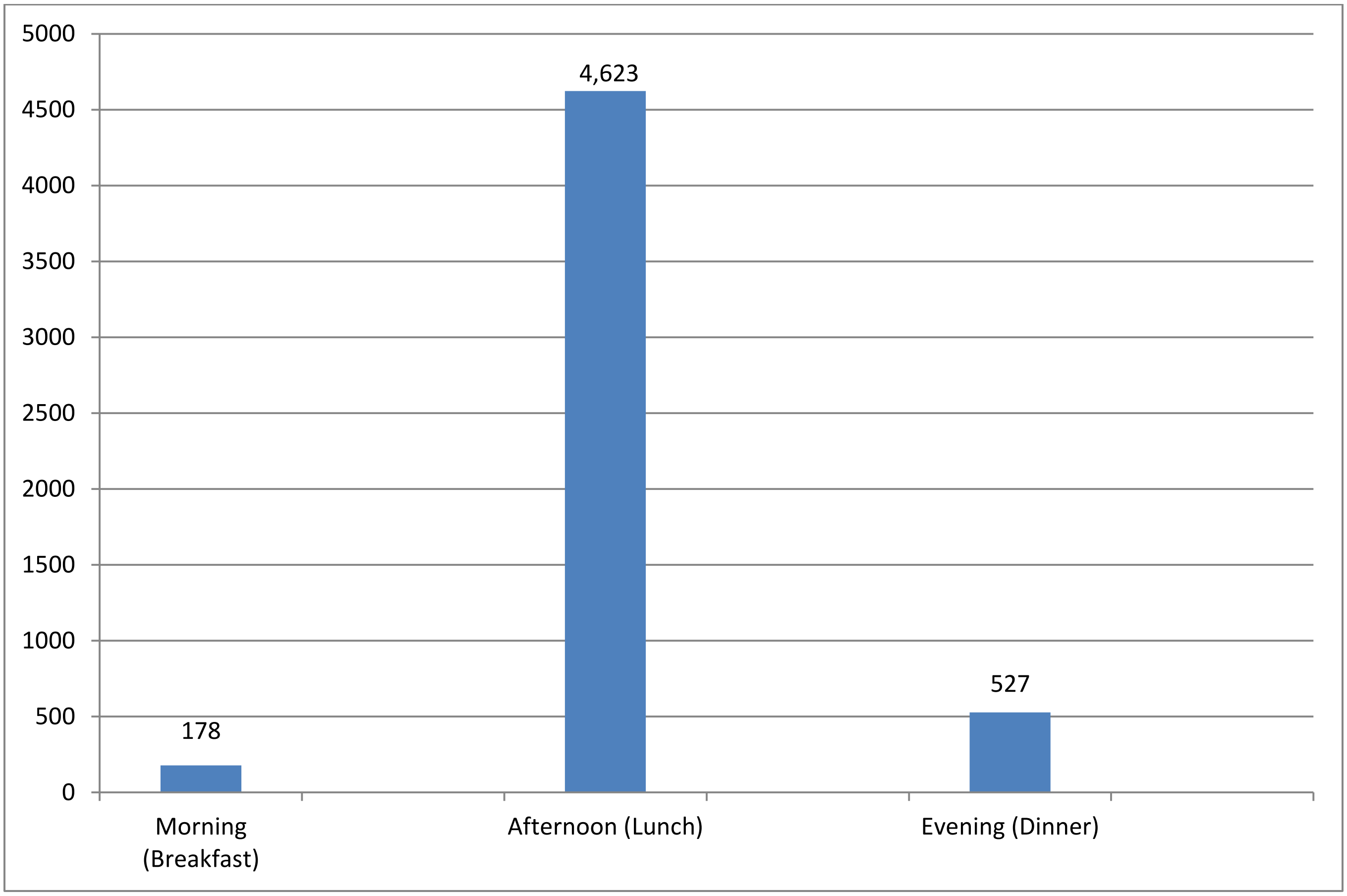


**Fig. 3.3 Graph of Forms of collecting datum, from kitchen Wastes at Jimma Institute Technology (JiT), Kito Furdisa campus**

### 3.1.3 Experimentally analyzing dining hall and kitchen wastes using small scale set up constructed Digestor.

#### 3.1.3.1. Experiment- One

This is done by constructing small scale set up Digestor and analyzing the result. For implementing small scale bio digester, we decide to fix the volume of digester 80 liter (for Experiment-I) and all the rest of its parts are as fig below.

**Table3.1. Necessary materials for constructing Experiment-One**

| S.N | Items | S.N | Items |
|---|---|---|---|
| 1 | Bucket | 5 | Digester (80L capacity) |
| 2 | Pipe (3m) | 6 | Water seal carriage |
| 3 | Glass beaker (1liter) | 7 | Tee, union, joint, tapes |
| 4 | Valves | 8 | Thermometer, thermocouples, nipples & etc. |

**Equipments for an Experiment**

The study was carried out in a laboratory at the School of Mechanical Engineering, Jimma institute Technology (JiT); on date of Nov 04, 2015 to Jan 09, 2016 for 66 days.

The waste materials used for the study were: From dining hall; enjera with atar kik, very small amount of bread, from kitchen waste; only potatoes peels.

I) **Equipments**

**Table 3.2 Equipments of Experiment- One**

| S.N | items | description | pictures |
|---|---|---|---|
| 1 | Weighing balance | to determine the weight of food waste samples |  |
| 2 | PH meter | to measure the pH of the digested materials |  |
| 3 | Measuring Cylinder | to measure the volume of water displaced by the biogas generated |  |
| 4 | Mixing Tank | a big plastic container for mixing the food waste and kitchen waste |  |
| 5 | Drying oven | Determination of moisture content |  |
| | | | |

II) **Anaerobic Digester Set-Up**: The batch type anaerobic digesters used for the study were made up of the following materials and specifications:

| | | | |
|---|---|---|---|
| 1 | Digester | An 80 liter plastic serves as the digester. |  |
| 2 | Water collector | A 5 liter transparent plastic, The method that was used for gas collection was water displacement method. |  |
| 3 | Rubber Hoses | The hose is about 1 meter in length and ½ inch inner diameter. It was used to convey gas from the digester to the water tank and to the water collector. |  |
| 4 | Digital Thermometer and thermocouple probe | To read temperatures. |  |
| 5 | Inlet chamber | To take the waste in slurry form inside digester. A bucket of 10 liter capacity was used for this. |  |

| | | | |
|---|---|---|---|
| 6 | Digital Multimeter | To measure internal digester temperature using Thermocouple. |  |
| 7 | Complete set of Anaerobic Digester Set-Up | Small scale digestor |  |

**Table 3.3 Quantity of Food Waste Added to the Digester for Experiment- One**

| S.N | items | Quantity in weight (kg) or (L) |
|---|---|---|
| 1 | Enjera with 'atar kik' and bread | 20 Kg |
| 2 | Potatoes peel | 10 Kg |
| 3 | water | 30 L |
| The ratio of dining hall waste to kitchen waste is 2:1 and also, ratio of wastes(Kg) to amount of water added is 1:1 | | |

**Experimental Procedure**

Potatoes peels were chopped into smaller sizes to facilitate digestion. Each of the food waste was measured and poured into the mixing tank and then stirred to ensure homogeneity. The homogenous mixture of food waste and kitchen waste was then introduced into the digesters and hermetically sealed. The schematic diagram of the set-up is as shown in Figure below. The water tank was filled with water to its brim. The gas produced by the substrates inside the anaerobic digester was channeled to the water tank on which two separate holes were drilled at the top, two rubber hoses were inserted in the holes, the first one (70cm in length and 0.5 inch in diameter) was used to connect the digester while the second (60 cm in length and 0.5 inch in diameter) was used to connect the water collector. The weight of gas produced was equivalent to the amount of water displaced in the water chamber. The temperature reading was taken between 1 pm and 2 pm weekly throughout the period of the experiment. The pH was measured weekly using a digital pH meter. The probe of the pH meter was immersed into the sample to be analyzed and the meter was allowed to stabilize before the reading was taken. Each treatment was replicated three times.

**Table 3.4 Measurements of different factors for generating biogas (temperature and PH) at different days.**

| Date | Temperature | | | PH | | | |
|---|---|---|---|---|---|---|---|
| | Ambient temp. ($^0$C ) | Inside digester temp. (mv) | Equivalent Inside digester temp. ($^o$C) | $PH_1$ | $PH_2$ | $PH_3$ | Average of PH |
| Nov 04, 2015 | 22 | 0.1 | 24 | 5.27 | 5.26 | 5.31 | 5.28 |
| Nov 07, 2015 | 24.5 | 0.1 | 26.5 | 3.71 | 3.74 | 3.74 | 3.73 |
| Nov 14, 2015 | 23.3 | 0.1 | 25.3 | 4.28 | 4.29 | 4.28 | 4.283 |
| Nov 21, 2015 | 27.7 | 0.2 | 31.7 | 3.45 | 3.44 | 3.46 | 3.45 |
| Nov 28, 2015 | 23.5 | 0.3 | 29.5 | 3.66 | 3.66 | 3.67 | 3.663 |
| Dec 05, 2015 | 24.6 | 0.2 | 28.6 | 3.68 | 3.68 | 3.68 | 3.68 |
| Dec 12, 2015 | 21.7 | 0.2 | 25.7 | 3.87 | 3.86 | 3.87 | 3.87 |
| Dec 26, 2015 | 27.20 | 0.4 | 35.20 | 4.10 | 4.00 | 3.90 | 4 |
| Jan 09, 2016 | 25.6 | 0.4 | 33.6 | 4.20 | 4.30 | 4.28 | 4.26 |

**Determination of moisture content**

The moisture content of the samples was determined using the oven–drying method. Pre weighed samples were dried in the oven at 150 °C for 24 hours. Moisture content was calculated using equation below.

**Moisture content** = $M_{initial} – M_{Final}$

Where, $M_{initial}$ is the mass of the sample before drying and $M_{Final}$ is the mass of the sample after drying.

**Table: 3.5 Determination of moisture content**

| Item No | Mass of waste with plate before drying (g) | Mass of waste with plate after drying (g) | Moisture content; difference (g) | Percentage of Moisture content |
|---|---|---|---|---|
| 1 | 168 | 89 | 79 | 47% |
| 2 | 156 | 83 | 73 | 46.8% |
| 3 | 162 | 88 | 74 | 45.7% |
| 4 | Average | | | 46.5% |

**Fig.3.4 Experimental-One set-up.**

**Table 3.6 Result and discussion of experiment-One**

| S.N | Description | Picture |
|---|---|---|
| 1 | After 66 days there is no change of wastes; On the top of wasted in the digestor, there is only oil like structure. |  |
| 2 | Wastes from kitchen are completely no change at all. I.e. peels of potatoes. |   |
| 3 | Generally even there is no odor change. | |

### 3.1.3.2 Experiment- Two

From Experiment-One, because of several reasons we did not get a biogas within the first 66 days. This is because of;

- Ambient temperature of Jimma town did not rise beyond 25 $^{0}$C in average.
- Our wastes covered by high lipid oil.
- Our digestor wasn't covered by insulator for conserving heat from external environment.
- Our wastes didn't mix with cow dung and additional bacteria from other biogas generating wastes which can easily speed up the rate of acidogenesis formation.

Therefore, in order to solve those problems in Experiment-One, we have done this Experiment two. For Experiment-two we have used the following materials:

- From dining hall
- Enjera with 'atar kik',
- Very small amount of bread, and
- Cow dung.

In addition we have used insulating digestor using combust to conserve inside and outside temperature.

This Experiment-two is done at Jimma University Institute of Technology, School of Mechanical Engineering; on date of January 29, 2016 to May 11, 2016 for 103 days. It is combination of 15 Kg of Fresh cow dung, 10 Kg of bread and 10Kg of enjera and 35 L of water.

**Table 3. 7 Experiment- Two Measurements of temperature at different days.**

| Date | Temperature | | |
|---|---|---|---|
| | Ambient temp. $^0$C | Inside digester temp. (mv) | Equivalent Inside digester temp. ($^o$C) |
| Jan 29, 2016 | 27 | 0.4 | 35 |
| Feb 05, 2016 | 26 | 0.6 | 38 |
| Feb 29, 2016 | 24 | 0.6 | 36 |
| Mar 04, 2016 | 25 | 0.5 | 35 |
| Mar 18, 2016 | 27 | 0.4 | 35 |
| Apr 1, 2016 | 28 | 0.3 | 34 |
| May 9,2016 | 26 | 0.3 | 32 |
| May 10,2016 | 24 | 0.2 | 28 |
| May 11,2016 | 28 | 0.3 | 34 |

**Equipments**

**Equipments-** Additional materials we used for this Experiment-Two is described as the following table 3.8 below.

**Table 3.8 Equipments of Experiment- Two**

| S.N | items | description | pictures |
|---|---|---|---|
| 1 | Insulating digestor using combust. | To conserve inside and outside temperature. |  |
| 2 | Fresh cow dung | To speed up reaction of acid formation. |  |

Fig. 3.5 Experiment- two set-up

#### 3.1.3.3 Experiment-Three

Experiment-III contains three different types of wastes; combination of food waste and cow dung, only food waste and only cow dung. All of those different types of Experiments 800ml of water is ready in 1L of beaker for displacement method and settled in the drying oven that set at a temperature of $40^oc$.

This Experiment-III is done for 60 days from June 22, 2016 to August 21, 2016 at School of Mechanical Engineering.

1) **Combination of food waste and cow dung**: 1Kg of injera and 1Kg of cow dung plus 3 liter of water. The digester volume is 4L and height of mixed substrate reach upto 16cm from total 18cm of the digester.

Fig.3.6 Combination of food waste and cow dung

2) **Only food waste**: 1Kg of injera and 1.5L of water and its digester volume contain 2L and height of substrate within a digester is 13cm from total of 15cm height of a digester.

Fig. 3.7 Only food waste

3) **Only cow dung**: 1Kg of cow dung and 1.5L of water and its digester volume contain 2L and height of substrate within a digester is 13cm from total of 15cm height of a digester.

Fig.3.8 Only cow dung


**Fig. 3.9 Overhaul of Experiment-Three**

**Table.3.9 Amount of water displaced from all three types of wastes at Experiment-Three**

| Date | Experiment-1 Water displaced (ml) | Experiment-2 Water displaced (ml) | Experiment-3 Water displaced (ml) | Remark |
|---|---|---|---|---|
| July 1, 2016 | 2.5 | - | - | Displaced water |
| July 7, 2016 | - | 3 | 2.5 | Displaced by vapour |
| July 14, 2016 | 2 | - | - | Displaced water |
| July 21, 2016 | - | 1.5 | 1.0 | Displaced water |
| July 28, 2016 | 1.5 | - | - | Displaced water |
| August 4, 2016 | - | 1.0 | 1.0 | Displaced water |
| August 17,2016 | 1.2 | 0.5 | 0.5 | Displaced water |
| Total | 7.2 | 6 | 5 | |

### 3.1.4 Location

This thesis is done at Jimma University, Jimma Institute of Technology (JiT) located in latitude and longitude of $7^0$40’54.54 and $36^0$51’0.86 or $7.6820^0$N and 36.8560’ E respectively. It is located in Jimma town, Oromia region, the largest city in southern western in Ethiopia.

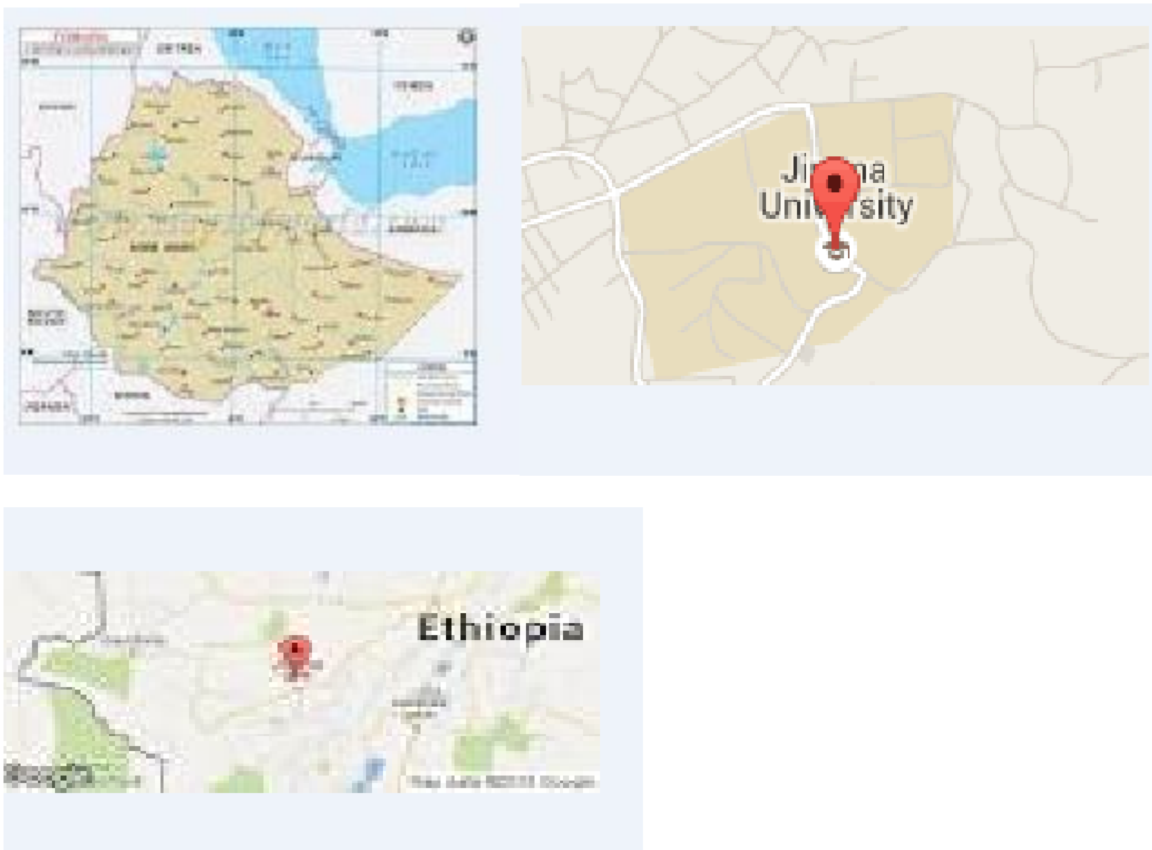


**Fig 3.10 Location of thesis work**

## 3.2 Research Design

### 3.2.1 Designing of digester

The biodigester is a physical structure, commonly known as the biogas plant. Since various chemical and microbiological reactions take place in the biodigester, it is also known as bioreactor or anaerobic reactor. The main function of this structure is to provide an anaerobic condition within it. As a chamber, it should be air and water tight. It can be made of various construction materials and in different shapes and sizes.

**Fixed dome digester or Chinese model digester**

This type of digester is installed under the ground where the gas and the slurry are in the same storage tank [12]. In this design, the fermentation chamber and gas holder are combined as one unit. This design eliminates the use of costlier mild steel gas holder which is susceptible to corrosion. Both the pit and dome are constructed by bricks and cement [13]. As the gas is collected above the decomposing feedstock it displaces the sludge towards the displacement tank where it is collected as the fertiliser. Biogas is collected through the gas pipe and transferred to the point of use where it is used as an energy source either for heat or electricity generation.

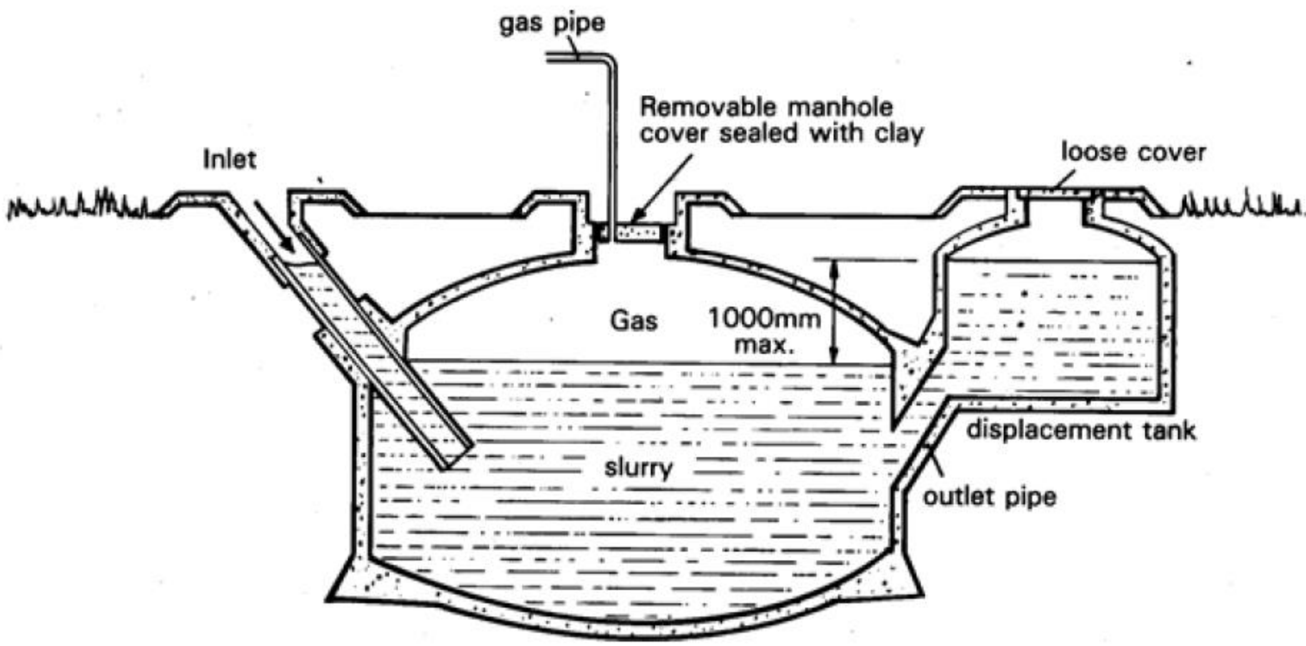


Fig. 3.11 Chinese Fixed dome digester [11]

**Fixed Dome Biogas Plant** A fixed dome Biogas plant is an airtight underground tank in which organic materials mixed with water are digested/ fermented through anaerobic bacteria action in the purpose of generating biogas fuel. The advantages of the fixed dome plant include the simplicity of design, few moving parts, low cost to construct and maintenance. The disadvantages when compared to a floating-dome digester are primarily the inability to store gas for use on demand; gas from the fixed dome digester must be used as generated or expelled to avoid damaging the digester.

**Slurry**

After extraction of biogas (energy), the slurry (also known as effluent) comes out of digester as by-product of the anaerobic digestion system. It is almost pathogen-free stabilized manure that can be used to maintain soil fertility and enhance crop production. Slurry is found in different forms inside the digester as mentioned below:

- A light rather solid fraction, mainly fibrous material, which floats on the top forming the layer;
- A very liquid and watery fraction remaining in the middle layer of the digester;
- A viscous fraction below which is the real slurry or sludge and heavy solids, mainly sand and soils that deposit at the bottom.

There is less separation in the slurry if the feed materials are homogenous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogeneous slurry.

**Utilisation of biodigester effluent (slurry) as feed and fertilizer**

By-products of agriculture, mainly animal wastes and crop residues are the primary inputs for biogas plants. The digested slurry as one of the outputs of a biogas plant can be returned to the agricultural system. Proper application of the slurry as organic fertilizer increases agricultural production because of its high content of soil nutrients, growth hormones and enzymes. Dried slurry can also safely replace a part of animal and fish feed concentrates. Furthermore, slurry treatment also increases the feed value of fodder with low protein content. When the digested slurry is placed into the food chain of crops and animals, it leads to a sustainable increase in farm income.

In Jimma Institute of Technology (JiT), Kito Furdisa campus students cafeteria and kitchen wastes, potential have been assessed for one month (from April 27, 2015 to May 26, 2015).

According to data collected for 30 days;

- 28,574 kg of dining hall wastes (food wastes) measured.
- 5,328 kg of kitchen wastes measured.
- Totally 33,902 kg of wastes from both dining hall &kitchen wastes measured.

From experiment we have done above moisture content of food waste and kitchen is 46.5%. This means amount of dryness is 53.5%. The density food and kitchen wastes are taken from graphical representation figure below and it is 515 kg/m$^3$.

As the substrate moves away from being mostly water, the density of the substrate decreases. This is an important factor to note when converting from tons of input material to a volumetric measurement of meters cubed. A graphical representation below show that as dry material in a substrate increases, density decreases [35].

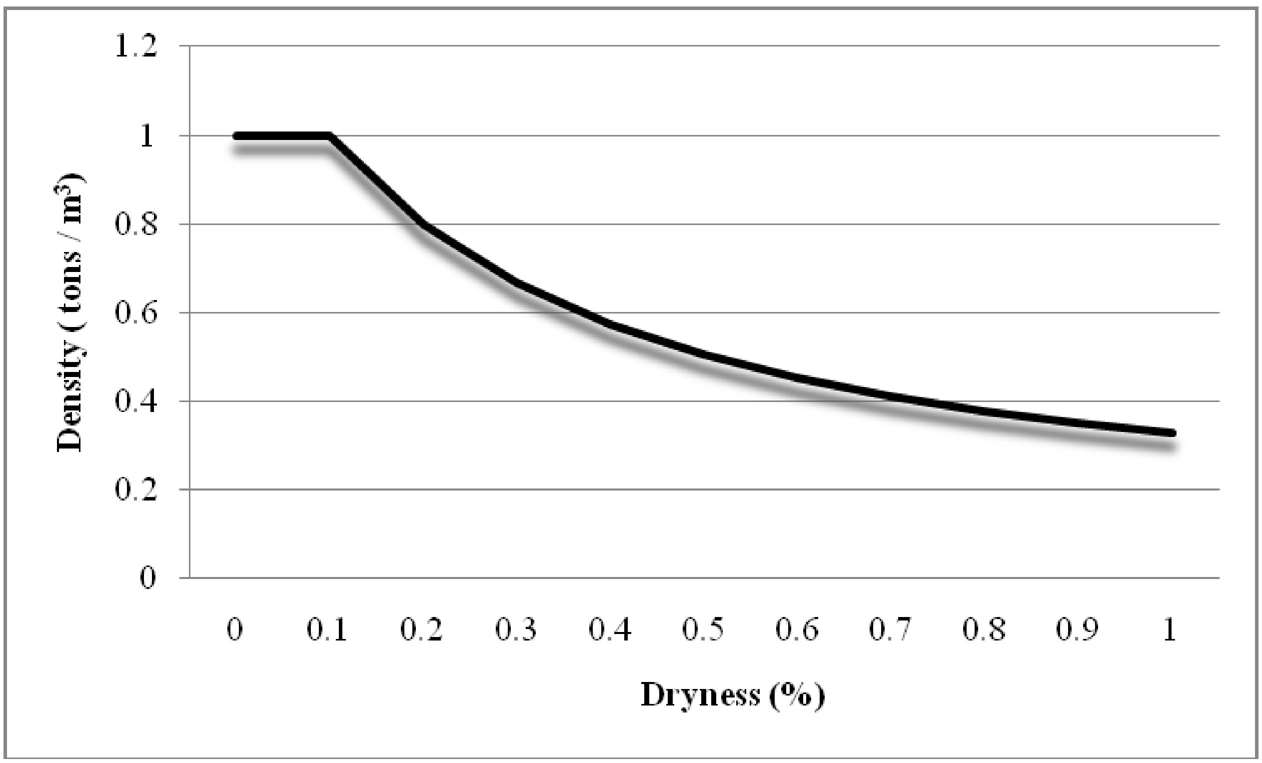


Fig. 3.12 Dryness Vs Density for Organic Materials [33]

Therefore, in order to design the volume of digester, [20].

- Average mass food waste= 28,574 kg /30 days=952kg/day
- Average mass of kitchen waste =5328kg/30 days =178 kg/day
- Volume of food and kitchen wastes per day = (952kg/day +178 kg/day)/515kg /$m^3$
  = 2.19 $m^3$ / day.
- Total volume of both wastes (food and kitchen) =2.19 $m^3$per day.

Since the waste is wet, applying one to one ratio of water added to waters, volume of daily charge will be(2.19 *2)( $m^3$ /day). Which implies that 4.38 $m^3$ /day.

- The volume of digester is defined as, the product of volume of daily charge (Q) and hydraulic retention time (HRT). But HRT, by referring different literatures, taken as 60 days [20].
- Therefore, volume digester ($V_D$) = Q*HRT …………(5)
  = 4.38 $m^3$ per day*60 days
  $V_D$ =263 $m^3$ ~ (6.4m X 6.4m X 6.4m) let us fix size of digestor (i.e. LXWXH).

Consequently, we have to take volume digester 263$m^3$.

- Organic loading rate is determined as a counter check for the digester volume.
- By referring different literatures assume that, -Ratio of volatile solid to total solid is 90%.

Therefore, from the above graph, density of our wastes gives us 515kg/$m^3$.

Organic Loading Rate (OLR) = $\frac{Q*S}{V}$

Where: Q: Flow rate of input [$m^3$/day]

S: Concentration of VS in the input [kg/$m^3$]

V: Reactor Volume [$m^3$]

Hence S= 515 kg/ $m^3$ * 0.9 = 463.5 kg/ $m^3$

Consequently, OLR = $\frac{Q*S}{V}$ = $\frac{4.38*463.5}{263}$ = 7.72 kg substrate / $m^3$ / day. Therefore, organic loading rate is 7.72 kg substrate / $m^3$ / day. Therefore, 7.72 kg substrate / $m^3$ / day are found to be acceptable and the calculated digester size then valid. Other studies have shown that the OLR for food waste can go as high as 10 kgVS/$m^3$ [35].

#### 3.2.1.1 Dimension of digester

Among the various types of digester, in our design fixed dome spherical a continuous feed (displacement digester is selected).This because of it is relatively small amounts of slurry (mixture of food and kitchen) wastes plus water are added daily.

We have used; hydraulic retention (HRT) of this design is taken as 60 days. [20].

***1)* Design of hydraulic tank**

Hydraulic tank is designed which contain 3 days of food waste for bacteria to do or work place and also ,the feed flow rate of 4.38 $m^3$ per day .

Hence, size of hydraulic tank = $(HRT)_{ht} * Q_{ht}$

$$V_{ht} = 3\text{days} * 4.38\ m^3$$

$$V_{ht} = 13.14 m^3$$

In terms of diameter, (hydraulic tank is cylindrical and its diameter is equal to its height]

$$Vht = \pi r^2 h$$

$$V_{ht} = \frac{\pi d2\ (d)}{4} = \frac{\pi d3}{4} = 13.14$$

$$d^3 = 16.73$$

$$d = 2.55m$$

Cross section of digester

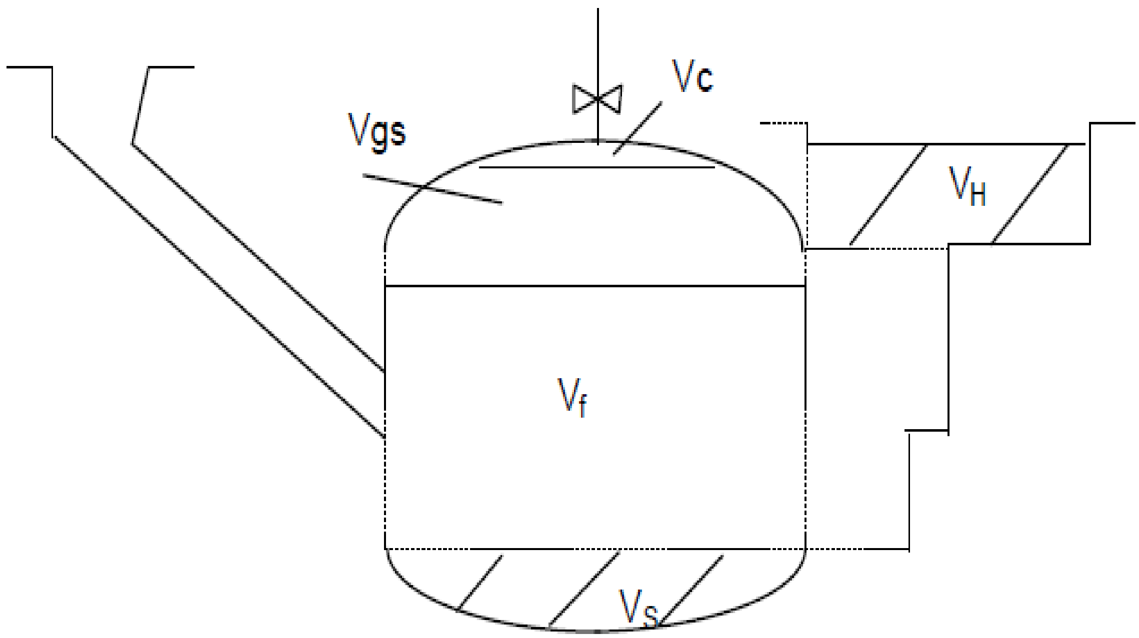


**Fig 3.13 Cross section of digester**

i) Volume of gas collecting chamber=$V_c$

(ii) Volume of gas storage chamber=$V_{gs}$

(iii) Volume of fermentation chamber=$V_f$

(iv) Volume of hydraulic chamber =$V_H$

(v) Volume of sludge layer=$V_s$

(V i)Let $R_1$&$R_2$ is the crown radius of upper and bottom spherical layer of digester respectively.

(vii) $S_{1 \text{ and}}$ $S_2$ are the surface area of upper and lower dome respectively.

(viii) $F_1$&$F_2$ are max. Distance of upper and lower dome.

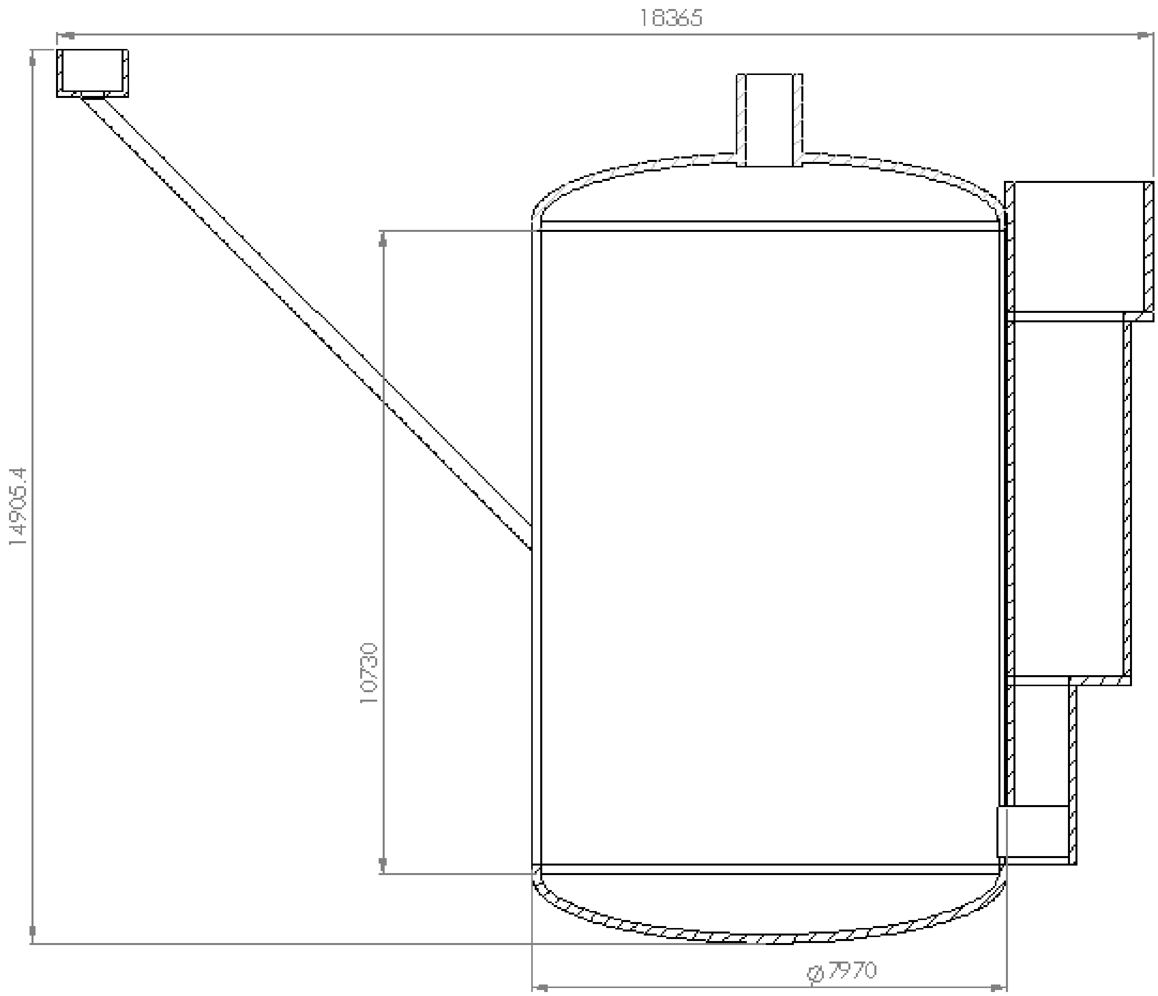


**Fig. 3.14 Total volume of digester**

$$\boxed{(V_{Tot}) = V_c + V_{gs+} V_s + V_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

➢ Geometrical dimension of cylindrical shaped digester.

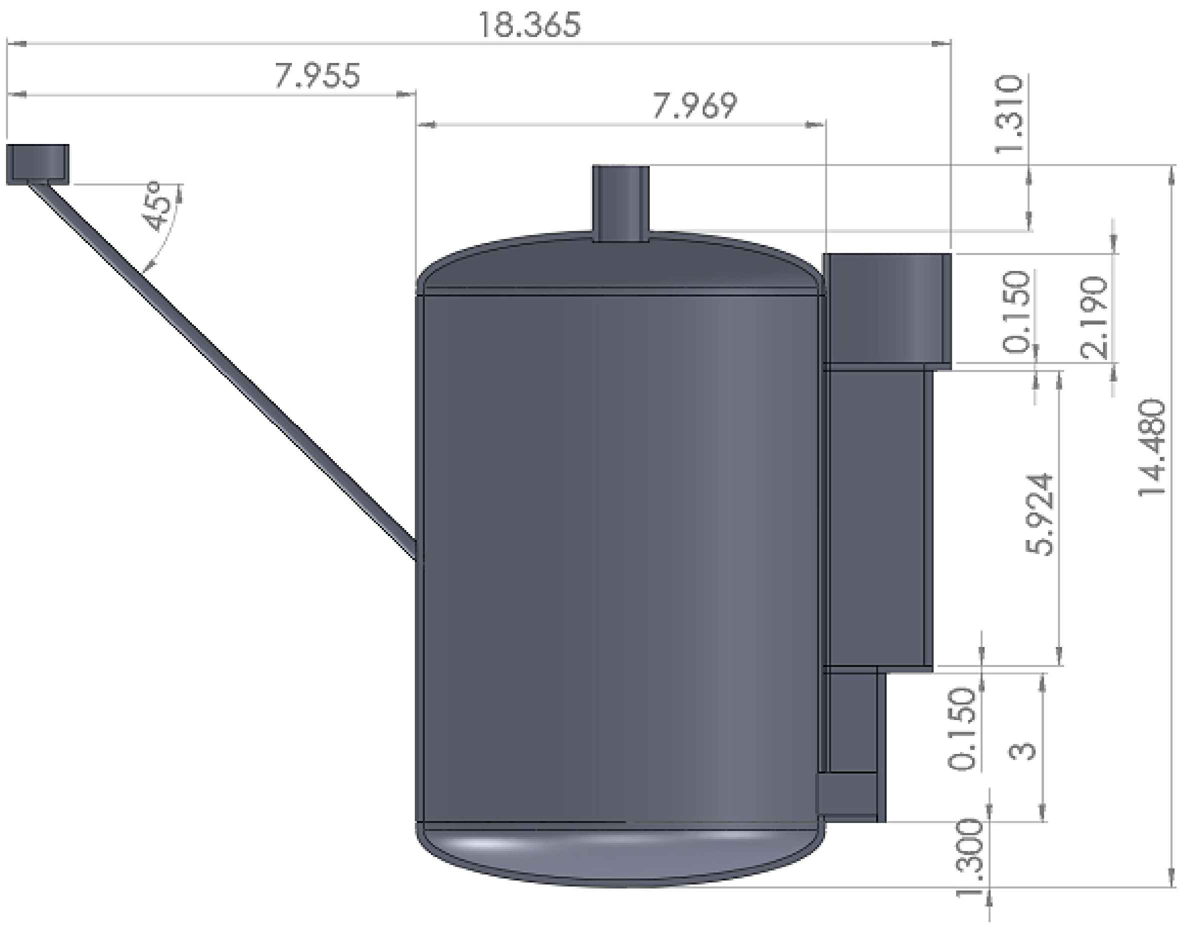


**Fig. 3.15 Complete drawing of cylindrical fixed dome digester.**

- For structure stability and efficient performance, fixed dome digester is expressed by the following correlation.

**Table 3.10 Correlation for fixed dome digester**

**Assumptions:**

| For volume | For geometrical dimensions |
|---|---|
| $V_c \leq 5\%\ V$<br>$V_s \leq 15\%\ V$<br>$V_{gs} + V_f = 80\%\ V$<br>$V_{gs} = V_H$<br>$V_{gs} = 0.5\ (Vgs + Vf + Vs)\ K$<br>Where K = Gas production rate per $m^3$ digester volume per day. | $D = 1.3078 \times V^{1/3}$<br>$V_1 = 0.0827\ D^3$<br>$V_2 = 0.05011\ D^3$<br>$V_3 = 0.3142\ D^3$<br>$R_1 = 0.725\ D$<br>$R_2 = 1.0625\ D$<br>$f_1 = \frac{D}{5}$<br>$f_2 = \frac{D}{8}$<br>$S_1 = 0.911\ D^2$<br>$S_2 = 0.8345\ D^2$ |

Volume of digester ($V_D$) = $V_3 + V_2$

$$263 = (0.05011+0.3142)\ D^3$$

$$721.91 = D^3$$

$$D = 8.97\ m$$

*$R_1$ = 0.725D

= 0.725(8.97) m

$R_1$ = 6.5 m

*$V_3$ = $0.3142D^3$

= $0.3142(8.97)^3$

$V_3$ = 226.76 $m^3$

* $V_2 = 0.05011D^3$

= $0.05011(8.97)^3$

= 36.166 $m^3$

* $V_c$ = 0.05 (v)

= 0.05(263)

= 13.15 $m^3$

*$f_1$ = D/5= 8.97 /5= 1.79 m

* $f_2$ = D/8=8.97 /8= 1.12m

* $S_1 = 0.911D^2$

$= 0.911(8.97)^2$

$= 73.3\ m^2$

$S_2 = 0.8345(8.97)^2$

$= 67.14\ m^2$

$V_1 = 0.08227(D^3) = 0.08227(8.97)^3$

$V_1 = 59.37\ m^3$

$R_2 = 1.065(D)$

$= 1.065(8.97)$

$= 9.55\ m$

- Total Volume ($V_{tot}$) $= V_1+V_2+V_3$

$= (59.37 + 36.166 + 226.76)\ m^3$

$= 322\ m^3$

$$V_{gs} = \frac{k\,(V2+V3)}{1-0.5(k1-0.5(0.4)}$$

$$= \frac{0.4(36.166\ +226.76)}{0.8}\ m^3 = 74m^3$$

$V_{gs} = 74\ m^3$

From $V_1 = (V_c + V_{gs}) - (\frac{\pi D2H1}{4})$

$59.37 = (13.15 + 74) - (\frac{\pi(8.97)2H1}{4})$

$111.12 = \pi(8.97)2H1$

$H_1 = 1.87\ m = 187cm$

The value of the height of the above dome up to the end, have fixed h = 8m (water volume, 1mm = 10 N/ m$^2$)

$h = h_3 + f_1 + H_1$

$h_3 = h - (f_1 + H_1)$

$= 8 - (1.79 + 1.87)$

$= 4.34m$

Again we know that

$Vgs = V_H$

$$74 = \frac{\pi(DH)2h3}{4}$$

$$(D_H)^2 = \frac{74}{3.14}$$

$D_H$ = 4.85m, diameter of hydraulic chamber

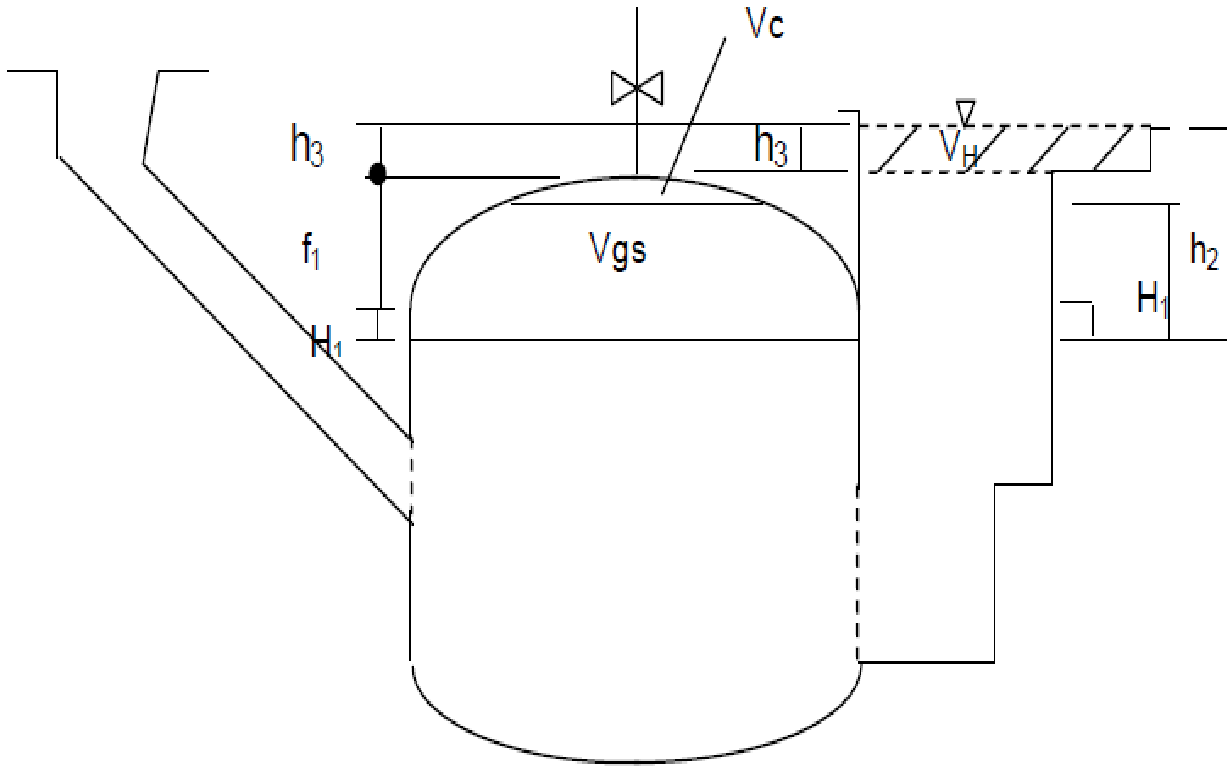


**Fig. 3.16 Volume of hydraulic chamber, gas collecting chamber and gas storage chamber**

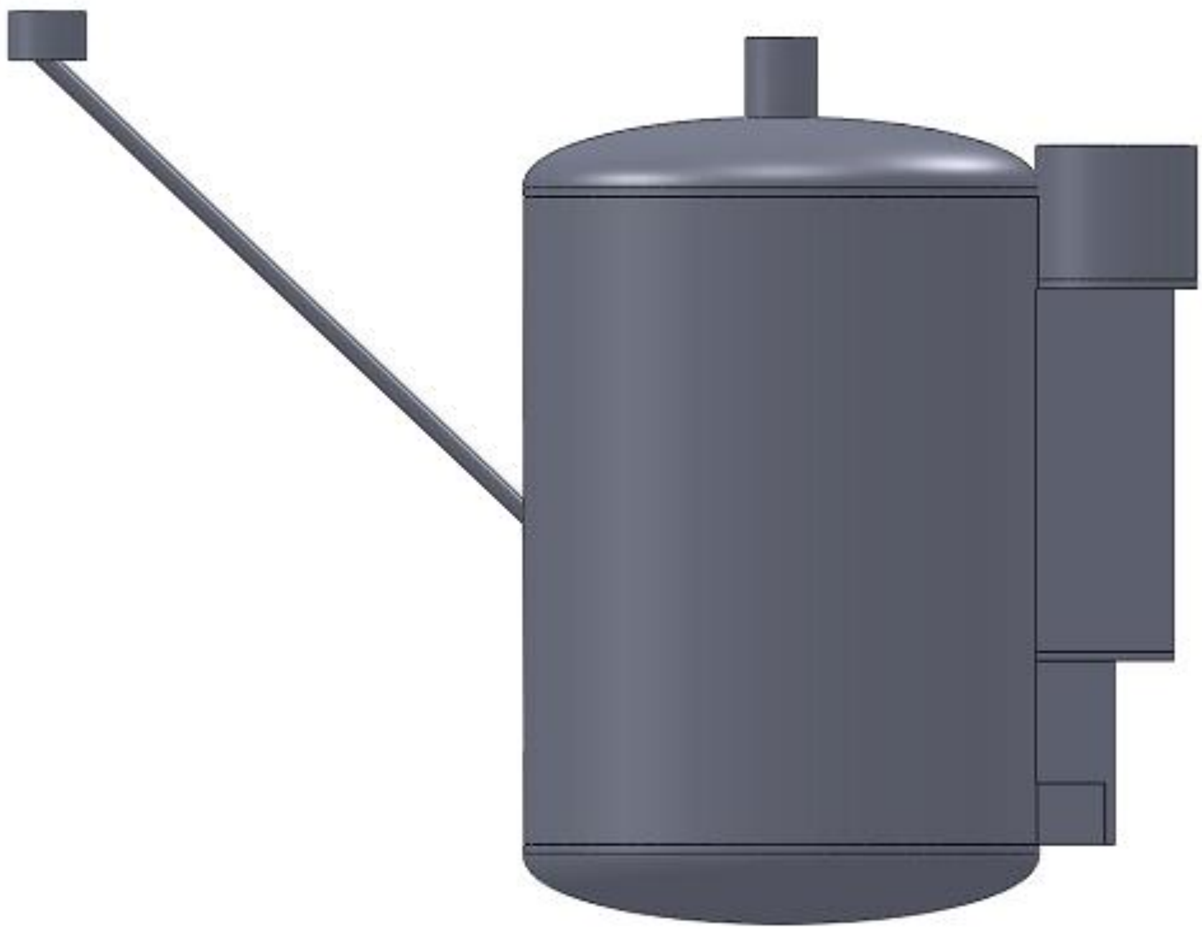

Fig 3.17 Designed digester

### 3.2.1.2 Selection of construction materials for fixed dome biogas plant digestor

Domestic fixed dome biogas plant should be constructed by Stones round wall and outlet, Dome with plain Concrete and slabs with reinforced concrete, inlet with either stones or Bricks. A brief description regarding the specifications for some of the construction materials is provided below to assist with selection of the best quality materials.

**Cement**

The cement to use in the plant construction must be of high quality Portland cement from a brand with a known reputation. It must be fresh, without lumps and stored in a dry place.

**Sand**

Sand for construction purpose must be clean. Dirty sand has a very negative effect on the strength of the structure.

**Water**

Water is mainly used for preparing the mortar for masonry, concrete and plastering work. It is also used to soak bricks/stones before using them. Water is also used for washing sand and aggregates.

**Bricks**

Bricks must be of the best quality locally available. When hitting two bricks together, the sound must be crisp or clean. They must be well baked and regular in shape. Before use bricks must be soaked for few minutes in clean water. This will prevent the bricks from soaking moisture from the mortar after being laid in place.

## Gas pipe, valve and accessories

The diameters of the pipes are depending on the required flow rate of biogas through the pipe line and the distance between biogas digester and gas appliances. Long distances and high flow rates lead to decrease of the gas pressure. The longer the distance and the higher the flow rate, the higher the pressure drops due to friction. The pipe should be laid straight as far as possible with minimum joints and bends [35].

**Table 3.11 Appropriate pipe diameter for different pipe lengths and flow rate [33].**

| **Flow rate ($m^3$/hr.)** | **Galvanized steel pipe length(m)** | | | **PVC length (m)** | | |
|---|---|---|---|---|---|---|
| 0.1 | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" |
| 0.2 | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" |
| 0.3 | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" |
| 0.4 | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" |
| 0.5 | 1/2" | 1/2" | 1/2" | 3/4" | 1/2" | 1/2" |
| 1.0 | 3/4" | 3/4" | 3/4" | 1/2" | 3/4" | 3/4" |
| 1.5 | 3/4" | 3/4" | 1" | 1" | 3/4" | 3/4" |
| 2.0 | 3/4" | 1" | 1" | | 3/4" | 1" |

The values in this table show that a pipe diameter of (1/2") is suitable for flow rates up $0.2m^3/h$ and distances up to 50m (Galvanized steel pipe). Therefore one could select the diameter of (1/2") as single size for the hole piping system of small biogas plants.

**Selection of construction site**

The following points should be kept in mind when deciding on a site for biogas plant construction.

Please note that it will not be possible to meet all the requirements as stated below, however, it should be ensured that as many points as possible are considered:

- The site should facilitate easy construction works;
- The selected site should be such that the construction cost is minimized;
- The selected site should ensure easy operation and maintenance activities like feeding of the plant, use of the main gas valve, composting and use of slurry, checking of gas leakages, draining condensed water from the pipeline, etc.;
- The site should guarantee plant safety;
- For proper function of the plant, the optimal temperature has to be maintained in the digester.
- The area to construct the plant should have an even surface
- The site should be in a slightly higher elevation than the surrounding. This helps in avoiding water logging. This also ensures free flow of slurry from the outlet overflow to the composting pit;
- there should be enough space for compost pit(s) as these are integral parts of the biodigester;
- the site should be at sufficient distance from trees to avoid damage of biodigester from roots;
- to make plant operation easier and to avoid wastage of raw feedstock the plant must be as close as possible to the feedstock supply (food and kitchen wastes, etc.) and water source;
- If a supply of feedstock or water or both is not available then the biogas plant should not be installed.
- Gas pipe length should be kept as short as possible. A longer pipe increases the risk of gas leaks because of the increased number of joints; the cost of a longer pipe is also a factor;

- The main gas valve should be opened and closed before and after each use, therefore the plant should be as close as possible to the point of use to facilitate proper operation;
- The edge of the foundation of the plant should be at least two meters away from any other structures to avoid risk of damage during construction;
- The plant should be at least 10 meters away from groundwater wells or surface water bodies to protect water from pollution.

**Total Gas produced**

Total gas produced from food waste is calculated as, amount of food waste per day time its gas production rate.

- $952*0.1m^3 = 95.2m^3$ /day (for food waste).
- $178*0.01m^3 = 17.8m^3$/day(for kitchen waste)

Total gas production $= (95.2+17.8)m^3/day = 113m^3$ / day.

From energy conversion

$1m^3$ of bio gas =6.39kwh

$113m^3$ =x

X=722kwh, Therefore from our wastes we can get, 722kwh of power is received per day.

**Food waste and kitchen waste to energy system**

Based on biogas estimation above, biogas produced will be diverted to combined heat and power (CHP) system to generate electricity and heat is recovered to produce hot water using stove for cafeteria of Kito Furdisa and its kitchen itself.

**Production of biogas**

The required quantity of food and kitchen wastes and water is mixed in the hydrolysis tank and the slurry is discharged to the digester vessel for digestion. The gas produced through methanogenesis bacteria in the digester is collected in the dome. The digested slurry flows to the outlet tank through the manhole. The slurry then flows through the overflow opening in the outlet tank to the compost pit. The gas is supplied from the dome to the point of application through a pipeline.

When a biogas plant is underfed the gas production will be low; in this case, the pressure of the gas might not be sufficient to fully displace the slurry in the outlet chamber. It is important to design the plant keeping hydrostatic pressure higher at the inlet tank than the outlet tank. The hydrostatic pressure from slurry in the inlet and outlet tanks will pressurize the biogas accumulated in the dome. If too much material is fed into the digester and the volume of gas is consumed, the slurry may enter the gas pipe and to the appliances.

The required quantity of feedstock and water is mixed in the inlet tank and the slurry is discharged to the digester vessel for digestion. The gas produced through methanogenesis bacteria in the digester is collected in the dome. The digested slurry flows to the outlet tank through the manhole. The slurry then flows through the overflow opening in the outlet tank to the compost pit. The gas is supplied from the dome to the point of application through a turret and pipeline;

When a biogas plant is underfed the gas production will be low; in this case, the pressure of the gas might not be sufficient to fully displace the slurry in the outlet chamber. It is important to design the plant keeping hydrostatic pressure higher at the inlet tank than the outlet tank. The hydrostatic pressure from slurry in the inlet and outlet tanks will pressurize the biogas accumulated in the dome. If too much material is fed into the digester and the volume of gas is consumed, the slurry may enter the gas pipe and to the appliances.

- Below diagram is systematic diagram of proposed food & kitchen waste to energy system.

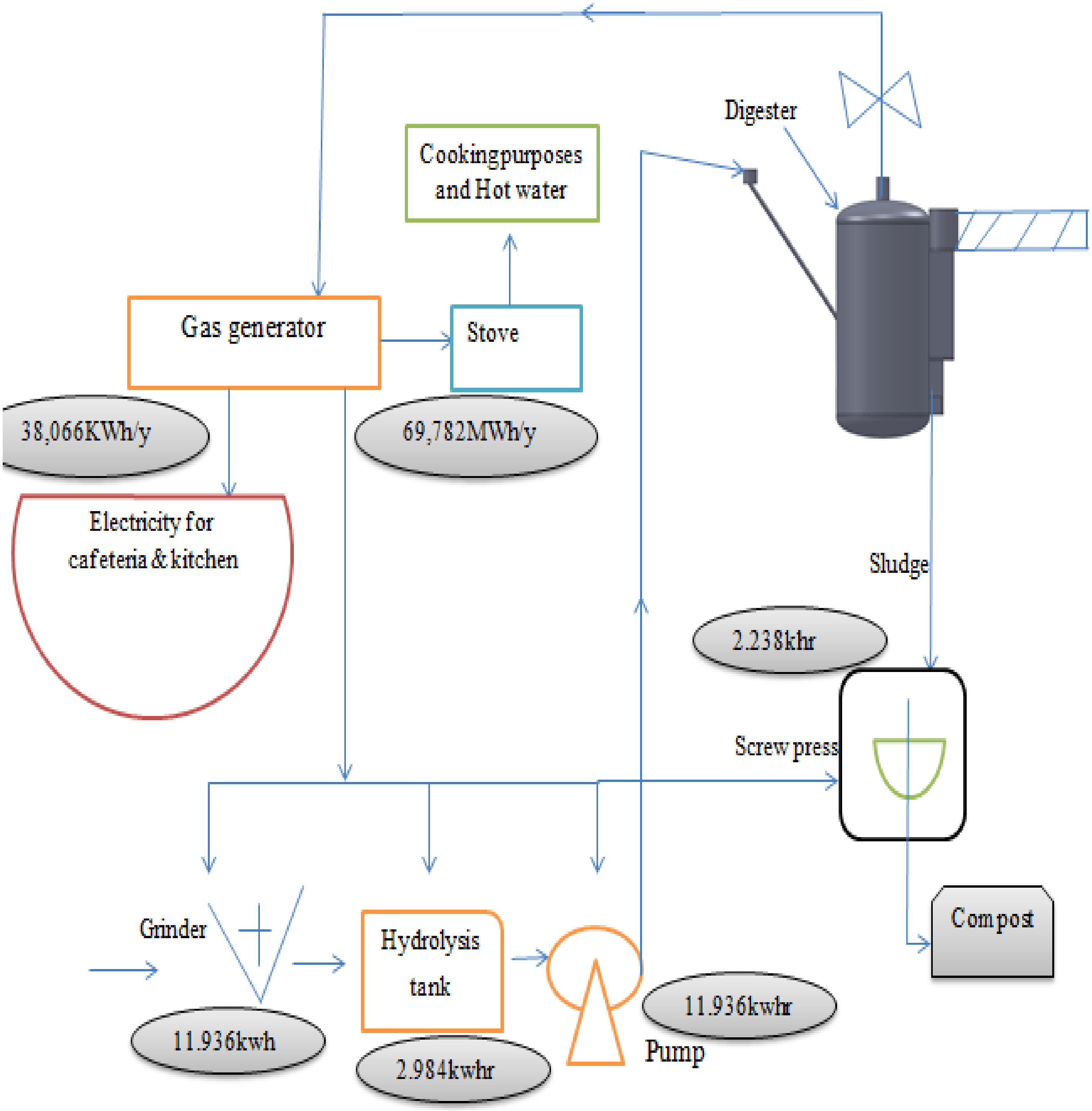


**Fig. 3.18 Proposed food & kitchen wastes to energy system**

There are various types of centrifugal slurry pumps, which are identified by their capability to handle solids ranging in size, hardness, concentration, and velocity. An understanding of these important factors will lead to an optimum choice of pump design where the materials of construction and rotational speed are ideally matched to the process system.

**Pressure in the Gas Holder or Container**:

Assume the gas in gasholder obeys ideal gas law i.e. PV=nRT, where n is the mole of gas (n),

$$\text{Mole (m)} = \frac{\text{Mass of the gases (m)}}{\text{molecular mass of gase (M)}} \qquad \ldots\ldots\ldots\ldots (7)$$

$$\text{Mass (M)} = \frac{\text{density of biogas } (\rho)}{\text{volume of gase(V)}}$$

Substituting all values it gives,

$$P = \frac{\rho RT}{\text{volume of gase(V)}} \qquad \ldots\ldots\ldots\ldots (8)$$

The value of M=25.8 (65% $CH_4$ and 35%$CO_2$), universal gas constant(R) =8.314J/mole K, temperature (T) =298K ($25^0$C) density of biogas (ρ) =1.15Kg/$m^3$; hence P=1.1bar.

## BIOGAS UTILIZATION

There are several viable options for the utilization of biogas. Foremost among these are:

- Direct combustion,
- Fueling engines, and
- Sales to natural gas pipelines.

This means to produce power from biogas

1. Biogas used in duel fuel engine with 75% -80 % replacement of diesel

2. Through 100% biogas engines

3. Through fuel cells–direct conversion of biogas into electricity.

4. through burning biogas in boiler → steam → turbine → electricity

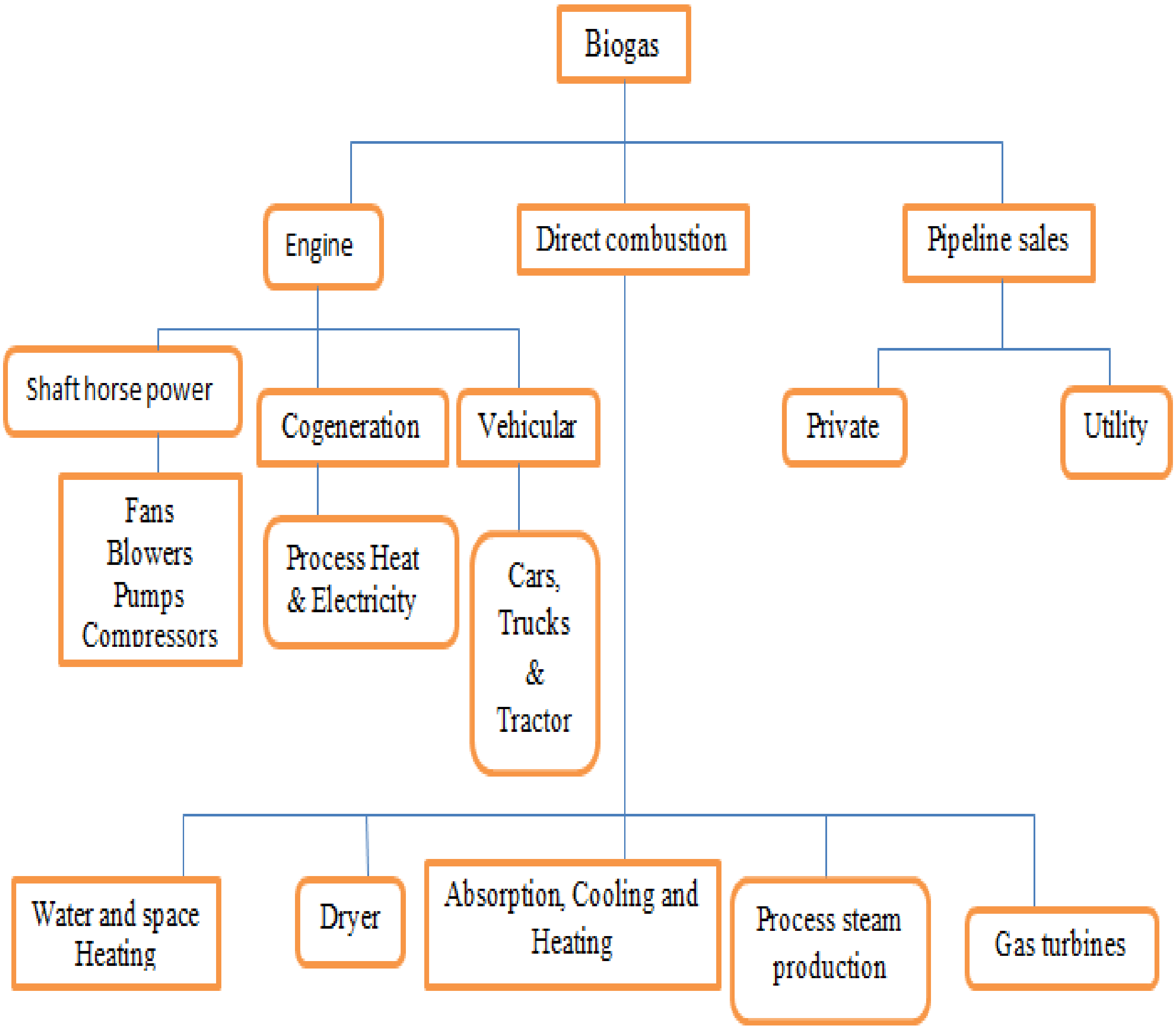


**Fig.3.19 Several viable options for the utilization of biogas.**

### I) Direct Combustion

Direct combustion is inarguably the simplest method of biogas utilization. Conversion of combustion systems to biogas combustion is basically a matter of fuel orifice enlargement and intake air restriction, with attendant modification of the fuel delivery and control system.

### II) Engine Systems

Internal combustion engines have been fueled by biogas from municipal digester systems with varying degrees of success. In recent years, this application has been extended to agricultural and industrial systems for a variety of power requirements.

Stationary spark ignition engines can supply power for many loads including:

- Cogeneration.
- Pumps,
- Fans and blowers,
- elevators and conveyors, and
- Heat pumps and air conditioners.

**Cogeneration**

Cogeneration is best defined as the simultaneous production of two or more forms of energy from a single fuel source. In our design discussion, the two forms of energy exemplified are combined electricity and heat energy in the form of hot water. A number of variables will affect the design of an interconnect system including:

**Generator type**

For our design we select gas engines type generator, Because of it generate a Power through 100% biogas engine.

- They are also called as gas engines
- Both compression and spark ignition can be employed
- Carburetor is replaced by venturi system to introduce gas into the air flow
- Maximum power output is lower than dual fuel engine
- Electrically efficiency is lower than duel fuel engine
- Will cause corrosion in mechanical parts
- Overall, the dual-fuel engines perform well and have great potential for use on-farm energy utilization.

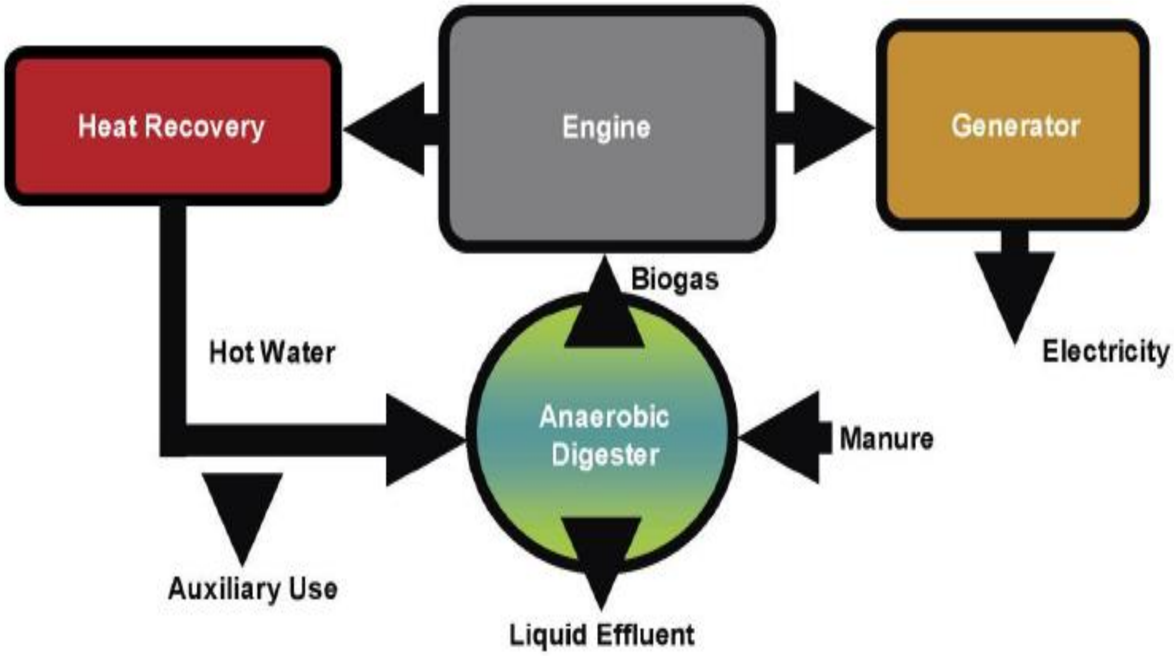


Fig. 3.20 Biogas into Electricity conversion through Engines

Fig. 3.21 Gas Generator type for biogas generation

**Biogas for Electricity Generation**

The most common alternative use for biogas has been for power generation. The electrical power generated can be used for plant operations or for sale or credit to the local power utility. Engine generators typically consist of a skid-mounted package of a reciprocating engine, generator, and a control panel.

The electrical efficiencies of engine generators operating on biogas can range from 30% for smaller engines to around 35% for larger engines. Approximately 40–45% of the total energy input to the engine generators can be recovered from the engine exhaust and the cooling systems to produce either hot water or steam for combined heat and power applications. The overall efficiency of engine generators can approach 70–80%.

**Assessing the potential of generating electricity and heat using biogas**

The biogas that can be harvested from the waste resources chosen in this study carry potential energy that can be converted to useful energy in the form of electricity, heat, etc. The total energy input that can be generated using biogas can be expressed using equation (3-5) as follows [18].

$$E_t = \frac{\text{E content} * \text{V CH4} * \text{Availablity}}{24} \qquad \text{.............................................. (9)}$$

Where:

V CH4 = the volume of biogas produced ($m^3$)

E content = the energy content of CH4 gas (6kWh/$m^3$) **[**18].

Availablity = the availability of energy source (%)

This is divided by 24 to convert the units kWh into kW

- availability of energy from this waste type after the first year of waste disposal would be:

$$\text{Availablity} = \frac{365\text{ days } - 25\text{ days}}{365\text{ days}} * 100 \qquad \text{.......................................... (10)}$$

The electrical power that can be generated from biogas can be estimated as follows:

$$Ep = E_t * \text{efficiency} \qquad \text{.......................................... (11)}$$

The typical electricity efficiency of biogas is 35% [18].

The thermal power that can be generated from biogas and used directly can be estimated as follows:

$$E_{th} = E_t * \text{thermal efficiency} \qquad \text{.......................................... (12)}$$

The biogas has a typical thermal efficiency of 50%.

Some of the electricity generated from the biogas fuel is used in the plant to drive electrical equipment such as agitators, compressors, and pumps as well as to provide light in the plant.

Therefore the electricity consumed in the plant is:

$E_{consumed} = E_p * F_{consumed}$ ……………………………………….. (13)

Where: $F_{consumed}$ is the fraction of the electricity consumed internally before supplied to the grid [18].

#### 3.2.1.3 Energy usage

Energy consumption of this proposed an aerobic digestion of system in dining hall &kitchen wastes, calculated as below;

1) Grinder ($G_e$) Grinder uses 4HP power for 4hrs per day.

4HP*4hrs=4(746w)*4hrs

=<u>11.936kwh</u>

**2)** Pump ($P_e$):

**Pumps for Biogas Plants**

Pumps are required to bridge differences in height between the levels of slurry-flow through the biogas unit. They can also be required to mix the substrate or to speed up slow flowing substrates. If substrates have high solids content and do not flow at all, but cannot be diluted, pumps or transport belts are essential.

**Rotary pumps**

Rotary pumps operate with a rotor which presses the liquid against the outside wall of the rotor chamber. Due to the geometry of the chamber the liquid is pushed into the outlet pipe.

Rotary pumps are very common in liquid manure technology. They are simple and robust and used mainly for substrates of less than 8% solids content. The quantity conveyed per time unit depends largely on the height of lift or the conveying pressure. Pumps uses 2HP, power for 8hrs per day.

2HP*8hrs

2(746w)*8hrs

<u>11.936kwhrs</u>

3) Hydrolysis mixer tank (He): For mixing purposes, hydrolysis tank use 1Hp for 4 hrs per day.

1 Hp*4hrs

746w*4hrs

2.984kwhrs

(4) Screw press (Se): It uses 1Hp for 3hrs per day

1Hp*3hrs

746*3hrs=2.238khr

(5) Stove (Ste): For heating purpose, the Stove uses for boiling and cooking purposes. 2HP for 8hrs.

2* 746w*8hrs =11.936 Kwh

Total Energy consumption = $(G_e+P_e+H_e+S_e+B_e)$

= (11.936) + (11.936) + (2.984) + (2.238) + (11.936) kwhr

= 41.03 kwhrs

- Net energy used =(Total energy received) - (energy consumption)

= (722kwh) - (41.03 kWh)

= 681kwh

Consequently, net energy used is 681kwh kWh.

From above result calculated also, the amount of biogas produced per year is 41,245 $m^3$. That gives 4.7 $m^3$ per hour. The electricity and heat production is:

With caloric value of biogas of 22MJ/$m^3$,

$4.7 * \frac{22*10^6}{3600}$= 28,722W that is approximately 28.72KW

So, the power available for CHP unit is 28.72KW. Assuming that the CHP unit has a conversion efficiency of 30% for electricity and 55% for heat: [33]

28.72* 0.3 = 8.61 KW

8.61 *24*365 = 75.42MWh/y

The production of electricity will be 75.42MWh/y.

For production of heat;

28.72* 0.55 = 15.785KW

15.785* 24* 365 = 138.27 MWh/y

The production of heat will be 138.27 MWh/y. this heat could be used for the process (digester heating, sterilization) and for many other applications.

#### 3.2.1.4 Cleaning Of Biogas

### Gas impurities

The raw gas contains several impurities, like water, dust, $H_2S$, $CO_2$, siloxanes, Hydrocarbons, $NH_3$, oxygen and several other elements that must be removed in order to reach certain standards of quality.

**I) Removal of Water**

Untreated or raw biogas is usually saturated with water and the absolute water quantity depends on the temperature (according to chemical equilibrium). Different standards have been made in order to achieve a correct gas composition and water removal is one of the most important steps to achieve them.

**II) Removal of $H_2S$**

Hydrogen sulfide is the chemical compound with the formula $H_2S$. It is corrosive and toxic. Burning biogas with hydrogen sulfide produces the environmentally hazardous sulfur dioxide. It has been observed that corrosiveness of hydrogen sulfide increases with increasing concentration, temperature and pressure and is enhances by the presence of water. It is a colorless, very poisonous, flammable gas with the characteristic foul odor of rotten eggs. It results mostly from the bacterial breakdown of organic matter in the absence of oxygen, such as in swamps and sewers; this process is commonly known as anaerobic digestion and is the main process in biogas formation. Due to its corrosive nature, $H_2S$ have to be removed in an early state of the biogas upgrading process. To reach the composition specification and therefore to remove $H_2S$ there are two main ways of separation

- Removal of $H_2S$ during digestion;
- Removal of $H_2S$ after digestion.

**1) Removal of $H_2S$ during digestion**

$H_2S$ can be treated directly in the digester vessel and the most used techniques to interfere with its formation are adding air/oxygen or iron chloride.

**a) Air/oxygen dosing to the biogas system**

This technique is based on the biological aerobic oxidation of $H_2S$ to elemental sulphur by a group of specialized microorganisms. The following reaction occurs in the biogas:

$$2H_2S + 0_2 \longrightarrow 2S + 2H_20 \quad \text{………………………………………….. (14)}$$

Unfortunately a parasite reaction takes place forming sulphate ($SO_4$), which can cause corrosion in solution. Thanks to this method a reduction of $H_2S$ concentrations down to 20-100 $cm^3/m^3$ at standard condition and a removal efficiency of 80-99% can be achieved.

**b) Addition of iron chloride into the digester**

Iron chloride reacts with the $H_2S$ present in the biogas to form FeS as solid precipitated particles. These are the chemical reactions:

$$2Fe^{2+} + 3S2^- \longrightarrow 2FeS + S \quad \text{…………………………………………… (15)}$$

$$Fe^{2+} + S^{2-} \longrightarrow FeS \quad \text{………………………………………… (16)}$$

Due to the precipitation of FeS, the presence of $H_2S$ in the biogas is avoided and therefore this method can achieve a reduction of $H_2S$ concentration in the biogas.

**2) Removal of $H_2S$ after digestion**

There are several chemical and mechanical mechanisms to remove the hydrogen sulphide. Here the most common are summarized:

**a) Adsorption using iron oxide or hydroxide**

Hydrogen sulphide reacts easily with iron oxide ($Fe_2O_3$), iron hydroxide ($Fe(OH)_3$) and zinc oxide (ZnO) forming iron sulphide or zinc sulphide respectively.

$$Fe_20_3 + 3H_2S \longrightarrow Fe_2S_3 + 3H_20 \quad \text{………………………………..… (17)}$$

$$2Fe\,(0H)_3 + 3H_2S \longrightarrow Fe_2S_3 + 6H_20 \quad \text{………………………………..…. (18)}$$

The reaction is slightly endothermic: a minimum temperature of about 12 °C is required to provide the necessary energy. The reaction is optimal between 25 °C and 50 °C. The iron oxide can be regenerated with oxygen according to the following reaction:

$$2Fe_2\,s_3 + 30_2 \longrightarrow 2Fe_20_3 + 6S \quad \text{………………………………… (19)}$$

This reaction is exothermic and therefore a large quantity of heat is released during regeneration. This may lead to self-ignition of the wood chips, if air flow and temperature are not carefully controlled.

Typically two reaction beds are installed. One bed is regenerative while the other bed removes $H_2S$ from the biogas. The former elementary sulphur remains on the surface and blocks the active iron oxide or hydroxide, restricting the number of cycles that can be performed.

**b) Absorption with liquids**

Absorption of $H_2S$ in liquids can be either physical or chemical. Physical absorption involves dissolving the trace component in the solvent, whereas chemical absorption involves dissolving the component followed by a chemical reaction of the trace component and the solvent.

Chemical absorption liquids that can be used are:

- Diluted NaOH-solution: NaOH reacts with $H_2S$ to form $Na_2S$ or NaHS which precipitates. The formed sodium salts are not regenerative and have to be disposed of;
- $FeCl_2$- solution: this process is based on the formation of insoluble FeS that needs to be removed;
- Fe $(OH)_3$- solution: $H_2S$ is removed using Fe $(OH)_3$ resulting in the formation of $Fe_2S_3$.

**III) Removal of oxygen/air**

It might happen that some air penetrates in the digester or in collectors. This will result in a certain amount of oxygen or nitrogen in the biogas mixture. The oxygen and nitrogen content has to be carefully controlled because biogas in air with a methane content of 60% is explosive between 6 and 12%, depending on the temperature. Lower methane content in the biogas will increase the share of biogas needed in air for explosion to occur. Oxygen and nitrogen can be removed with expensive methods such as using membranes or adsorption at low temperature and pressure. Preventing the introduction of air in the biogas by careful monitoring is far cheaper than gas treatment.

**IV) Removal of $CO_2$**

The techniques for $CO_2$ removal are listed below:

- Physical and chemical $CO_2$-absorption
- Pressure Swing Adsorption (PSA) and Vacuum Swing Adsorption (VSA);
- Membrane separation
- Cryogenic separation and Biological methane enrichment.

### 3.2.1.5 Instrumentation and Controls for Biogas Equipment

There are a number of measurements that are desirable for designing, monitoring, and controlling both the anaerobic processes which produce biogas and the systems which recover the energy from the biogas. The equipment required will vary depending on the source of the biogas (digester) as well as the complexity of the utilization system. Some of these measurements are performed continuously, but some portable and laboratory equipment is essential. There is a wide variety of equipment available off the shelf which can be used to measure all parameters of interest for gas production and quality. The operation and maintenance costs of such equipment can be high due to the corrosive nature of the gases. Based on these reviews and practical experiences, ley we see an overview of equipment and strategies needed for proper biogas monitoring and control [22].

**Gas Composition**

Gas composition (%$CH_4$, %$CO_2$, %$N_2$, %$O_2$, %$H_2S$) is a useful parameter for energy and mass calculations and for monitoring the relative health of the anaerobic process. Data on composition is needed for design of clean-up equipment, burners, and engine modifications such as compression ratio and spark advance. Variations in gas composition can indicate problems in digester operation or depletion of gas being produced. Natural gas distributors purchasing pipeline quality biogas may require periodic or continuous measurements of gas composition. Composition can be measured with simple, hand-held instruments or complex continuous monitoring equipment. The more common instruments used for determination of biogas composition are briefly described in the following sections [26].

**Diffusion Tube**

Chemical sensing diffusion tubes are hand-held instruments that determine biogas composition by measuring the chemical reaction of a single constituent in the gas with material in the tube. These devices can be used to measure most all of the constituents of biogas including water vapour, but different tubes must be used for each constituent. In addition, the tubes are designed for a specific concentration range and thus, the appropriate tube must be used to measure a specific range of concentration.

**Gas Chromatograph**

The best equipment for measuring gas composition is an on-line chromatograph. This instrument contains a packed column (tubing filled with absorbent material) which serves to separate the different components of the gas on the basis of molar weight and other molecular properties. The individual components of the exiting gas are measured by a detector (preferably a thermal conductivity detector since flame ionization detectors are not useful for measuring carbon dioxide). The output from the detector is plotted as a function of time, and component concentrations are calculated from the areas under each output peak.

**Gas Flow**

One of the more basic biogas instrumentation requirements is that of gas flow. Gas production from a digester is an indication of performance and is directly related to the general "health" of the anaerobic system. Biogas being blended with an auxiliary fuel must be controlled and thus the flow rate must be known. The total quantity of biogas supplied to a natural gas pipeline must be recorded to establish the basis for payment for the fuel.

**Biogas Safety Considerations**

There a number of safety issues to be considered when working with a biogas system.

**I) Fire (Explosion)**

Biogas mixtures containing more than 60 % methane are combustible, while lower percentages may support or fuel, combustion. With this in mind no naked flames should be used in the vicinity of a digester and electrical equipment must be suitable quality and normally "explosion proof".

**II) Disease**

As Anaerobic digestion relies on a mixed population of bacteria of largely unknown origin, but often including animal wastes, to carry out the waste treatment process care should be taken to avoid contact with the digester contents and to wash thoroughly after working around the digester (and particularly before eating or drinking). This also helps to minimise the spread of odours that may accompany the digestion process. The digestion process does reduce the number of pathogenic (disease causing) bacteria, particularly at higher operating temperatures, but the biological nature of the process need to be kept in mind.

**Efficiency of Sludge Pretreatment**

The parameters commonly used to determine the effectiveness of sludge disintegration can be classified into the three categories discussed as follows [13].

**1) Physical Characteristics**

Particle size distribution and microscopic examination have been widely used as a qualitative measure of sludge disintegration. Researchers have assessed disintegration by changes in particle size distribution and turbidity [13]. Disintegration reduces the size of the sludge particles and flocs, which subsequently increases turbidity. Light and electron microscopy examinations reveal structural changes that occur in the cells and flocs.

**2) Chemical Evaluation**

Cell disintegration is measured by the increase in released soluble chemical oxygen demand (SCOD). However; pretreatment also disintegrates extracellular materials, including organic debris and extracellular polymers, which become part of the SCOD. A parameter known as "degree of disintegration" (DD) has often been used to quantify the efficiency of sludge disintegration [13].

**3) Biological Evaluation**

Since waste-activated sludge (WAS) is composed primarily of microbial cells, a measure of their survival rate following pretreatment will furnish data on the efficiency of the pretreatment. The parameter typically used to determine survival is the oxygen uptake rate (OUR).

## 3.3 Economic Analysis

The benefits are calculated based on replacement rate biogas and commonly used Eucalyptus wood. It has been suggested that 1 $m^3$ biogas replaces 1.3kg fire wood [30]. Amount of fire wood replaced 113*1.3=146.9 kg wood/day.

Market survey indicates 10kg wood costs 35 birr giving a ratio of 3.5 birr/kg wood. Monthly saving is then, 146.9 kg/day*3.5 birr/kg*30days=15424.5 birr/month.

Assuming 113 $m^3$ /day gases is available for 10 months a year due to lower gas production annual saving is 15424.5 *10 = 154,245 birr [31].

**Table 3.12 Bill of quantities and cost estimation of construction materials for fixed dome biogas plant digestor**

| Items | Unit | Size of bio digester ($322m^3$) | | Estimate cost total (ETB) |
|---|---|---|---|---|
| **Building materials** | | Unit cost (ETB) | quantity | |
| Digging operations | $m^3$ | 1100 for each $m^3$ | 322 | 354,200 |
| Cement bags/pieces | Kg | | | |
| Gravel | $m^3$ | | | |
| Brick | $m^3$ | | | |
| Acrylic emulsion paint | Cal | 320 | 15 | 4800 |
| Main gas pipe (galvanized steel) 1/2" diameter & 40m | Pcs | 80 | 40 | 3200 |
| Binding wire | kg | 60 | 5 | 300 |
| Galvanized wire | kg | 70 | 5 | 350 |
| PVC pipe 1/2" | pcs | 40 | 10 | 400 |
| PVC elbow 1/2" | pcs | 35 | 10 | 350 |
| PVC tee 1/2" | pcs | 35 | 10 | 350 |
| PVC socket 20 mm | pcs | 40 | 10 | 400 |
| PVC Adapter nipple 1/2" | pcs | 15 | 15 | 225 |
| PVC Adapter socket 1/2" | pcs | 45 | 10 | 450 |
| Tangit Glue | kg | 55 | 6 | 330 |
| Galvanized Nipple 1/2" | pcs | 25 | 10 | 250 |
| Galvanized Union 1/2" | pcs | 25 | 6 | 150 |
| Galvanized Plug 1/2" | pcs | 30 | 5 | 150 |
| Gas hose pipe 1/2" | m | 50 | 40 | 2000 |
| Hosepipe Nipple 1/2" | pcs | 30 | 10 | 300 |
| Hosepipe clamp | pcs | 25 | 10 | 250 |
| Gas valve 1/2" | pcs | 60 | 10 | 600 |

| | | | | |
|---|---|---|---|---|
| Biogas lamp | pcs | 60 | 10 | 600 |
| Pressure gauge | pcs | 150 | 4 | 600 |
| Teflon tapes | pcs | 60 | 5 | 300 |
| Wood screws | pcs | 20 | 4 | 80 |
| Mixing device | pcs | 80 | 6 | 480 |
| Various fittings | Pcs | 70 | 10 | 700 |
| Masonry | Days | 25 | 50 | 1250 |
| Labor | Days | 25 | 60 | 1500 |
| Supervision | Days | 25 | 400 | 10,000 |
| Excavation (using Excavator machine) | hrs | 20 | 1000 | 20,000 |
| **Subtotal ( ETB)** | | | | **404,415** |

**Table 3.13 Additional necessary materials for overall project**

| S.N | Items | Unit | Estimate cost (ETB) |
|---|---|---|---|
| 1 | Gas generator | 1 | 120,000 |
| 2 | Centrifugal Slurry pump | 1 | 60,000 |
| 3 | Food and kitchen grinder | 1 | 35,000 |
| 4 | Hydrolysis mixer | 1 | 18,000 |
| 5 | Screw press | 1 | 25,000 |
| 6 | Electrical Stove | 1 | 12,000 |
| **Subtotal ( ETB)** | | | **270,000** |
| **Total ( ETB)** | | | **674,415** |

### 3.3.1 Financial Analysis

Projects are assumed to be economically feasible if the Net Present Value (NPV) is positive, the internal rate of return (IRR) is≥ 20%. The major parameters that need to be considered for the financial feasibility, of biogas plants are:

**a) Project life**

A fixed dome type plant could last for more than 40 years depending on the quality of construction and the materials used. However, the economic life of a plant is taken as 20 years mainly because any cost or benefit accrued after 20 years will have insignificant value when discounted to the present worth.

**b) Benefits and Cost**

All benefits of a biogas plant cannot be readily priced or even compared with the price of similar products or services in the market. The biogas plants produce both biogas and organic fertilizer. The biogas could be used mainly instead of firewood, charcoal, kerosene and etc. while organic fertilizer used to improve crops yield, and so could be used instead of manufactured fertilizers. Therefore; the annual direct financial benefits for biogas plants could be estimated as follows:

$B_a = B_{ab} + B_{af} - C_a$ ……………………………………………………. (20)

Where,

$B_a$ Annual benefit $B_{ab}$ Annual benefit from biogas

$B_{af}$ Annual benefit from organic fertilizer $C_a$ Annual cost

#### 3.3.1.1 Organic Fertilizer

Amount of organic matter gets out from digester into compost tank is:

$O_m = L_a - C_b$ ……………………………………………………. (21)

Where, $O_m$ Organic matter gets out from digester

$L_a$ Loaded amount of substrate

$C_b$ Organic matter converted in to biogas

The daily food and kitchen waste input is 1130kg. Total solid content of night soil is, TS = 0.2 and Volatile solid content of night soil is, VS = 0.15. The underground temperature is assumed to be 33℃ for Jimma which is found in tropical zone [35].

$O_m = 0.2\,(1130 * 30*10) – 0.15\,(1130 * 30*10)$

= 67,800 – 50,850 (Kg per year)

= 16, 950 Kg per year.

Manufactured fertilizer of the lowest price available in the local markets is Urea fertilizer which sales to farmer by about 1300 Birr per 100kg. By selling the organic matter gets out of the digester by 30% Urea price, and then the price of 1130 kg gives us; $O_{mp}$ (Organic matter gets out from digester profit) [35].

$O_{mp}$ = 0.3 * 13* 16, 950 Birr per year

= 66,105 Birr per year

#### 3.3.1.2 Cash Flow Analysis

Basic procedure of a cash flow analysis is to enter all the year-by-year income to be received over the estimated life of the project as inflows. Similarly, yearly expenditures are entered in the analysis as outflow. Finally, for each year, expenditure is deducted from the income.

### Time Value of Money and Discount Ratio

Real value of money changes over time. The reasons for such changes are:

- Money of today can be invested to earn a return in the future; and
- People have time preference, i.e. they prefer now to the future.

#### 3.3.1.3 Net Present Value

As the costs and benefits of a project are spread over the useful years of project life, they need to be expressed in terms of one common denominator to make the comparison possible. Once the annual cash flow of a project is derived, it needs to be discounted so that all values could be compared to the value of a single year. This discounted net cash flow provides a widely used criterion for measuring the profitability of a project. For this purpose, all future values are discounted to make them equivalent to the present value and is expressed as Net Present Value (NPV). The NPV technique measures the worthiness of a project by converting the annual cash flow to a single present value. A positive NPV indicates that the benefits are higher than the costs that accrue over the project life.

The NPV is calculated as:

$$P = A\left[\frac{(1+r)^{n}-1}{r(r+1)n}\right] \quad \text{..............................................} \quad (22)$$

Where, P = present sum of money    A = Annual cost

F = Future sum of money

r = Rate of interest    n = Number of years

**Benefit Cost Ratio**

Benefit cost ratio (BCR) is another tool for assessing the profitability of a project. If the ratio is greater than unity (i.e. B/C > 1.0) the project is profitably.

### *3.3.1.4 Simple Payback Period*

Simple payback period is time period required to recover the original investigated for the construction of a plant. It represents the number of years in which the investment is expected to pay for itself. It is given by:

$$SPP = \frac{Ic}{As} \qquad \text{.........................................................} \quad (23)$$

Where, SPP Simple payback period

Ic Initial cost

As Annual saving (benefits)

The net present value, benefit cost ratio and simple payback period are given as follows. The present costs during the lifetime of the project are determined as [35].

**Table.3.14 Financial analyses of a 322 m³ biogas plant (in ETB)**

| **Year** | 1 | 2 | 3 | 4 | 5 to 15 |
|---|---|---|---|---|---|
| Saving Firewood | 154,245 | 154,245 | 154,245 | 154,245 | 154,245 |
| Selling organic fertilizer | 66,105 | 66,105 | 66,105 | 66,105 | 66,105 |
| Total | 220,350 | 220,350 | 220,350 | 220,350 | 220,350 |
| | | | | | |
| Investment | **674,415** | | | | |
| Maintenance cost | 35,000 | 35,000 | 35,000 | 35,000 | 35,000 |
| Operation cost | 55,000 | 55,000 | 55,000 | 55,000 | 55,000 |
| Total | 764,415 | 90,000 | 90,000 | 90,000 | 90,000 |
| Net Benefit in ***ETB*** | -544,065 | 130,350 | 130,350 | 130,350 | 130,350 |

$$P_c = I_c + A\left[\frac{(1+r)^n - 1}{r(r+1)n}\right] \qquad \text{...... ............................................} \quad (24)$$

Where, $I_c$ = Initial cost

A = Annual cost r = Discount rate

$P_c$ = 674,415+ 130,350$\left[\frac{(1+0.12)^{15}-1}{0.12(0.12+1)15}\right]$ r = 0.12 rates

$P_c$ = 1,500,773 ETB

The present value of benefits or saving during the life time of the project

$$P_b = A\left[\frac{(1+r)^n-1}{r(r+1)n}\right] \quad \text{.......................................................... (25)}$$

Where A = Annual benefits

$P_b$ = Total benefits during the lifetime of the project

$P_b$ = 220,350$\left[\frac{(1+0.12)^{15}-1}{0.12(0.12+1)15}\right.$

= 1,562,211 ETB

The Net Present Value is determined as

$NPV = P_b - P_c$

= 1,562,211 - 1,500,773 = 61,438 ETB

The annual saving is

$A_s = A_b - A_c$ = 220,350 – 90,000

= 130,350 ETB

The simple payback period is

$$SPP = \frac{Ic}{As} \quad \text{.......................................................... (26)}$$

$= \frac{674,415}{130,350}$

= 5.174 years. This means the project will get back the capital of constructing biogas plant with in about five years.

The benefit cost ratio (BCR) = $\frac{Pb}{Pc}$ ................................................... (27)

$= \frac{1,562,211}{1,500,773}$ = 1.041 >1 Hence, project is profitably.

# 4. Result and Discussion

We can compare all of three experiments; Experiment one, Experiment Two and Experiment Three easily as the following s table below.

**Table: 4.1 Comparison of Experiment one, Experiment Two and Experiment Three**

| S.N | Description | Experiment one | Experiment Two | Experiment Three |
|---|---|---|---|---|
| 1 | Type wastes | Enjera with 'atar kik' and bread and Potatoes peel and also it is mixed with oily fluid. | Fresh cow dung, Bread and enjera | Combination of food waste and cow dung, only food waste and only cow dung. |
| 2 | Digestor | It's freely stand without any insulator. | It's covered with 'combust' insulator for conserving temperature. | Two 2L containers with Plastic and 4L container with aluminium cylinder put into drying oven settled at 40$^{o}$C. |
| 3 | Generation of biogas | It does not generate biogas, even upto 66 days. | It does not generate biogas; but there is simply a bad odor, starting from two weeks. | It generates biogas starting from three days. |
| 4 | Odor of wastes in the digestor | There is no odor change | There is a bad odor; even if you touch its smell stays on your hand for a day. | There is a bad odor, but we did not open digestor cover since it generates biogas. |
| 5 | Addition of a bacteria from other generating biogas (for accelerating the reaction) | We did not use it. | We did not use it | We have used it. |
| 6 | Duration of experiment | 66 days | 103 days | 60 days |

From those experiments we conclude that;

- When we generate the biogas from food and kitchen wastes, we have to use like fresh cow dung and addition of a bacteria from other generating biogas which can quickly give up bacteria that start up the process of acidogenesis.
- Using insulators for conserving temperatures of digestor is very crucial.
- Cleaning unusable and dirty oil is speeding up our work progress easily.
- Adjusting a temperature of surrounding digester is a key for generating a biogas.

From Experiment one, we have done inside digester temperature affects the values of pH values; as inside digester temperature increases pH values of almost decreases. Graph 4.1 below describes the relationship between inside digester temperature and pH values.

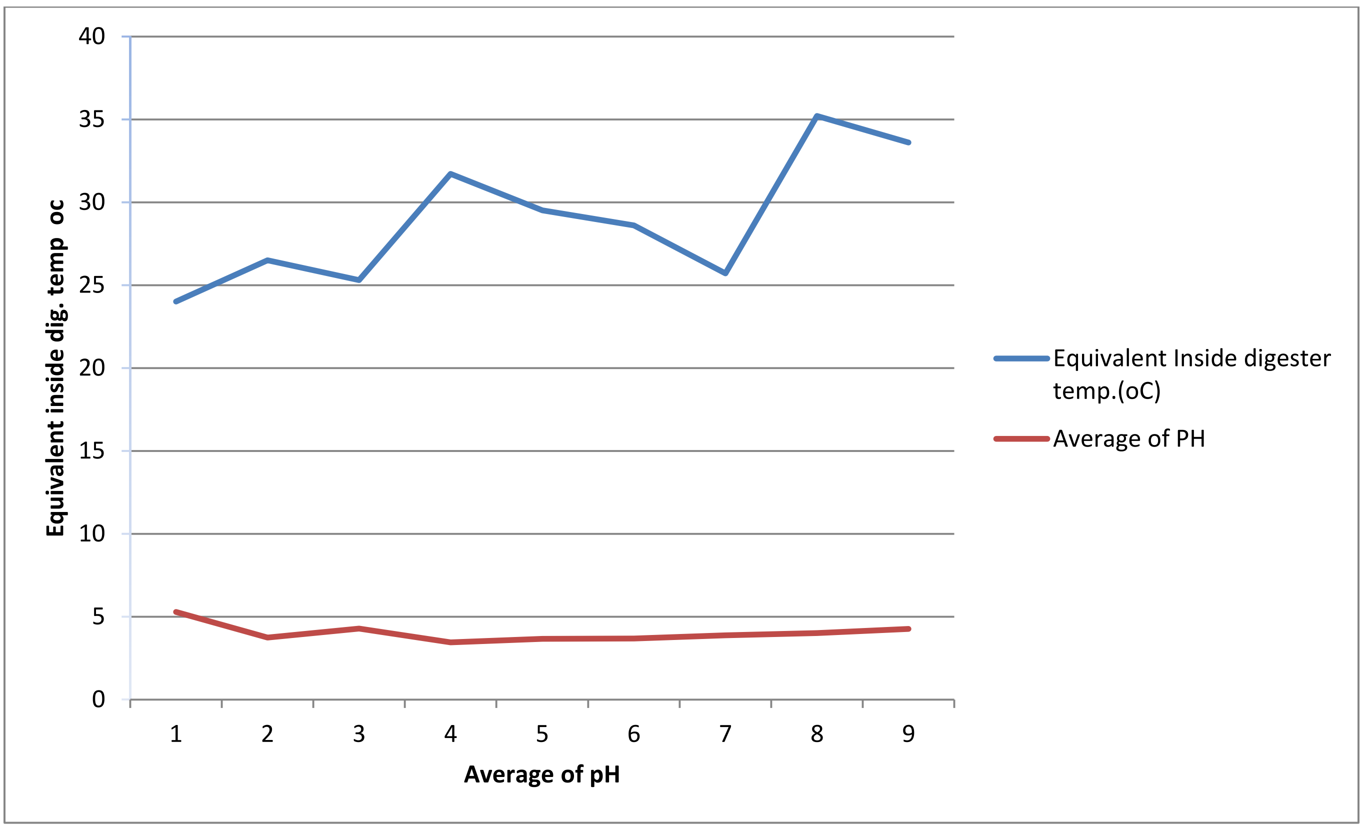


**Fig 4.1 Graph of measurements of inside digester temperature and Average at different days (at Experiment one)**

- Likewise as ambient temperature increases, pH values of almost decreases. Graph 4.2 below describes the relationship between ambient temperature and pH values.

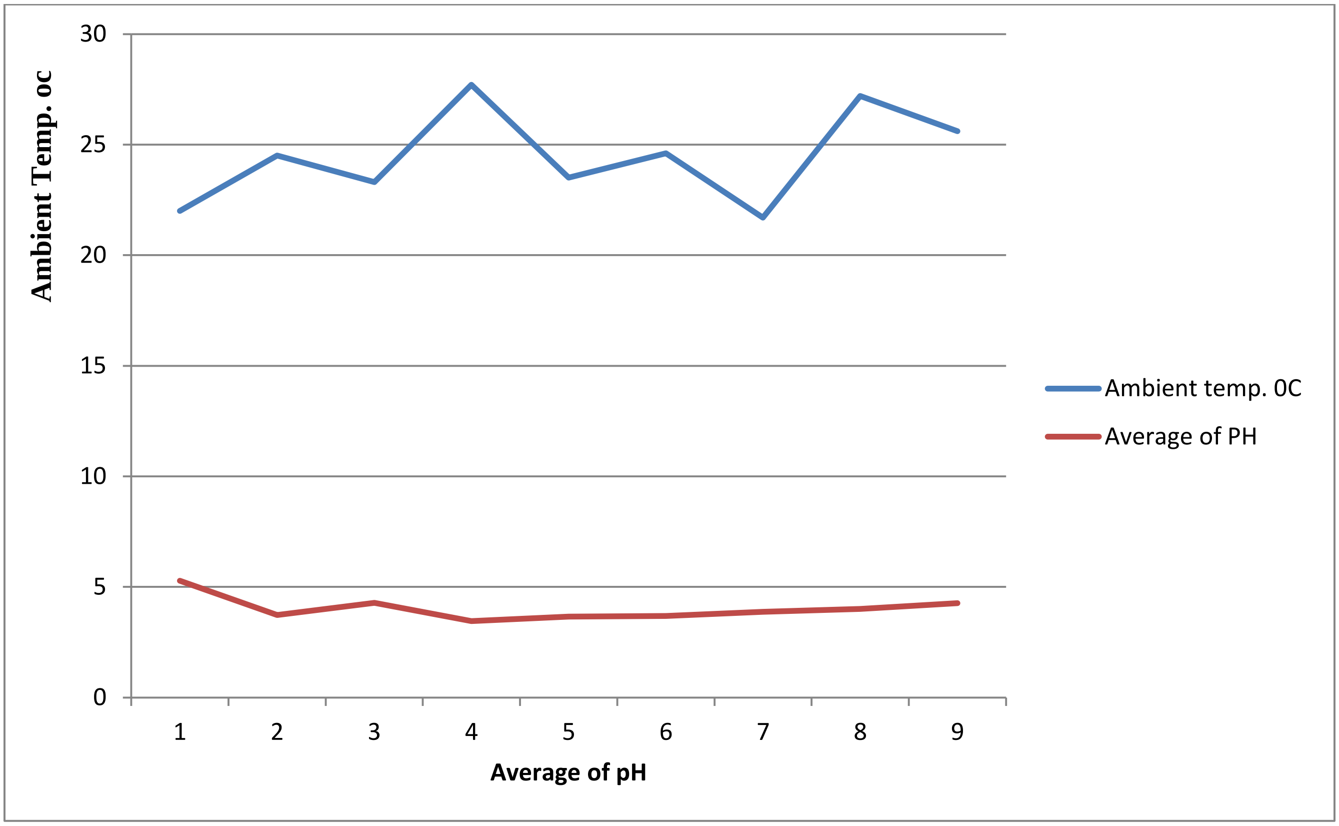


**Fig 4.2 Graph of measurements of ambient temperature and Average of PH at different days (at Experiment one)**

- Inside digester temperature and ambient temperature are directly proportional; as ambient temperature increases inside digester temperature is also increases. Graph 4.3 below describes the relationship between ambient temperature and inside digester temperature.

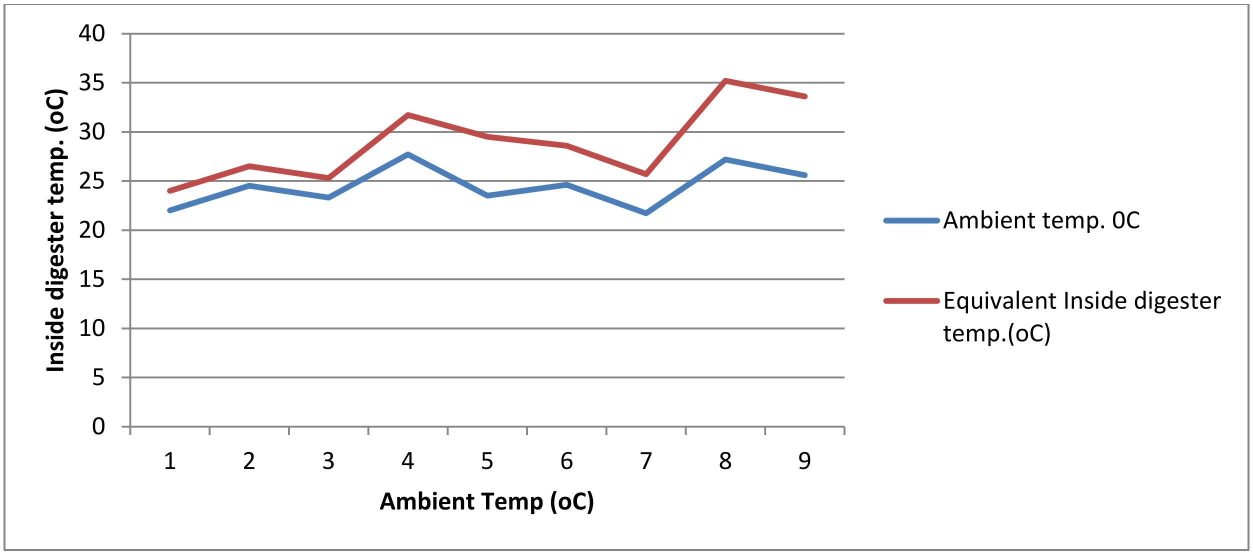


**Fig 4.3 Graph of measurements of inside digester temperature and ambient temperature at different days (at Experiment one)**

- From our Experiment one also, at the beginning the values less acidic, but when time goes longer it become some extent goes more acidic. Graph 4.4 below describes the relationship between PH values and Days.

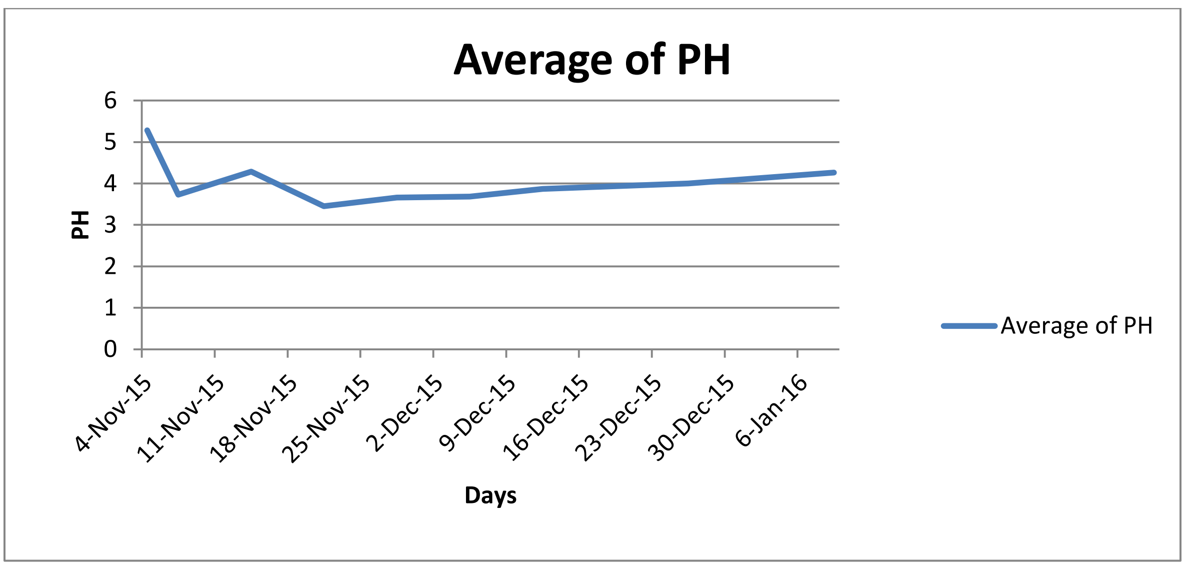


**Fig 4.4 Graph of measurements of pH values against duration of time (at Experiment one)**

- From Experiment-Two also we have done measurements of inside digester temperature at different days; at the beginning the temperature values some extent high, but when time goes longer it become less and lastly it goes to rise. It depends on ambient temperature.

Graph 4.5 below describes the relationship between inside digester temperature values and Days.

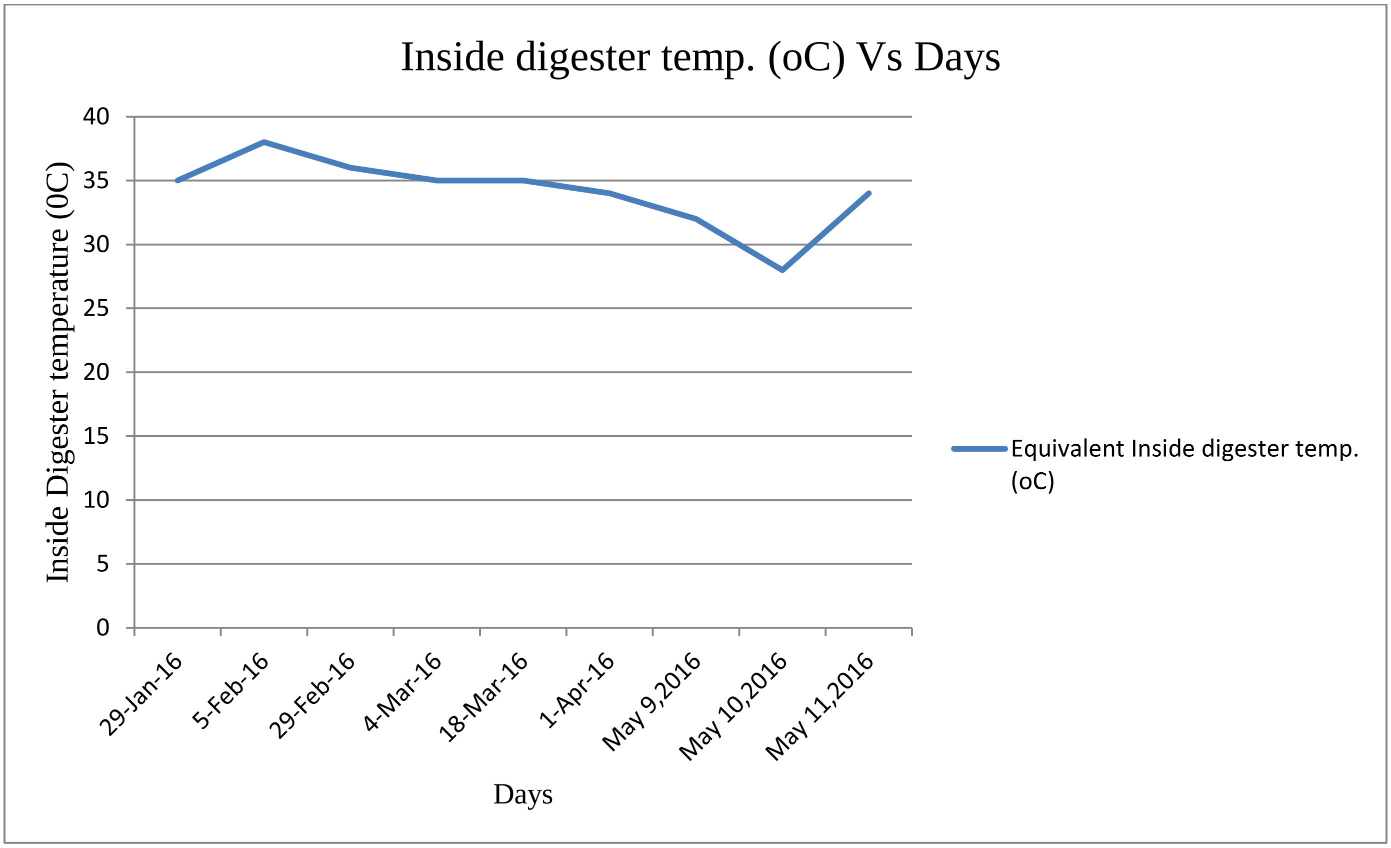


**Fig 4.5 Graph of measurements of pH values against duration of time (at Experiment Two)**

From Experiment-Three also we have done measurements of biogas produced at different days; at the beginning produced biogas values some extent high, but when time goes longer it becomes less and less. Generally, from combination of food waste and cow dung we get 7.2ml volume of biogas, from only food waste we get 6ml volume of biogas and from only cow dung we get 5ml volume of biogas within 60 days. From this we conclude that addition of bacteria from other generating biogas and putting our wastes into drying oven settled at 40$^{o}$C is one of the best method how to generating biogas than Experiment-Two and Experiment-one.

Graph 4.6 below describes the graph of biogas produced from experiment- three at different Days.

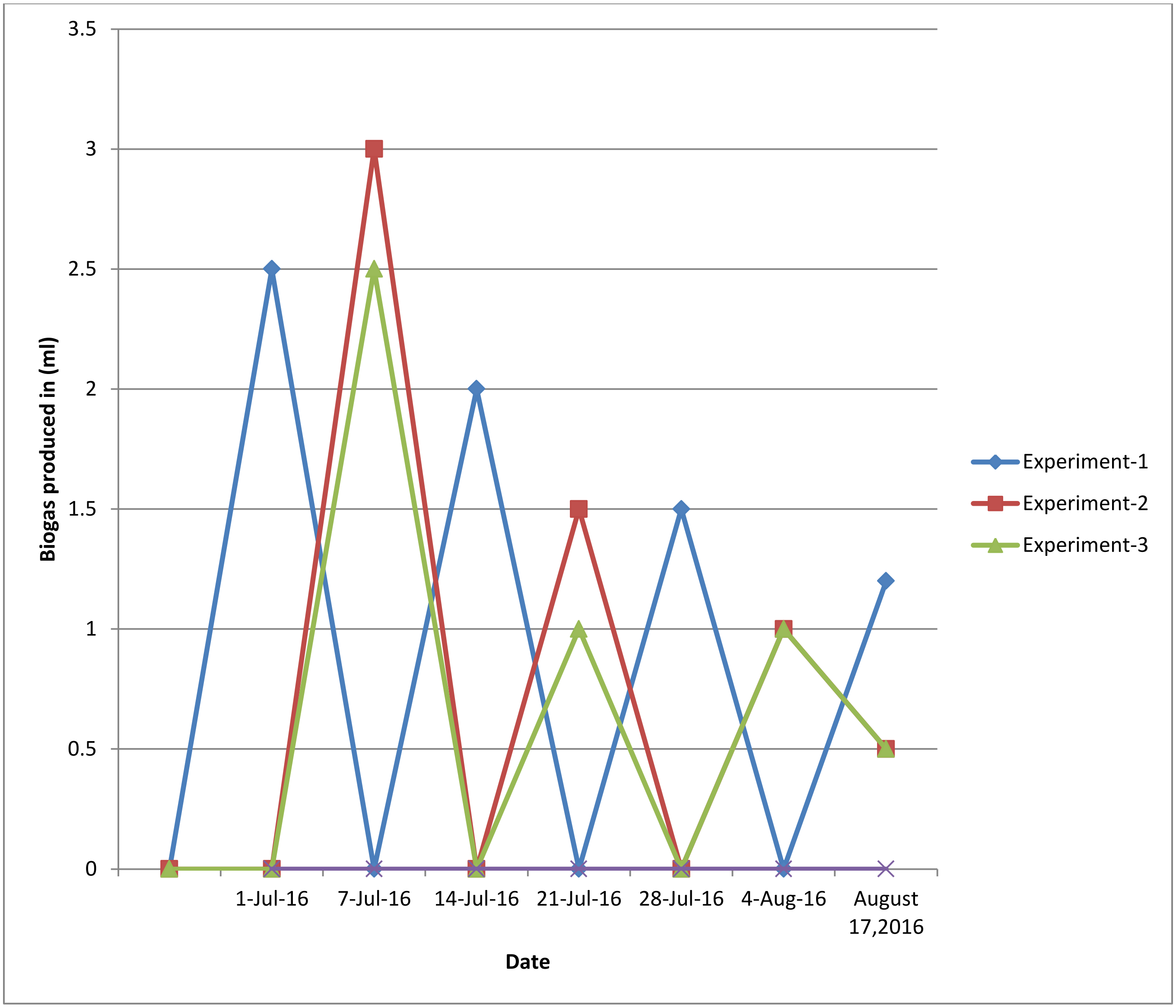


**Fig.4.6 Graph of biogas produced at different Days from experiment-III**

# Conclusion

In Jimma Institute of Technology (JiT), Kito Furdisa campus student's cafeteria and kitchen wastes potential have been assessed for one month (from April 27, 2015 to May 26, 2015). According to data collected for 30 days; 28,574 kg of dining hall wastes (food wastes) measured and 5,328 kg of kitchen wastes measured. Totally 33,902 kg of wastes from both dining hall & kitchen wastes measured. From both food and kitchen wastes collected data in the afternoon (lunch), in the evening (dinner) and in the morning (breakfast) wastes were collected in amount from largest to smallest respectively.

Calculated volume of daily charge is 4.38 $m^3$/day and volume digester we have designed is 322$m^3$. Hydraulic tank is designed which contain 3 days of food waste for bacteria to do or work place and its volume gives us 13.14$m^3$. We select a type of digester Fixed dome digester or Chinese model digester type. This type of digester is installed under the ground where the gas and the slurry are in the same storage tank. In this design, the fermentation chamber and gas holder are combined as one unit. This design eliminates the use of costlier mild steel gas holder which is susceptible to corrosion. Both the pit and dome are constructed by bricks and cement. As the gas is collected above the decomposing feedstock it displaces the sludge towards the displacement tank where it is collected as the fertiliser. Biogas is collected through the gas pipe and transferred to the point of use where it is used as an energy source for heat and electricity generation.

Total gas produced from food and kitchen wastes calculated, from amount of food and kitchen wastes per day. Total gas produced is 113$m^3$ / day. This gas produced using energy conversion gives us 722kwh of power per day. Based on biogas produced it diverted to combined heat and power (CHP) system to generate electricity and heat that recovered to produce hot water using stove for cafeteria of Kito Furdisa and its kitchen itself. Energy consumption of this anaerobic digestion of system in dining hall & kitchen wastes give us 41.03 kwhr and the net energy used is 681 kWh which used for CHP. This means the production of electricity will be 75.42MWh/y and the production of heat will be 138.27MWh/y. The pay back of this project takes about 5 years to replace its overall cost work.

We have done Experiment one, Experiment Two and Experiment Three using small scale up digester in the laboratory. Experiment one includes Enjera with 'atar kik' and bread and Potatoes peel and also it is mixed with vegetable oil and its digester is freely stand without any insulator. Experiment Two contains fresh cow dung, bread and enjera and its digester is covered with 'combust' insulator for conserving temperature. Experiment one can't generate biogas even upto 66 days and Experiment Two gives very a bad odor within two weeks. Experiment Three contains Combination of food waste and cow dung, only food waste and only cow dung. From Experiment-Three also we have done measurements of biogas produced at different days; at the beginning produced biogas values some extent high, but when time goes longer it becomes less and less. Generally, from combination of food waste and cow dung we get 7.2ml volume of biogas, from only food waste we get 6ml volume of biogas and from only cow dung we get 5ml volume of biogas within 60 days. From this we conclude that addition of bacteria from other generating biogas and putting our wastes into drying oven settled at $40^{o}C$ is one of the best method how to generating biogas than Experiment-Two and Experiment-one.

When we generate the biogas from food and kitchen wastes, we have to use like fresh cow dung, addition of a bacteria from other generating biogas which can quickly give up bacteria that start up the process of acidogenesis and using insulators for conserving temperatures of digestor is also very crucial. Cleaning unusable and dirty oil is speeding up our work progress easily. From our experiments we have done, what we analyze is that increasing inside temperature of the digester, addition of bacteria from other generating biogas and controlling the pH values are very important for overall progress.

## Recommendation and Future Work

Technical problems during implementing small scale up digester include a lack of materials, trained man power, poor equipment design, lack of good insulator materials, lack of different chemicals and failure to maintain the digester properly. The pH changes in the digester would affect methane formation process and therefore, pH fluctuation would be controlled by the addition of different chemicals. Hence, absence controlling this pH also one of the problem faced us. Temperature difference in the digester is minimum and most of the time in this experiment work Jimma covered with cloudy and rainy.

Food and Kitchen wastes will be the best alternative bioenergy under Universities, Hotels, Prisons and a community level biogas production. Here our research was just under a small experiment and designed biogas plant but if we will make this at a big level and availing necessary materials, it will generate more biogas production and increase their utilization under multiple roles. In this thesis we have used amount of wastes by only considering for 10 months of a year; since digestor can't be stopped other researcher who want to implement this project have to add another wastes from Jimma University campuses those teach during summer programme.

In the future further researcher can collect necessary additional data on the use of the Anaerobic Digester using food and kitchen wastes and also, further experiments should be performed for identifying the optimum operating parameters for producing higher concentrations of VFAs in the liquid product of an acetogenesis reactor. From our experiments we have done, what we analyze is that increasing inside temperature of the digester, adding of bacteria from other generating biogas and controlling the pH values is very critical. Hence, in the future further researcher can effectively increase the efficiency of generating biogas production by using increasing inside digester temperature, addition of bacteria from other generating biogas and controlling the pH values.

## Reference

1) Ruihong Z., Hamed M., El-M., Karl H., 2007. Characterization of food waste as feedstock for anaerobic digestion. Bioresource Technology;1:( 929-936).
2) Gijzen H. J., 2002. Anaerobic Digestion for sustainable development: a natural approach. Water research and technology. 45(10): 321-328.
3) Charles W., Walker L., Ruwisch Cord R., 2009. Effect of pre-aeration and inoculum on the startup of batch thermophillic anaerobic digestion of municipal solid waste. Bioresource technology. 100: 2329-2335.
4) EPA, 2009. United States Environmental Protection Agency. Municipal solid waste generation, recycling and disposal in the United States.
5) Troschinetz A. M., and Mihelcic J. R., 2009. Sustainable recycling of municipal solid waste in developing countries. Waste management. 29:915-923.
6) Chandrappa R., and Das D. B., 2012. Solid waste management. Environmental science and Engineering. Springer Verlag Berlin Heidelberg.
7) Khalid A., Arshad M., Anjum M., Mahmood T., Dawson L., 2011.The anaerobic digestion of Solid organic waste. Waste management. 31:1737-1744.
8) Curry N., Pillay P., 2012. Biogas prediction and design of a food waste to energy system for the urban environment. Renewable energy 41:200-209.
9) Zupancic G. D., and Jemea A., 2010. Anaerobic digestion of tannery waste: semi continuous and anaerobic sequencing batch reactor process. Bioresource technology. 101: 26-33.
10) Schober G., Schäfer J., Schmid Staiger U., and Trösch W., 1999. One and two stage digestion of solid organic waste. Water research. 33(3):854-860.
11) Cho J. K., Park S. C., Chang H. N., 1995 Biochemical methane potential and solid state anaerobic digestion of Korean food wastes. Bioresource Technology 52:245-253.
12) Zhang R., El-Mashad H. M., Hartman K., Wang F., Liu G., Choate C., Gamble P., 2007. Characterization of food waste as feedstock for anaerobic digestion. Bioresource technol. 98:929–935.
13) Neves L., Gonçalo E., Oliveira R., and Alves M. M., 2008. Influence of composition on the biomethanation potential of restaurant waste at mesophilic temperatures. Waste management 28: 965-972.

14) Kumar S., 2010. Effective municipal solid waste management in India (In waste management). 232.

15) Khoiyangbam R.S., Kumar S., Jain M.C., Gupta N., Kumar A., Kumar V., 2004. Methane emission from fixed dome biogas plants in hilly and plain regions of northern India. Bioresource Technology. 95:35–39.

16) Kumar S., Gaikwad S. A., Shekdar A.V., Kshirsagar P. S., Singh R. N., 2004. Estimation method for national methane emission from solid waste landfills. *Atmospheric* Environment 38: 3481–3487.

17) Kashyap D. R., Dadhich K.S., and Sharma S. K., 2003. Biomethanation under psychrophilic conditions: a review. Bioresource Technol 87:147-153.

18) Alemayehu G., Abile T., 2014. Co-Digestion of Ethiopian Food Waste with Cow Dung for Biogas Production: International Journal of Research (IJR), 1:7475-500.

19) Molla A., 2014. Design of cylindrical fixed dome bio digester in the condominium houses for cooking purpose at Dibiza Site,East Gojjam, Ethiopia: American Journal of Energy Engineering 2(1): 16-22

20) Yang S. J., Hamilton S. D. B., Engle N. L., Tschaplinski T. J., Doeppke C., Davis M., Westpheling J., and Adams M. W. W., 2009. Efficient Degradation of Lignocellulosic Plant Biomass, without Pretreatment, by the Thermophilic Anaerobe "Anaerocellum thermophilum" DSM 6725. Applied And Environmental microbiology 75(14): 4762-4769.

21) Cho J. K., Park S. C., Chang H. N., 1995 Biochemical methane potential and solid state anaerobic digestion of Korean food wastes. Bioresource Technology 52:245-253.

22) Angelidaki I, Sanders W., 2004. Assessment of the anaerobic biodegradability of Macro pollutants. *Rev. Environ. Science and Biotechnol.* 3:117-129.

23) Honorato T. L., Rabelo M. C., Gonçalves L. R. B., Pinto G. A. S., and Rodrigues S., 2007.Fermentation of cashew apple juice to produce high added value products. World Journal of Microbiology and Biotechnology. 23:1409–1415.

24) Rodrigues T. H. S., Dantas M. A. A., Pinto G. A. S., and Gonçalves L. R. B., 2007. Tannase production by solid state fermentation of cashew apple bagasse. Applied Biochemistry and Biotechnology 136: 675–688.

25) Wu J.H., Liu W. I., Tseng I. C., and Cheng S. S., 2001. "Characterization of microbial consortia in a terephthalate degrading anaerobic granular sludge system". Microbiology. 147: 373-382.

26) Ojikutu A., Osokoya O., 2014. Evaluation of Biogas Production from Food Waste. The International Journal of Engineering and Science (IJES). 3(01): 01-07.

27) Jenny Aragundy, Michael Kottner, IBBK, Fachgruppe Biogas Weckelweiler, "Biogas Reference Manual," Weckelweird, Germany, Prepared for Ontario Biogas Systems Operators Course, 2008.

28) J. Mata-Alvarez, "Biomethanization of the Organic Fraction of Municipal Solid Wastes," IWA Publishing, 2003, ISBN 1900222140.

29) Information and advisory service on appropriate technology (ISAT) and GTZ biogas application and product development, Biogas digest Vol. II

30) Gallert, C., Henning, A., winter, J. 2003. Scale-up of anaerobic digestion of the biowaste fraction from domestic wastes. Water Res., 37: 1433–1441.

31) Patrick M., Golden M., Sampson M., Sherpherd M. 2013. A possible design and justification for a biogas plant at Nyazura Adventist High School, Rusape, Zimbabwe, Journal of Energy in Southern Africa; 24 :4

32) Ravi P. A., G. N. Tiwari. 2014. Comparative Study of Biogas Production: Utilization of Organic Waste; International Journal of Environment and Resource (IJER)., (3) ; 1

33) N.H.S. Ray, M.K.Mohanty, R.C.Mohanty. 2013. Anaerobic digestion of kitchen wastes: "Biogas production and treatment of wastes, a review"; International Journal of Scientific and Research Publications; 3:11

34) Bekele G. (2011). Biogas production system designs for condominium and its feasibility. Msc. Thesis, Addis Ababa Institute of Technology, Addis Ababa UNIVERSITY.

35) Nathan C. (2010).Modeling and Design of a Food Waste to Energy System for an Urban Building. Msc. Thesis, Concordia University, Canada.

# Appendix

### Table .1 Forms of collecting datum of Food Wastes from Dining hall, at Jimma Institute Technology (JiT), Kito Furdisa Campus

| Date | Morning (Breakfast) | | Afternoon (Lunch) | | Evening (Dinner) | |
|---|---|---|---|---|---|---|
| | Type of food wasted | Mass of food wasted (Kg) | Type of food wasted | Mass of food wasted (Kg) | Type of food wasted | Mass of food wasted (Kg) |
| April 27,2015 | Rice | 113 | Shiro be-atikilt | 514 | Misir-Kik | 381 |
| April 28,2015 | Firfir | 115 | Rice with-atikilt | 510 | Potatoes | 335 |
| April 29,2015 | Kinche | 175 | Misir-Kik | 410 | Ater-kiki | 396 |
| April 30,2015 | Rice | 177 | Ater-kiki | 376 | Misir-Kik | 644 |
| May 1,2015 | Kinche | 140 | Ater-kiki | 400 | Misir-Kik | 531 |
| May 2,2015 | Firfir | 136 | Potatoes | 331 | Ater-kiki | 459 |
| May 3,2015 | Rice | 138 | Ater-kiki | 314 | Misir-Kik | 492 |
| May 4,2015 | Rice | 127 | Shiro be-atikilt | 404 | meat | 384 |
| May 5,2015 | Firfir | 120 | Rice with-atikilt | 563 | Potatoes with meat | 304 |
| May 6,2015 | Kinche | 126 | Misir-Kik | 385 | Ater-kiki | 293 |
| May 7,2015 | Rice | 137 | Ater-kiki | 336 | meat | 364 |
| May 8,2015 | Kinche | 128 | Ater-kiki | 271 | Misir-Kik | 294 |
| May 9,2015 | Firfir | 88 | Potatoes with meat | 331 | Ater-kiki | 378 |
| May 10,2015 | Rice | 143 | Ater-kiki | 387 | Misir-Kik | 400 |
| May 11,2015 | Rice | 149 | Shiro be-atikilt | 459 | meat | 318 |

| | | | | | | |
|---|---|---|---|---|---|---|
| May 12,2015 | Firfir | 107 | Rice with-atikilt | 902 | Potatoes with meat | 315 |
| May 13,2015 | Kinche | 168 | Misir-Kik | 481 | Ater-kiki | 406 |
| May 14,2015 | Rice | 158 | Ater-kiki | 491 | Misir-Kik | 509 |
| May 15,2015 | Kinche | 139 | Ater-kiki | 412 | Misir-Kik | 481 |
| May 16,2015 | Firfir | 135 | Potatoes with meat | 373 | Ater-kiki | 394 |
| May 17,2015 | Rice | 126 | Ater-kiki | 464 | Misir-Kik | 459 |
| May 18,2015 | Rice | 121 | Shiro be-atikilt | 413 | meat | 302 |
| May 19,2015 | Firfir | 119 | Rice with-atikilt | 532 | Potatoes with meat | 373 |
| May 20,2015 | Kinche | 131 | Misir-Kik | 396 | Ater-kiki | 313 |
| May 21,2015 | Rice | 127 | Ater-kiki | 347 | Meat | 324 |
| May 22,2015 | Kinche | 141 | Ater-kiki | 342 | Misir-Kik | 303 |
| May 23,2015 | Firfir | 91 | Potatoes with meat | 387 | Ater-kiki | 412 |
| May 24,2015 | Rice | 133 | Ater-kiki | 403 | Misir-Kik | 418 |
| May 25,2015 | Rice | 129 | Shiro be-atikilt | 498 | Meat | 392 |
| May 26,2015 | Firfir | 102 | Rice with-atikilt | 512 | Potatoes with meat | 317 |
| Total (Kg) | 3,939 | | 12,944 | | 11,691 | |

**Table. 2 Forms of collecting datum, from kitchen Wastes at Jimma Institute Technology (JiT), Kito Furdisa campus**

| Date | Morning (Breakfast) | | Afternoon (Lunch) | | Evening (Dinner) | |
|---|---|---|---|---|---|---|
| | Type of waste from kitchen | Mass of waste from kitchen (Kg) | Type of waste from kitchen | Mass of waste from kitchen (Kg) | Type of waste from kitchen | Mass of waste from kitchen (Kg) |
| April 27,2015 | Onion peels | 7 | Cabbage peels<br>Potatoes peels<br>Onion peels | 234<br>67<br>17 | Onion peels | 15 |
| April 28,2015 | Onion peels | 10 | Potatoes peels<br>Onion peels | 269<br>22 | Potatoes peels<br>Onion peels | 260<br>26 |
| April 29,2015 | - | - | Onion peels | 13 | Onion peels | 19 |
| April 30,2015 | Onion peels | 12 | Onion peels | 12 | Onion peels | 12 |
| May 1,2015 | - | - | Onion peels | 13 | Onion peels | 13 |
| May 2,2015 | Onion peels | 18 | Onion peels<br>Potatoes peels | 17<br>274 | Onion peels | 15 |
| May 3,2015 | Onion peels | 19 | Onion peels | 28 | Onion peels | 20 |
| May 4,2015 | Onion peels | 17 | Onion peels<br>Potatoes peels<br>Cabbage peels | 15<br>80<br>275 | Onion peels | 18 |
| May 5,2015 | Onion peels | 18 | Potatoes peels | 233 | Onion peels<br>Potatoes peels | 27<br>207 |
| May 6,2015 | - | - | Onion peels | 11 | Onion peels | 12 |
| May 7,2015 | Onion peels | 10 | Onion peels | 12 | Onion peels | 13 |
| May 8,2015 | - | - | Onion peels | 15 | Onion peels | 17 |
| May 9,2015 | Onion peels | 21 | Potatoes peels<br>Onion peels | 234<br>26 | Onion peels | 22 |
| May 10,2015 | Onion peels | 12 | Onion peels | 15 | Onion peels | 13 |

| | | | | | | |
|---|---|---|---|---|---|---|
| May 11,2015 | - | - | Cabbage peels<br>Potatoes peels<br>Onion peels | 268<br>161<br>24 | Onion peels | 27 |
| May 12,2015 | Onion peels | 19 | Onion peels<br>Potatoes peels | 20<br>271 | Potatoes peels<br>Onion peels | 297<br>26 |
| May 13,2015 | Onion peels | 8 | Onion peels | 11 | Onion peels | 17 |
| May 14,2015 | Onion peels | 12 | Onion peels | 14 | Onion peels | 15 |
| May 15,2015 | Onion peels | 10 | Onion peels | 17 | Onion peels | 9 |
| May 16,2015 | Onion peels | 12 | Onion peels | 16 | Onion peels | 13 |
| May 17,2015 | Onion peels | 9 | Onion peels<br>Potatoes peels | 18<br>259 | Onion peels | 19 |
| May 18,2015 | Onion peels | 14 | Onion peels<br>Potatoes peels | 14<br>99 | Onion peels<br>Cabbage peels | 18<br>283 |
| May 19,2015 | Onion peels | 15 | Onion peels<br>Potatoes peels | 12<br>263 | Potatoes peels<br>Onion peels | 214<br>23 |
| May 20,2015 | Onion peels | 6 | Onion peels | 13 | Onion peels | 13 |
| May 21,2015 | Onion peels | 9 | Onion peels | 11 | Onion peels | 21 |
| May 22,2015 | Onion peels | 19 | Onion peels<br>Potatoes peels | 24<br>218 | Onion peels | 19 |
| May 23,2015 | Onion peels | 11 | Onion peels<br>Potatoes peels | 22<br>219 | Onion peels | 26 |
| May 24,2015 | Onion peels | 8 | Onion peels<br>Cabbage peels | 21<br>284 | Onion peels | 17 |
| May 25,2015 | Onion peels | 14 | Onion peels<br>Potatoes peels | 13<br>194 | Onion peels<br>Potatoes peels | 13<br>204 |
| May 26,2015 | Onion peels | 12 | Onion peels<br>Potatoes peels | 26<br>229 | Onion peels<br>Potatoes peels | 29<br>264 |
| Total (Kg) | 178 | | 4,623 | | 527 | |

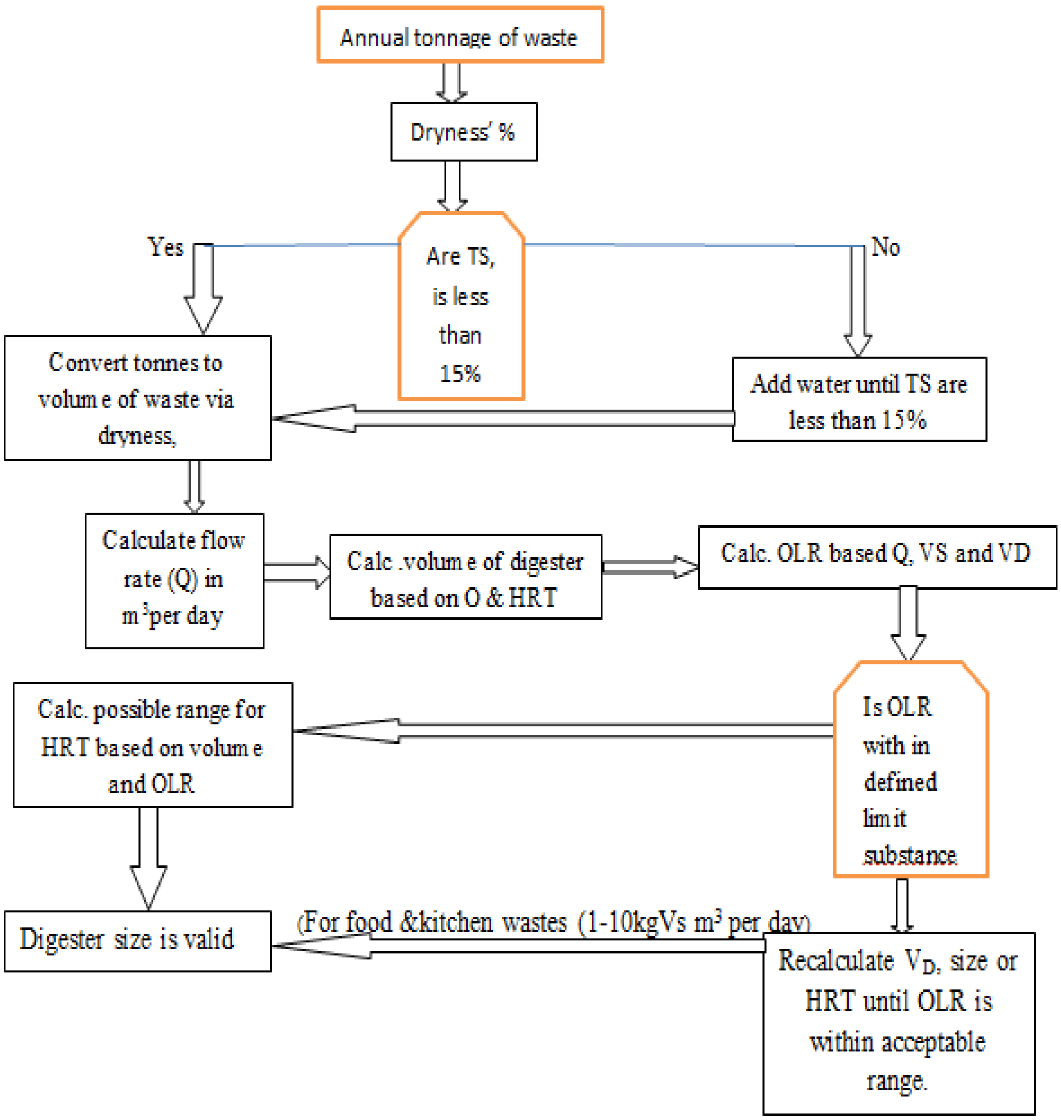


**Fig.1 Process flow chart used to determine the required digester size [35].**

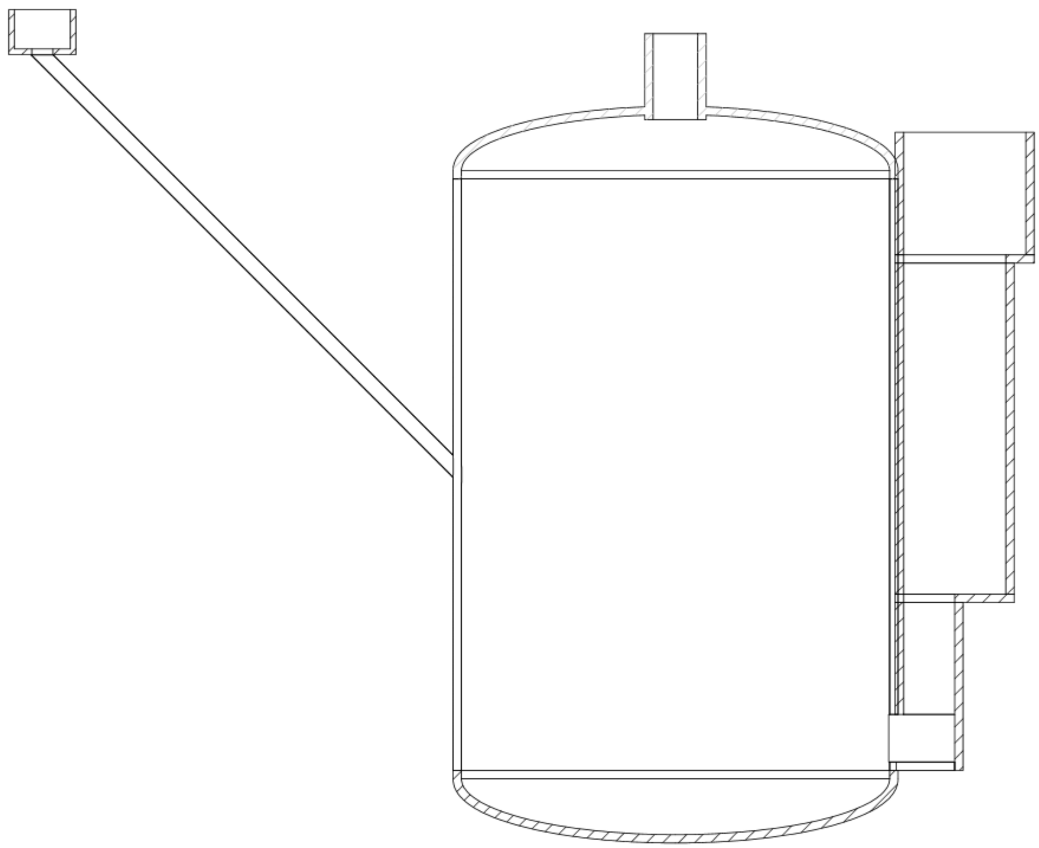

**Fig.2 Cross section of Digester**

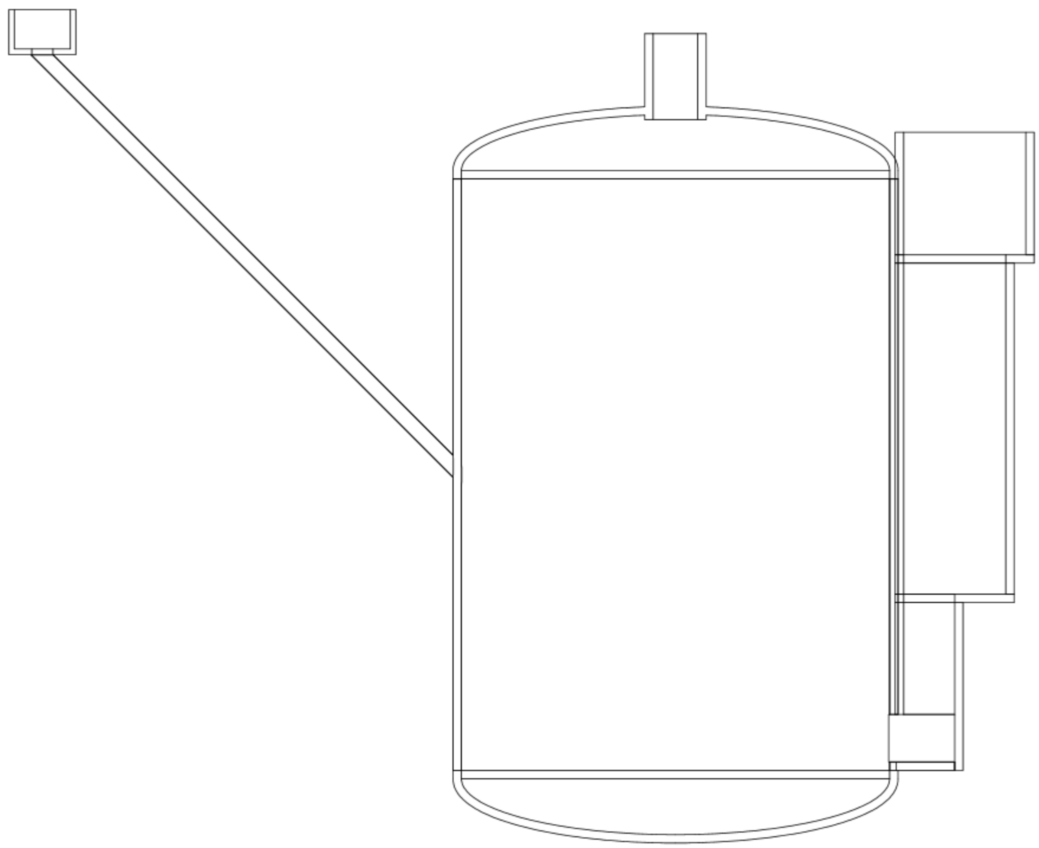

Fig.3 Side View of Digester

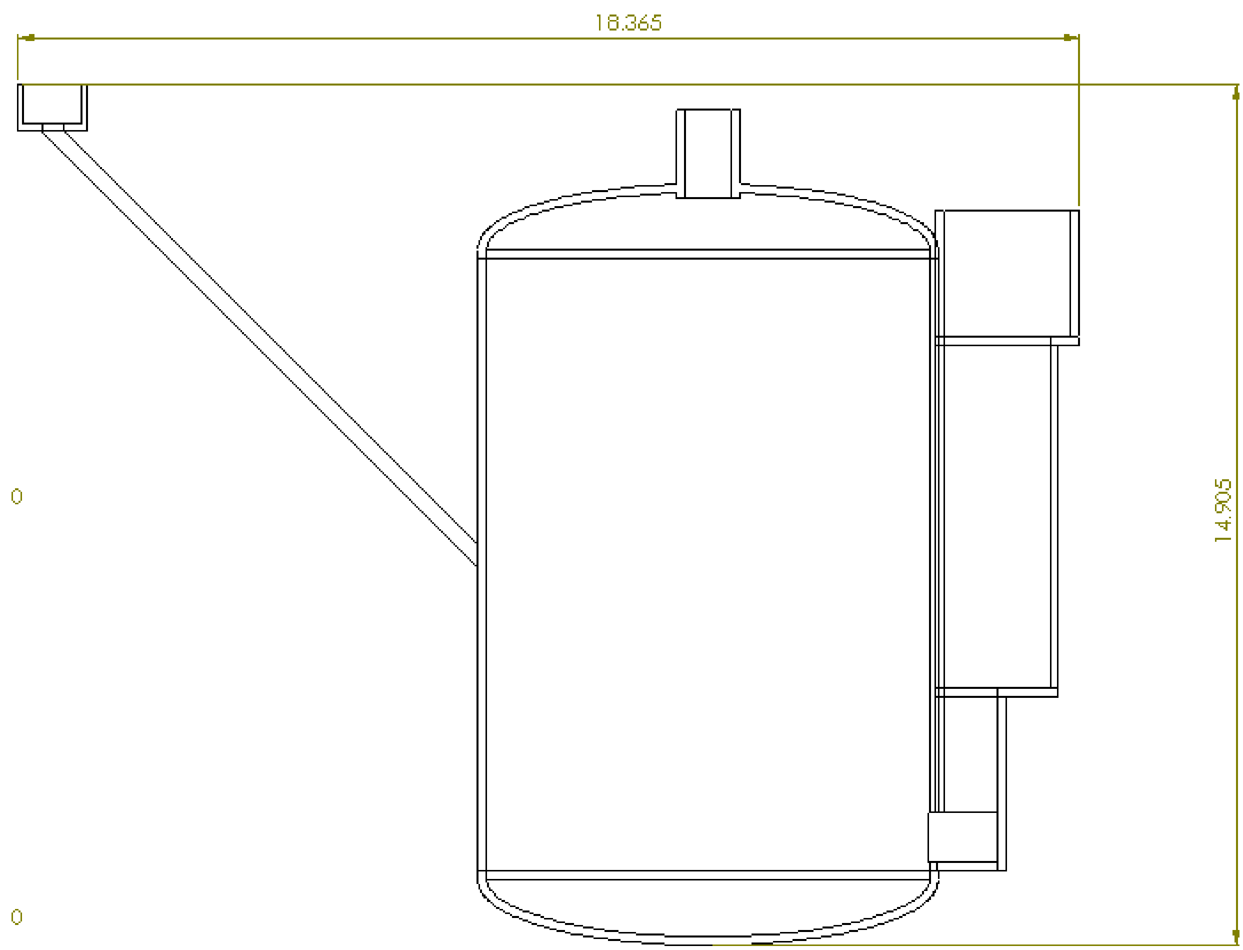


**Fig.4 Dimension of Digester (L X W)**

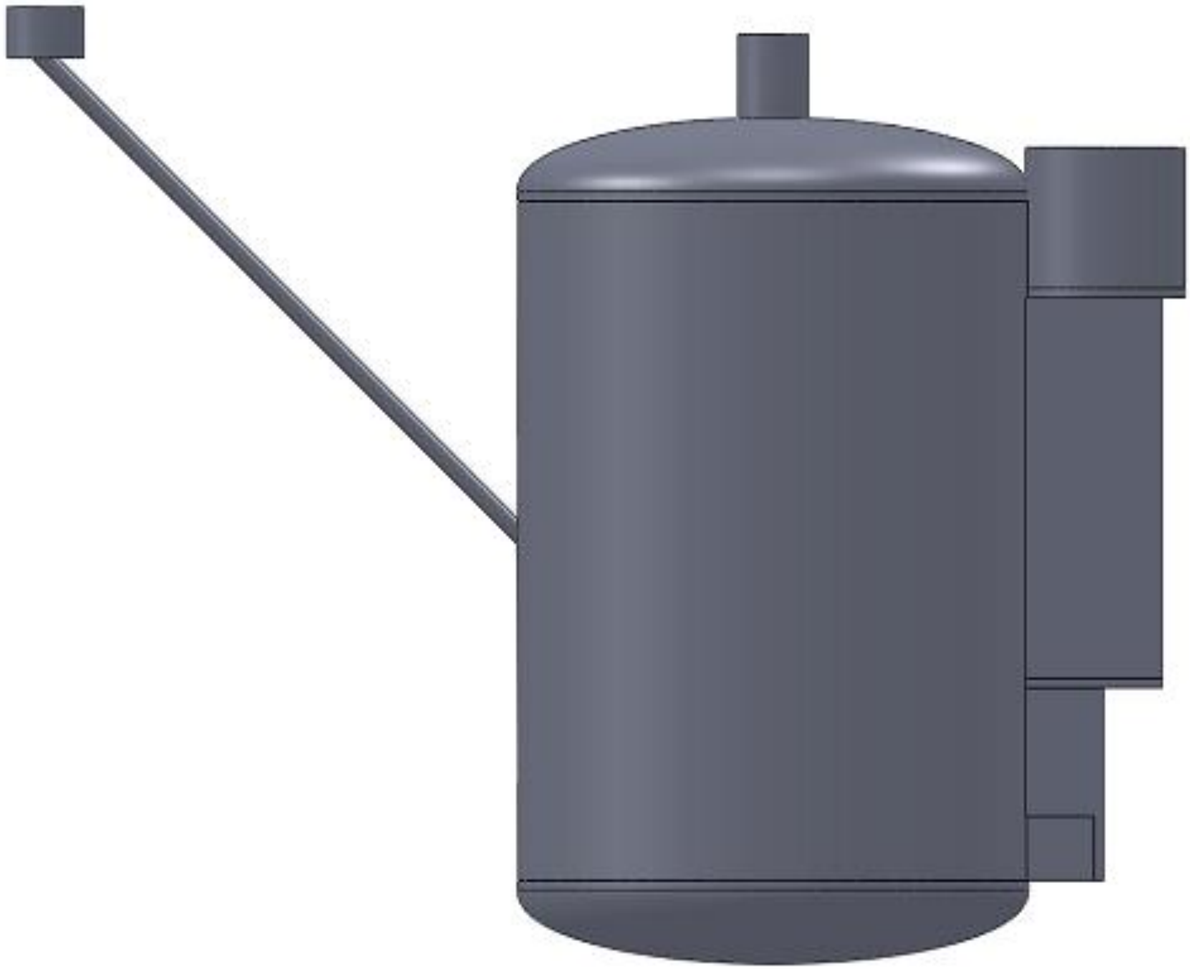

**Fig.5 Digester**

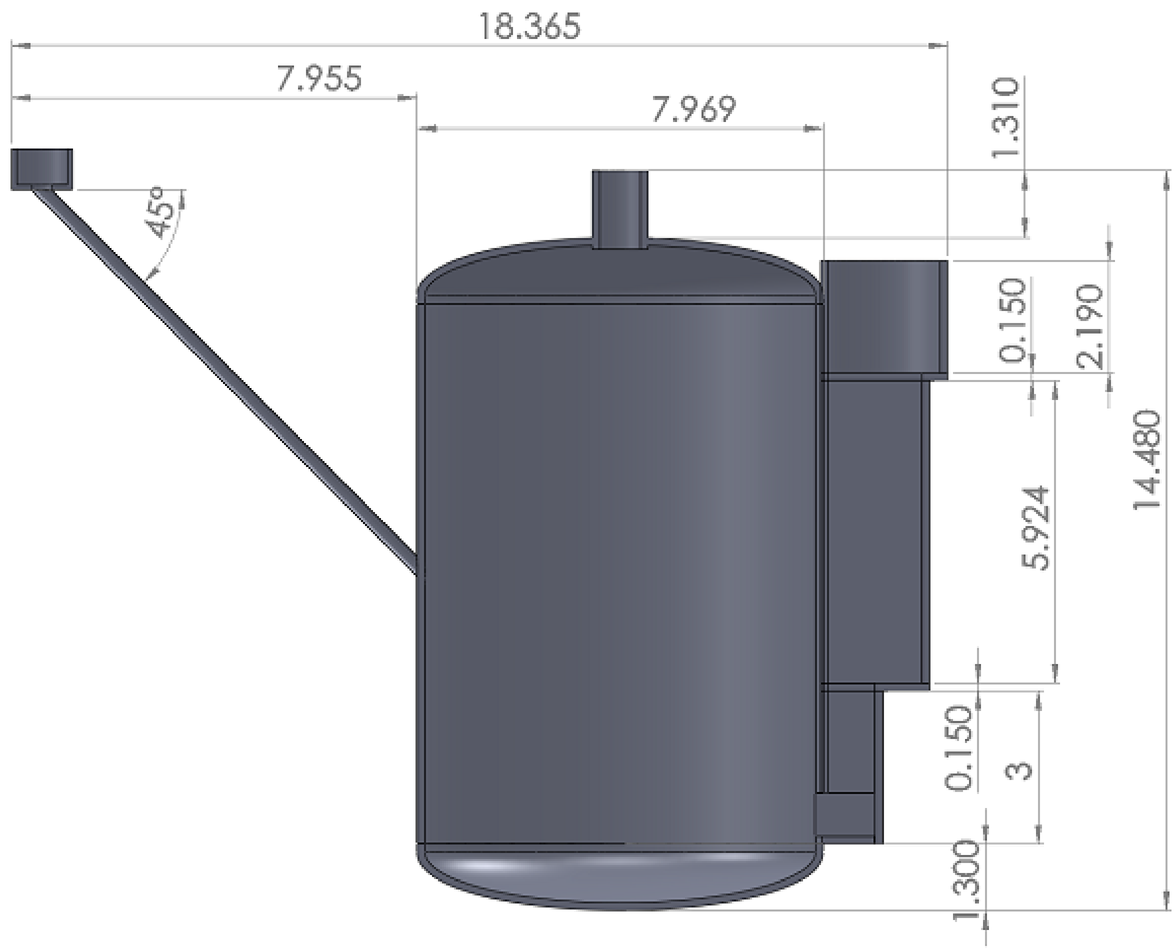


**Fig.6 Overall Dimension of Digester**

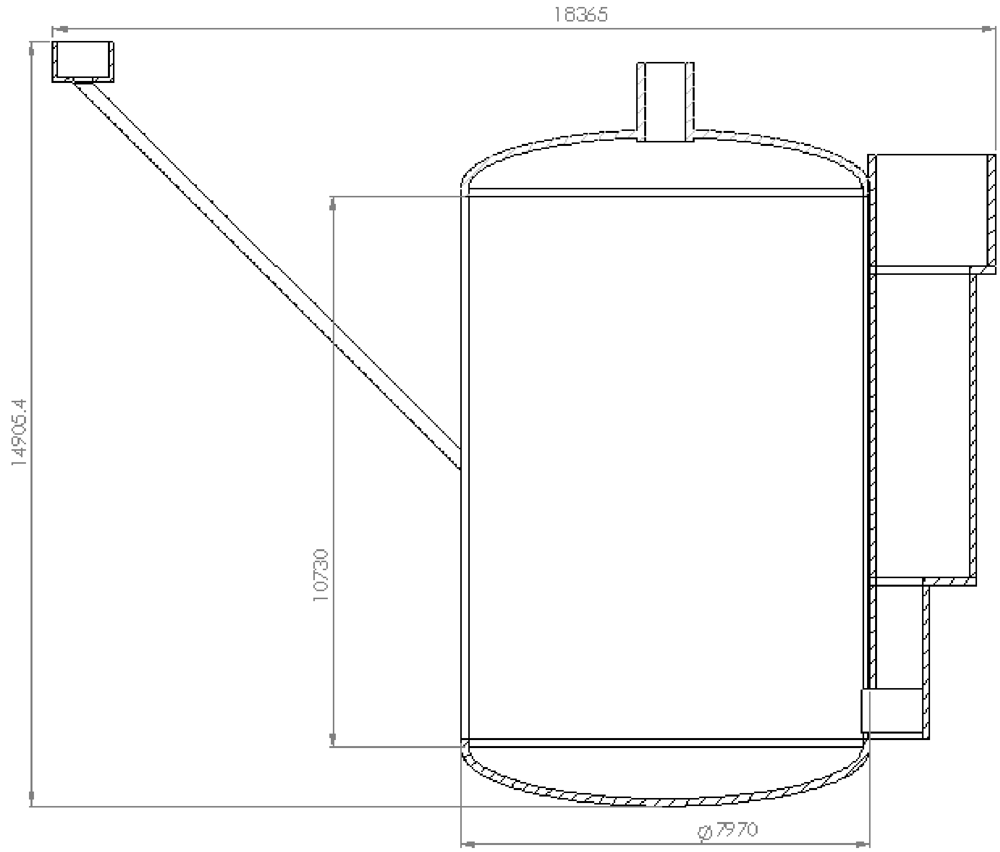


Fig.7 Some Cross sectional dimension of digester

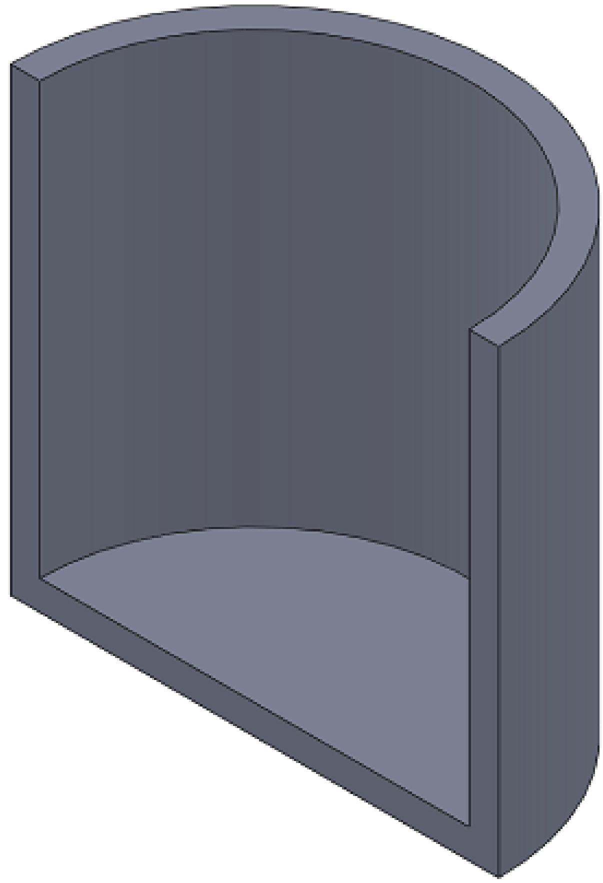

Fig. 8 Half part of digester

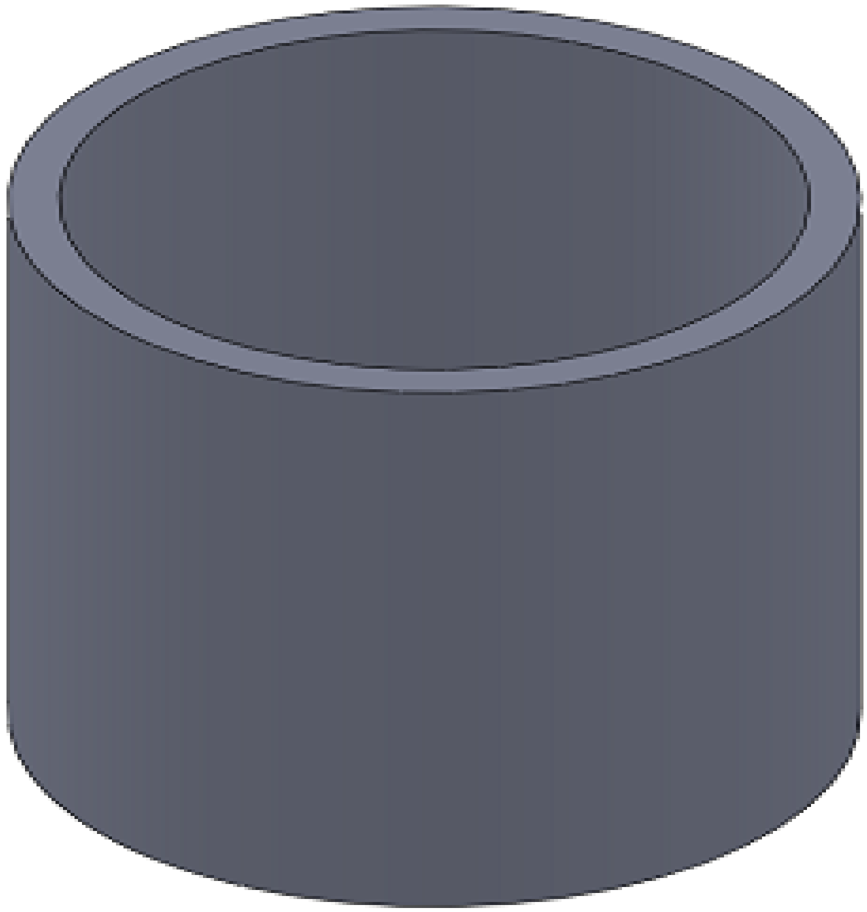

Fig.9 Cylindrical part of Digester

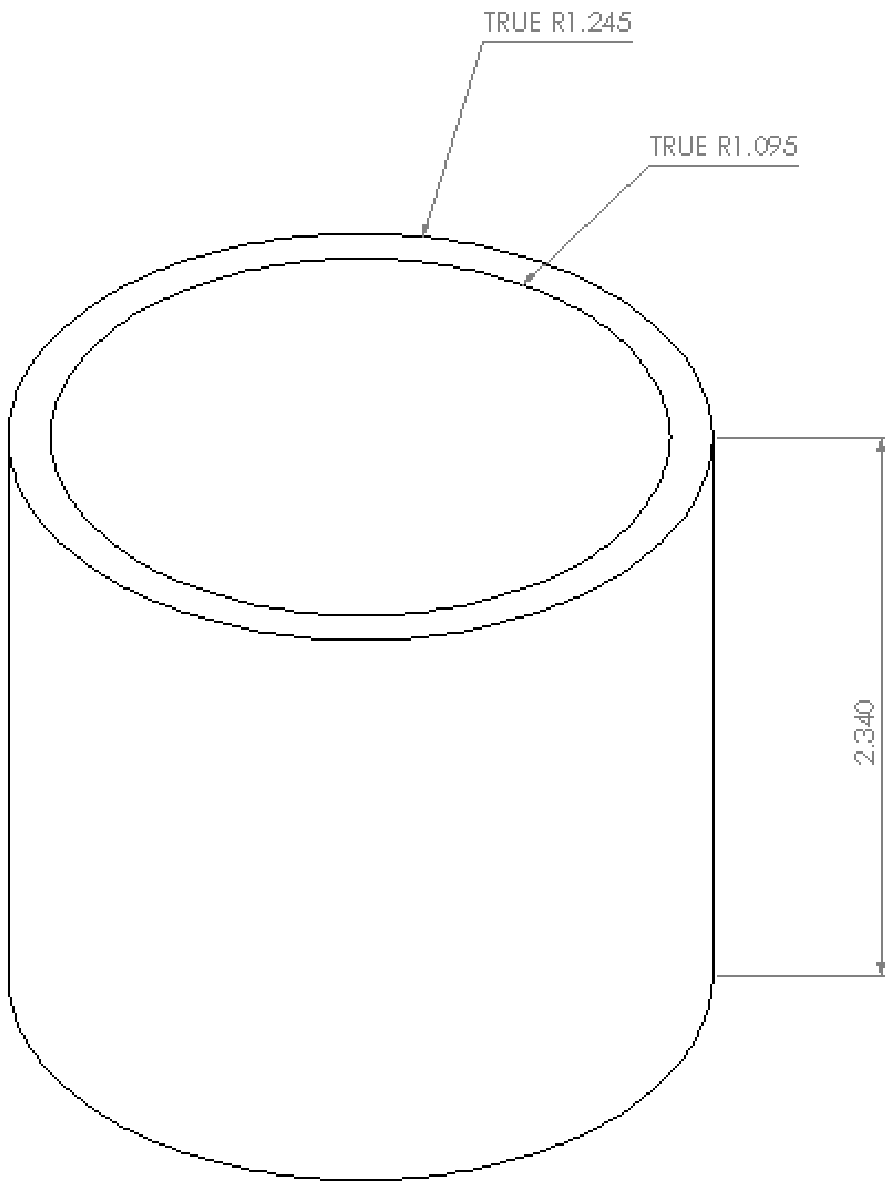


**Fig.10 Dimension of Cylindrical part of Digester**

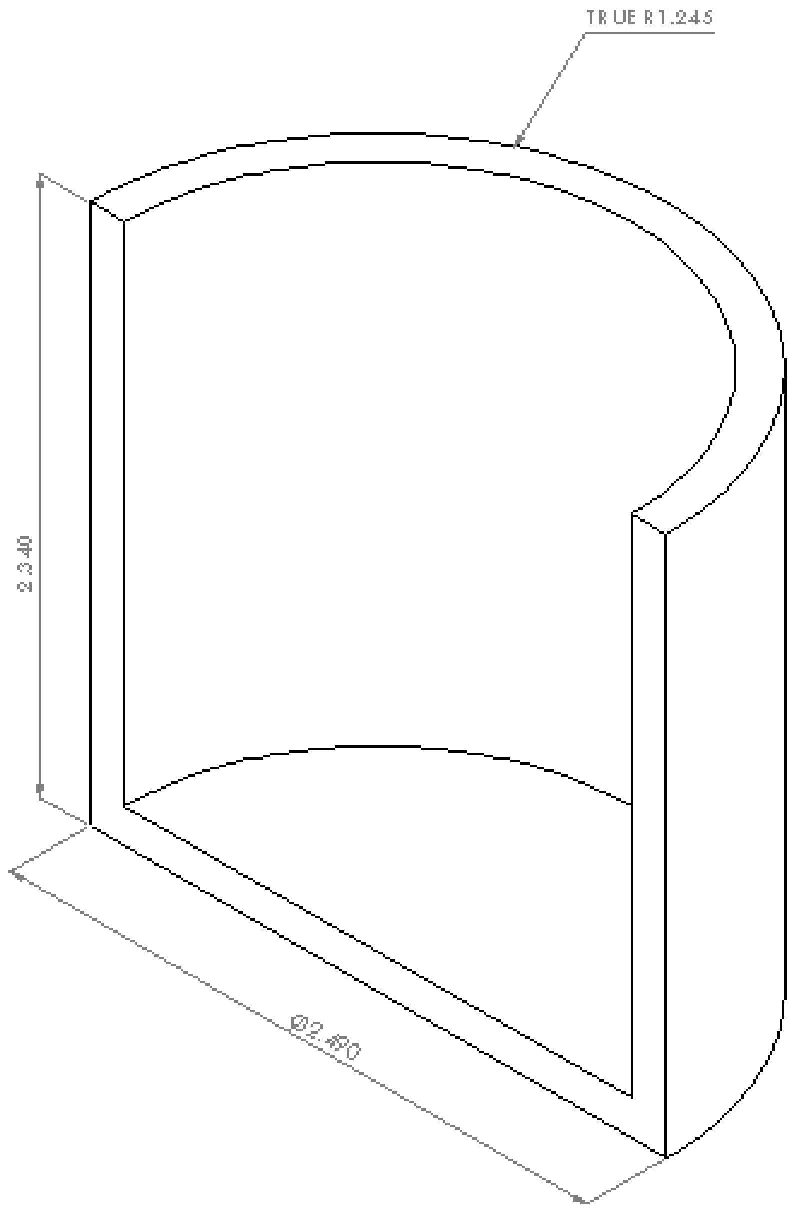


**Fig.11 Dimensions of Half part of digester**