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**COLLEGE OF ENGINEERING AND**  
**TECHNOLOGY**  
**DEPARTMENT OF CHEMICAL ENGINEERING**

**A Final year project Submitted to the Department of Chemical Engineering in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Chemical Engineering**

**Design of Biogas Production Plant from Wolkite University Student's Cafeteria Food Waste**

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## DECLARATION

We declare that this final year project for the BSc Degree at Wolkite University, Wolkite, Ethiopia. Hereby submitted by us, is our original work and has not previously been submitted for the degree at this or any other university, and that all resources of materials used in this final year project have been duly acknowledge.

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## **List of Acronyms**

**AD:** Anaerobic Digestion

**TS:** Total Solid

**VS:** Volatile Solid

**C/N:** Carbon to Nitrogen ratio

**WKU:** Wolkite University

**MSW:** Municipal Solid Waste

**ADM:** Anaerobic Digestion Model

**FW:** Food Waste

**VFA:** Volatile Fatty Acids

**Kg/V:** Kilogram per volume

**LFG:** Land fill gas

**HRT:** Hydraulic retention time

**TSd:** Total solid dissolved

**Gy:** Specific biogas yield

**Om:** Organic matter

## ***Abstract***

*Anaerobic digestion is a microbial process for production of biogas, which consists of primarily methane (CH<sub>4</sub>) & carbon dioxide (CO<sub>2</sub>). Co-digestion is also critical determinant for stable and efficient anaerobic digestion process. Biogas production requires anaerobic digestion. Anaerobic decomposition of different wastes which biodegradable in nature that can produce biogas. It can be used as healthy cooking alternative. The main objectives of the study are to design a biogas plant for food waste generated in our university. The materials used as feed were Injera with wot, Rice, Bread, Beef, Cabbage rolls, carrots and potato peels waste. The total solid, volatile solids, moisture content and ash content of the wastes were examined. Anaerobic digestion is very sensitive to change in pH and it was maintained and adjusted for healthy system. The temperature of the digester and the environment also affects the anaerobic digestion process.*

*In this small scale study the effect of different food waste to water ratio, the effect of inoculants and treatment with alkaline on the biogas production was investigated for the period of 2-4 weeks. The fixed dome biogas plant was designed according to the obtained value. Generation of biogas is enhanced by combination of co-digester mixture water cow dung with proportion of 1:1. Six batch experiments carried out to know the optimum mixing ratio of food sample to water. The anaerobic digester had a hydraulic retention time of 25 days and operated at 47<sup>0</sup>C, since it was greater than 45<sup>0</sup>C and which was at termoophylic conditions. From the simulation, it was observed that a total of 93.187m<sup>3</sup>/day biogas is produced from a feed rate of 497.882kg/day. The biogas yield was optimized by mixing food waste with water in 1:4 ratios and by introducing cow dung as inoculant.*

***Keywords*** *Anaerobic digestion, Vegetable peel wastes, Co-digestion, Food waste, Biogas*

# CHAPTER ONE

## Introduction

### 1.1 Background

Currently, the world is transferring from petroleum-based to a bio-based national economy due to the increasing prices and environmental effect of fossil fuels, in this instance, biological wastes, which are usually considered as low-valued materials, are now being converted from high volume waste dumping environmental crisis to constituting sustainable resources for the production of eco-friendly and clean fuels . In today's fast-growing world, the rate of accumulation of waste is rising at unexpected rate (Mery, et al. 2019).

As urbanization proceeds to take place, management of potential wastes including cafeteria waste, plastic waste, paper waste, and municipal solid waste is becoming a main public health and environmental concern. Especially, it is a serious concern in cities, universities and many industry sectors (Mery, et al. 2019).

Currently, in Ethiopia numerous industries, universities and other discharges substantial and significant amount of food waste to the environment that could result an ill-impact in the surrounding. More emphasis, a lot of food wastes are discharged from cafeteria and lounges of all Ethiopian universities(Fseha, et al. 2018).

Waste generated from WKU student cafeteria was left over food; vegetable peels waste, washing water and other organic matter. Due to its high biodegradability, calorific value & nutritive value to microbes those food and vegetable peel waste will be collected as feedstock in this project to generate biogas as well as to protect environment from pollution (Fseha, et al. 2018).

Anaerobic digestion is a microbial process for production of biogas, which consists of primarily methane ( $\text{CH}_4$ ) & carbon dioxide ( $\text{CO}_2$ ).Co-digestion is also critical determinant for stable and efficient AD process. Inoculants like cow dung, chicken manure, sugar cane... etc. they are among co-digester which improve biogas production process (Anton, et al. 2018).

Biogas-generating technology is a favorable dual-purpose technology at this time, as the biogas generated can be used to meet energy requirements while the organic residue is used as fertilizer (Sar, et al. 2019).

Biogas production requires anaerobic digestion. We should go for creating 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. Biogas can be used as energy source and also for numerous purposes. Any possible application requires knowledge & information about the composition and quantity of constituents in the biogas produced. (Anton,et al. 2018).

## **1.2 Statement of the Problem**

Application of wood as energy sources will generate environmental crisis, which affects the fertility of agricultural products, and it declines the quality of cooked foods. Burning of wood, which used as source of energy, is one of the time consuming. This unsustainable energy sources is causing environmental degradation such as deforestation, soil erosion and reduction of soil fertility, and adverse health problems like indoor air pollution and sanitation problems from household wastes. Furthermore, most of the time, women are responsible for the kitchen tasks and they are first victims for health risks.

## **1.3 Research questions**

The following are the research questions of the study.

- i. What is problem when we use fuel or wood for cooking?
- ii. What are the benefits when we use with biogas?
- iii. How much biogas will be produced from student cafeteria food and vegetable peels waste?

## **1.4 Objective of the Study**

### **1.4.1 General objective**

- The main objective of this study is to design biogas plant from Wolkite university student cafeteria food waste.

### **1.4.2 Specific objectives**

- ❖ To characterize physico-chemical properties of food waste.
- ❖ To develop lab scale biogas production system and determine the amount of gas produced from sampled food waste.
- ❖ To determine the optimum food waste mix
- ❖ To design the optimum biogas production plant

## **1.5. Significance of the research**

Wolkite University will gain an environmentally friendly alternate energy source for the cooking utilities and used as a backup electric generator when the Electric Agency power goes off. Wolkite University will get reliable energy source after successful completion of the research and implementation of the result. Since the electricity obtained from upgrading the biogas is new to Wolkite University the research will help as a reference for other studies, which may focus on similar issues, related to upgrading of biogas as an alternate energy source.

## **1.6 Scope of the research**

- ❖ The research was conducted considering the food and vegetable peel wastes that were collected from Main of WKU student cafeteria. The study was conducted using lab scale experimental design. Our primary scope starts from determining the optimum mixing ratio of water and food waste for biogas production to developing lab scale biogas production system and determining the amount of gas produced from sampled food waste. Then to design anaerobic digester

## **1.7 Limitations of the study**

During the course of this study i.e., time to conduct enough number of experiments and to complete, unavailability of some equipment's like perfect mixer, Gas analyzer and not functioning of some available equipment.

# CHAPTER TWO

## Literature review

### 2.1 Food waste

Food waste is food that is intended for human consumption that is wasted and lost, and refers not only to food that consumers don't finish at restaurants and are thrown out at home, but also raw materials and produce that are lost in the farming stage, harvesting processes, during transportation, and storage. Food waste has significant effects on the environment, global and national economies, food security and nutrition. The increasing and persistent global demand for food is also driving fertile land useless while contributing to more land degradation and deforestation, which as a result, destroys our precious natural habitats and biodiversity, limiting the services that they provide and disrupting entire ecosystems. Feedstock for the food waste-to-biogas plant includes leftover food, vegetable refuse, stale cooked and uncooked food, meat, tea, bags, napkins, extracted tea powder, milk products etc. (Anton et al., 2018).

### 2.2 Biogas

Biogas is a combustible mixture of gases mainly of methane ( $\text{CH}_4$ ) and carbon dioxide ( $\text{CO}_2$ ) and is formed from the anaerobic bacterial decomposition of organic compounds. Now a day's transformation of energy system from fossil to renewable sources is occurred for a purpose of decreasing the environmental changes and increasing energy security (Anton, et al. 2018). Use of biomass (organic matter containing solid and biological waste), as a renewable energy source plays a key role in reducing the environmental impact of burning fossil fuels to produce energy. Among biomass-based energies, biogas is an interesting option with a large potential, offering many exciting possibilities to supplant and therefore reduce the dependence on fossil fuels.

Biogas is converted to mechanical energy through an internal combustion engine. The mechanical energy rotates an electric generator which produces the electricity (Anton et al., 2018).

### **2.2.1 Technologies of biogas production**

Biogas production (primarily methane) is an anaerobic digestion process of food wastes that are widely adopted technology for food waste management and enables the effective use of accumulated animal waste from food production and of municipal solid waste from urbanization. Biogas technology can not only provide fuel, but is also important for comprehensive utilization of biomass forestry, animal husbandry, fishery, agricultural economy and protecting the environment. Biogas technology has been recognized as a suitable technology for improving energy access, waste management, and sanitation in Sub-Saharan Africa (SSA). Popularization of biogas technology has to go hand in hand with the actual construction of plants in the field. (Fseha et al., 2018)

### **2.2.2 Characteristics of biogas**

Biogas is characterized based on its chemical composition and the physical characteristics which result from it. It is primarily a mixture of methane ( $\text{CH}_4$ ) and inert carbon dioxide gas ( $\text{CO}_2$ ). However, the name “biogas” gathers a large variety of gases resulting from specific treatment processes, starting from various organic wastes - industries, animal or domestic origin waste etc. Different sources of production lead to different specific compositions. The presence of  $\text{H}_2\text{S}$ ,  $\text{CO}_2$  and water make biogas very corrosive and require the use of adapted materials. The composition of a gas issued from a digester depends on the substrate, of its organic matter, and the feeding rate of the digester (Placeholder4). Biogas is a gas appreciably lighter than air; it produces twice as fewer calories by combustion with equal volume of natural gas. (Al-wahaibi et al., 2020).

### **2.2.3 Feed stock's for biogas production**

Biogas can be generated from organic matter including manure, food waste, municipal solid waste, biodegradable waste or any other biodegradable feed stock under an aerobic condition. (Fseha, et al. 2018)

#### **2.2.3.1 Biogas from manure**

The basic component contributing to the organic strength of manure is organic solids. The most important parameters for characterizing these slurries are total solids content (TS) and volatile solids content (VS). There is an upper limit for TS content above which the material is no longer slurry,

and mixing and pumping becomes problematic. This upper limit for TS is dependent on the properties of the solids making up the slurry. For manure this occurs at TS of 10-15% VS content of the material is also an important as the TS content for the production of biogas from manure, since it represents the fraction of the solid material that may be transformed into biogas. Most manure from municipal wastes has a VS content of 70-90% of the TS content. The fixed solids (FS, also termed the ash content) is comprised of inorganic material (grit, minerals and salts), which dilute energy content and can impact the treatment process. (Ashenafi ,2020 )

### **2.2.3.2 Biogas from Municipal Solid Waste**

Anaerobic digestion of municipal solid waste can lead to biogas generation since this waste contains organic compounds which can be converted to methane by action of microorganisms. For MSW, the quantity of methane is significant and typically amounts to around 100 to 200 cubic meters of biogas per ton of organic MSW digested. (Al-wahaibi, et al. 2020) Generation of biogas from municipal solid waste is costly as it contains so many wastes other than the organic compounds which are basic to the biogas production, they have to be pre-treated.

### **2.2.3.3 Biogas From food waste**

Food waste is rich in organic matter. Subjecting this waste into anaerobic digestion provides high quality biogas. (Sar et al., 2019). Converting food waste of universities is crucial both environmentally as it decreases carbon emission and bad smells and economically as it needs low construction and operation costs. The TS% and VS% of Ethiopian food (enjera) is 39.43% and 93.78 respectively (Fseha et al., 2018). Currently numerous biogas stations are available in Ethiopia. The feedstock they are using to generate the energy is cow dung but in one of the Ethiopian universities.

Biogas production (Anaerobic digestion) process Anaerobic digestion is a series of biological process that use a different group of bacteria to break down organic compounds in a biomass to produce biogas in the absence of oxygen. Anaerobic digestion provides both fuel and fertilizer, while options on biomass uses without anaerobic digestion (burning, and composting) provide either one or the other, but not both. The biogas process is often divided into four steps: Hydrolysis, acidogenesis, acetogenesis, and Methanogenesis, where different groups of bacteria are each responsible for a step. (Al-wahaibi et al., 2020).

## **2.2.4 Biogas production (Anaerobic digestion) process**

### **I. Hydrolysis**

Enzymatic hydrolysis is the process where the fats, starches and proteins contained in biomass are broken down into simple compounds. Polymers are transformed into soluble monomers through enzymatic hydrolysis. These monomers become substrates for the microorganisms in the second stage where they are converted into organic acids by a group of bacteria (Ashenafi, 2020).

### **II. Acidogenesis**

The resultant product (monomers) obtained in hydrolysis stage serve as input for acid formation stage. Products produced in previous stage are fermented under anaerobic conditions to form different acids. The major products produced at the end of this stage are acetic acid, propionic acid, butyric acid and ethanol etc. (Al-wahaibi et al., 2020).

### **III. Acetogenesis**

In this stage, intermediate products and acids other than acetate that were formed in the acidogenesis stage are further converted to acetic acid as well as carbon-dioxide and hydrogen by different anaerobic oxidation reactions involving so-called acetogenic bacteria. In a stable anaerobic digestion, the acetate and H<sub>2</sub>-producing bacteria called acetogenic bacteria transform the products of acidogenesis into acetate, hydrogen and carbon dioxide which are substrates for the methanogens (Al-wahaibi et al., 2020).

### **IV. Methanogenesis**

This is the step in which organic acids which are formed above are converted into methane (CH<sub>4</sub>) and CO<sub>2</sub> by the bacteria which are strictly anaerobes, called methane fermenters. In this step, methanogenic bacteria generate methane by two routes, by fermenting acetic acid to methane (CH<sub>4</sub> and CO<sub>2</sub>) and by reducing CO<sub>2</sub> via hydrogen gas or by other bacterial species (Al-wahaibi et al., 2020).

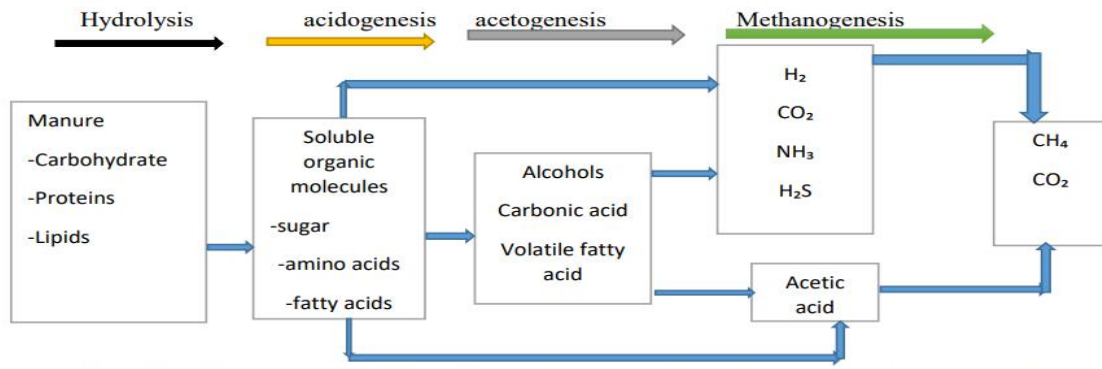


Figure 1 the AD pathway uploaded by Jonathan\_Rea

### 2.2.5 Parameters that affects biogas production rate

There are other parameters that influence the biogas production from an anaerobic digester depends on the ability of bacteria to thrive inside the digester. The bacteria survives inside a biogas digester depends on the temperature, pH, total solid, volatile solid, C/N ratio and physical conditions of the anaerobic digester (Fseha et al., 2018).

#### 2.2.5.1 PH

The survival of methanogenic bacteria also depends on the acidity of the environment that they are in Methanogenesis requires a near-neutral pH (between 6.5 and 7.5). A decrease in pH can inhibit gas production and can lead to further accumulation of acids. Methanogenic activities may be stopped or inhibited if the pH is lower than 6, because hydrogen production occurs instead of methane production. If pH is lower than 6.5 all the process could be stopped. However, CO<sub>2</sub> as carbonic acid and ammonia avoids either strong acidification or basification due to act as buffering system. CaCO<sub>3</sub> is used as alkaline to control the pH. Alkalinity can be increased by adding chemicals like MgO, NaHCO<sub>3</sub>, NaOH, NH<sub>3</sub> and Na<sub>2</sub>CO<sub>3</sub>(Fseha et al., 2018).

#### 2.2.5.2 Total Solid (TS)

The total solid (TS) test determines how much of the food waste is composed of water and how much of the food waste is solid. The food waste samples were homogenized in a blender and the mass of each sample was measured and recorded. The samples were then placed in an oven set to 105°C for a period of at least 24 hours and weighed. (Yin Li et al.,)

### 2.2.5.3 Volatile Solid (VS)

The sample which was dried in the total solid method was placed in a furnace at a temperature of 550°C for at least 4 hours. After cooling in desiccators, the sample was weighed. This test determines how much of the dry matter is composed of volatile organic material. The resulting residue is composed of inorganic material.(Fseha et al., 2018).

### 2.2.5.4 Temperature

Temperature is one of the basic parameters that affect the survival of the bacteria inside the digester. The three digestion types of temperature ranges are named psychrophilic digestion, mesophilic digestion and thermophilic digestions. Psychrophilic digestion occurs at below 25 °C, or below room temperature. Mesophilic digestion occurs between 25 and 45 °C, while thermophilic digestion occurs above 45 °C . Biogas production under thermophilic (55 °C) condition is more than double the output under psychrophilic (15 °C) condition. In general, higher temperatures result in higher biogas production. Further, rapid temperature changes can upset bacterial activity, so for experimental studies, it is important that temperature is held constant. With increase in temperature, the toxicity of H<sub>2</sub>S increases. (Yin Li et al.,)

Table 1 Summary of Temperature ranges

Anaerobic Process	Operating Temperature(°C)	Operating Days	Microbial Growth and Digestion Rates	Tolerance to Toxicity
Psychrophilic	10-25	>50	low	high
Mesophilic	25-45	25-30	medium	medium
Thermophilic	45-65	10-15	high	low

Sources: (Jay Cheng 2018) and (Deublein, D. et al. 2018) .

### 2.2.5.5 C/N Ratio

The production of biogas can also be influenced by the relative amount of organic carbon and nitrogen in the feedstock, which is measured as Carbon/Nitrogen (C/N) ratio. A low C/N ratio can lead to pH values above 8.5, while a high C/N ratio may result in lower methane production rates (wilkie, 2021).

### **2.2.5.6 Hydraulic retention time**

The average time spent by the biomass inside a continuous biogas plant before it comes out from the digester is known as the hydraulic retention time, also abbreviated as HRT. The required retention time for completion of the AD reactions varies with differing technologies, process temperature, and waste composition. The retention time for wastes treated in mesophilic digester range from 10 to 40 days. Lower retention times are required in digesters operated in the thermophilic range (Fseha, et al. 2018)

#### **Anaerobic environment**

The methanogens need an oxygen-free environment as they are obligatory anaerobic. A biogas reactor therefore has to be airtight. The small amount of oxygen dissolved in the liquid/biomass fed to the plant is quickly used up by, for example, aerobic bacteria that must have oxygen, or by facultative anaerobic bacteria that can use oxygen for their respiration, if it is present (wilkie, 2021).

#### **Stirring**

Optimum stirring substantially reduces the retention time. Stirring is very important for completing digestion process and enhancing biogas production. Since stirring break down the scum formed on the surface of digester contents and prevent the bacteria from stagnating in their own waste products (Fseha, et al. 2018)

#### **Inhibitors and Activators**

Presence of some substances in the contents of the digester below certain concentrations may activate the digestion process and so increasing the biogas production, but at higher concentration sit may become inhibitors. For example, presence of  $\text{NH}_4$  from 50 to 200 mg/l stimulates the growth of microbes, where as its concentration above 1500mg/l produces toxicity (Fseha, et al. 2018). Results of other study pointed that adding small amount of nickel metal (as nickel chloride) to rice straw substrate stimulate its biogas production while nickel larger amount gives opposite results.

#### **Digester Loading Rate**

The digester loading indicates how much organic material per day has to be supplied to the digester or has to be digested. The digester loading is calculated in kilograms of organic dry matter per cubic meter of digester volume per day (kg ODM/m<sup>3</sup>/day). Long retention times result in low digester loading. If the digester loading is too high, the pH falls. The plant then remains in the acid phase because there is more feed material than methane bacteria. (wilkie, 2021).

### **Mixing and Other Physical Conditions**

Contact between bacteria and the slurry that they are consuming is vital to the anaerobic digestion process. One way to maximize this contact is to keep the digester thoroughly mixed at all times. Methanogens naturally live inside the stomachs of animals, and attach to the stomach lining as a way to secure a safe habitat with a steady supply of food. When placed inside of a man-made anaerobic digester, instead of floating around in the slurry, the bacteria attach to surfaces while being exposed to the flow of digestible material. Some anaerobic digester designs address this issue by creating internal structures so that bacteria can attach to them and be exposed to more digestible material. Otherwise, mixing is an important design parameter in maximizing anaerobic digestion performance because it allows enhanced contact between bacteria and the material being consumed. (Fseha, et al. 2018)

#### **2.2.6 Properties of biogas**

Methane and carbon dioxide are odorless and colorless gases. Hydrogen sulfide is colorless but it has an odor of rotten eggs in addition to its toxicity. Carbon dioxide, hydrogen sulfide, ammonia and water vapor considered corrosive substances. In general; biogas with all its components is colorless, odorless and lighter than air. The common characteristics are:

- a. Change in volume as a function of temperature and pressure.
- b. Change in calorific value as function of temperature, pressure and water vapour content.
- c. Change in water vapor as a function of temperature and pressure.

#### **2.3 Applications of biogas**

Biogas is more convenient to use than traditional fuels, such as fire wood, dried dung and even Kerosene. It gives a hot, clean flame that does not dirty pots or irritates the eyes, as does the smoke from other fuels. The composite from the plant can be used for fertilizer. Biogas can also be used in engine to drive machinery and water pumps. Like any other fuel, biogas can be used for household and industrial purposes. (Antonio, 2022)

## **1. Cooking**

Cooking is by far the most important use of biogas in the developing world. Biogas burners or Stoves for domestic cooking work satisfactorily under a water pressure of 75 to 85 mm. The stoves may be single. (Antonio, 2022)

## **2. Lighting**

Biogas can be used for lighting in non-electrified rural areas. Special types of gauze mantle lamps consuming 0.07 to 0.14 m<sup>3</sup> of gas per hour are used for household lighting. Generally, 1 mantle lamp is used for indoor purposes and 2-mantle lamps for outdoors. (Antonio, 2022) Such lamps emit clear and bright light equivalent to 40 to 100 candle powers. These are generally strong, well built, bright, efficient and easy to adjust. The lamps work satisfactorily under a water pressure of 70 to 84 mm. (Antonio, 2022)

## **3. Refrigeration**

Biogas can be used for absorption type refrigerating machines operating on ammonia and water, and equipped with automatic thermo-siphon. Since biogas is only the refrigerator's external source of heat, the burner itself has to be modified. (Antonio, 2022)

## **4. Electricity Generation**

Generating electricity is a much more efficient use of biogas than using it for gas light. From energy utilization point of view, it is more economical to use biogas to generate electricity for lighting. (Antonio, 2022) In this process, the gas consumption is about 0.75 m<sup>3</sup> per kW hour with which 2540-watt. Lamps can be lighted for one hour, whereas the same volume of biogas can serve only seven lamps for one hour. Small internal combustion engines with generator can be used to produce electricity in the rural areas with clustered dwellings.

## **5. Energy Available**

As biogas plant utilizes locally available raw materials, the gas obtained from it can be cheaper and reliable. (Antonio, 2022) Biogas can be used for following purposes:

- ❖ Fuel wood can be saved while using it for cooking
- ❖ Kerosene can be saved while using it for lighting and refrigeration;
- ❖ Diesel can be saved while using it for running
- ❖ Electricity will be generated while using it for electricity generation.

## **6. Availability of Fertilizer**

Human waste used as a raw material in biogas plant is digested during gas production and the digested slurry comes out from the outlet as a byproduct. Thus, biogas replaces the excrete cake which otherwise is being used as a fuel for cooking and produces digested slurry that can be used as fertilizer in the field. Digested slurry contains plant nutrients in more concentrated form than raw materials and is in an easily available form compared to the traditional compost. (Antonio, 2022) The humus contained in digested slurry improves the physical properties of soil like water holding capacity, aeration, water stable aggregates and increases the crop production up to 20-30 percent.

## **7. Time Save**

Use of biogas saves time in following way

- ✓ Time is saved as it is very easy to ignite biogas compared to bum firewood
- ✓ Biogas generates higher temperature and requires less time for cooking
- ✓ Cleaning utensils are easy as the biogas does not produce soot and thereby reduces the workload of housewives.

## **8. Health and Sanitation**

Biogas helps to improve health and hygiene of the house wives and children in the following manner: (Antonio, 2022)

- Smoke from the firewood, dung cake and plant residues induces respiratory and eye disease especially to the housewives. Biogas, being smokeless, reduces infestation of such diseases.
- Biogas light, being bright enough for reading and minute works, helps reduce the eye disease of the children.

## **9. Reduction in Expenses**

Although biogas does not generate direct cash income, it reduces user expenses in a number of ways as described below:

- It reduces the medical expenses by reducing the smoke induced respiratory and eye diseases
- It reduces cooking fuel expenses; and It reduces kerosene expenses for lighting. (Antonio, 2022)

# CHAPTER THREE

## Materials and methods

### 3.1. Raw materials site

The food waste was obtained from Wolkite University main cafeterias and experimental evaluation was taken from returned food waste. There are four different food waste samples:

1. Injera with wot
2. Rice
3. Bread
4. Beef
5. Cabbage rolls, carrots and potatoes peels



Figure 2 location of food wastes behind WKU student cafeteria

The food waste samples were collected and transported to Wolkite University, Chemical Engineering Department laboratory. The biogas production experiment from food waste and total solid and volatile solid analysis was conducted in Wolkite University, Chemical Engineering Department laboratories. Weighing balance, pH meter, oven furnace and water bath are some of the major equipment's that was used for the experimental work.

### 3.2 Materials, chemicals and equipment's

The following materials and equipment will be used in the lab-scale experimental Set up.

Table 2 Materials, Chemicals and Equipment's

Material	Equipment	Chemicals
Plastic bottle	Oven	Sodium hydroxide
Water tube	Furnace	Water
Hand glove	Grinder	
Balloon	Bunsen burner	
Flasks	Weight balance	
Beaker	Heat sucker	
Plastic bag	Crucible	
Syringe	Agitator	
Sample of cow manure	pH meter	
Sample of food and vegetable peel waste	Thermometer	

### 3.3 Raw material preparation

#### Sample collection and size reduction:

Sample of food and peel waste was taken from main student cafeteria of Wolkite University using plastic bag and transported to the laboratory of food Engineering department, The size reduction methods of the food was proposed to grinder.



Figure 3 sample collection and after size reduction

Food and vegetable peel waste mixed with 10:1 ratio after preparation.

The food waste density was measured by determining the volume of a given mass of food waste. An Erlenmeyer flask was placed on a scale and initially fills up with water. Food waste was placed into the flask and its volume determined by the amount of displaced liquid in the flask, and then its mass measured by balance. Density can be calculated as the ratio of mass to volume determined and is found to be  $1.12 \pm 0.01$  Kg/L. The density of water is a standard value which is  $1000\text{Kg}/\text{m}^3 = 1 \text{ Kg}/\text{L}$ .

Table 3 Density of Food Waste (Kg/l)

Mass of sample(g)	Volume of sample (ml)	Density of sample (kg/l)
50	44.64	1.12
55	49.55	1.11
60	53.10	1.13

### 3.4 Characterization of raw materials

Food waste Characterizing was undertaken in biogas production system. The parameter that was characterized in this study was: total solid (TS %), volatile solid (VS %), moisture content and fixed solid.

## Total solid, Volatile solid, Fixed solid (FS) and Moisture content determination

### Total solid:

100 gram sample of food was weighed using a calibrated weight balance and was placed inside an oven at temperature of 105°C using a crucible and allowed to stay for 22 hours, then taken out, cooled in a heat sucker and was weighed. According to APA standard method (Fseha et al., 2018).

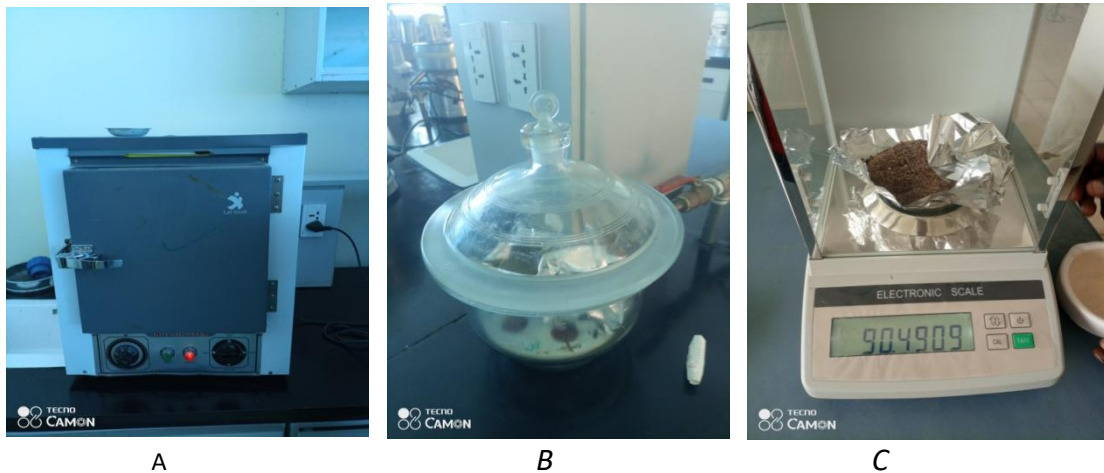


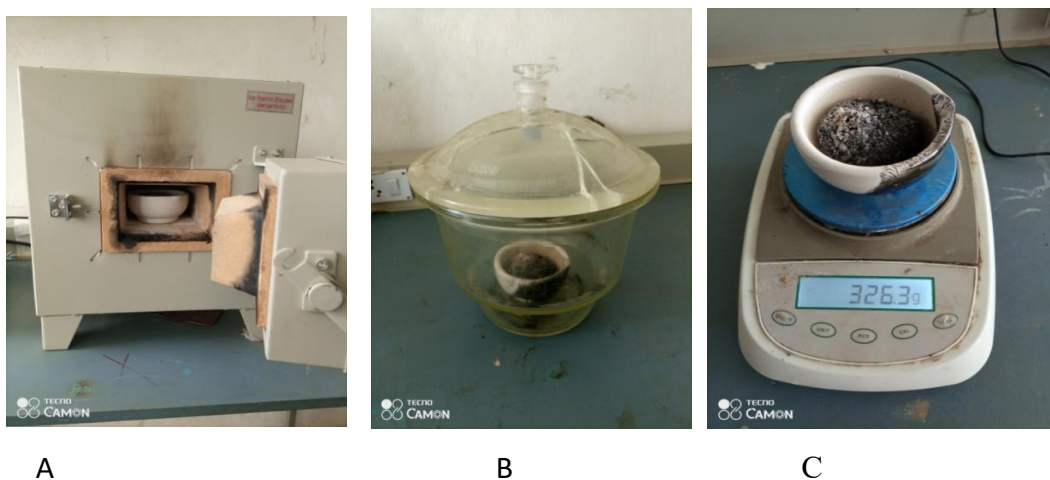
Figure 4 Oven (A) Heat sucker (B) Weight balance (C)

Then the percentage of the TS was calculated using the following equation:

$$TS \% = \left( \frac{\text{final weight}}{\text{initial weight}} \right) * 100 \dots \dots \dots \text{EQ1}$$

### Volatile solid

The weighed total solid was placed in blast furnace at a temperature of 550°C for 4 hours (Fseha et al., 2018). Then the sample was taken out, cooled in a heat sucker and weighed.



Furnace (A) heat sucker (B) crucible with ash (C)

The amount of volatile solid of the sample was calculated using the following equation.

$$VS \% = \left( \frac{V2-V3}{V1} \right) * 100 \dots\dots\dots EQ2$$

V1= total solid

V2= Weight of total solid & crucible.

V3= Weight of ash & crucible

**Fixed solid (FS):** The fixed solid was calculated using the following formula.

$$FS = TS-VS \dots\dots\dots EQ3$$

**Moisture content:** The amount of liquid present in a sample was estimated by:

$$100- TS \dots\dots\dots EQ4$$

### 3.4 Biogas production

The basic steps used for the production of biogas from food waste were:

Sample collection, size reduction, characterization of food waste, slurry preparation, and anaerobic digestion process

#### 3.4.1 Slurry preparation

To know the best slurry concentration (best ratio of food waste and water) that can be used for biogas plant design, six different slurry concentrations was prepared.

In this procedure, anaerobic digestion with inoculums and without inoculums was performed to know the effect of inoculums in the biogas production.

#### Experimentation set up without inoculants

Laboratory scales anaerobic batch digesters with different amount of food waste and water were used in this experiment.

Table 4 Slurry prepared having different amount of food waste at constant water

Slurry number	Food waste (g)	Water in milliliter	Ratio
1	100	500	1:5
2	50	500	1:10

Table 5 Slurry prepared having different amount of water at constant food waste

Slurry number	Food waste (g)	Water in milliliter	Ratio
1	200	800	1:4
2	200	500	1:2.5

### 3.4.2 Procedure

The procedures used for this experiment were:

- 1) The prepared slurries were introduced to the different leveled plastic bottles.
- 2) Balloons were tied at the top of the bottle attaching with 30 cm tube. The balloons were used to collect the biogas produced.
- 3) The plastic bottles were sealed properly in order to avoid any contamination with environment and to be anaerobic condition.



Figure 5 Slurry prepared with different ratio

#### Experimentation set up with inoculants

Anaerobic digestion with inoculants also was performed to know the effect of inoculants in the biogas production.

The inoculants source, cow dung, was collected from field. The weight of the cow dung was 5g. 5ml of water was added to the sample cow dung and was mixed nicely.

Generally, from the experiments (experiment with inoculant and without inoculant ) the biogas production potential of food waste was investigated.



Figure 6. Sample of cow dung

Feedstocks of 2000 g food waste and 200g vegetable peel waste which is ratio of 10:1 feed to Digester of 10m<sup>3</sup> plastic bottle and the 10ml slurry was fed to the digester by the inlet bottle. The inlet was closed and care was taken to avoid any leakage. During the biogas production the pH, were initially measured and its 5.34. Since its pH is lower than 6.5 CO<sub>2</sub> as carbonic acid and ammonia avoids either strong acidification or basification due to act as buffering system. The Prepared 28 ml solution of NoaH was used as alkaline to increase and control pH. Temperature maintained at 47°C which is thermophilic condition by using water bath. Biogas result collected and measured for 4 Days within 3-4 weeks.



Figure 7 digesters with the optimum mixing ratio (left) and Water bath (right)

#### 3.4.4 Intermittent measurements with syringe:

Biogas volume was measured using a 1,000-ml syringe. The syringe was connected to the digester by injecting the needle through the butyl bung, then drawing the plunger out until the pressure in the head space dropped to ambient pressure. The volume of gas in the syringe was taken as a measurement of the gas produced.

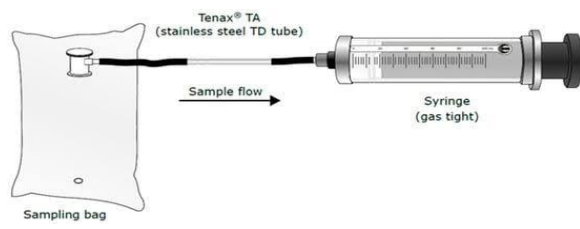


Figure 8 Measurement of gas produced by syringe protocol method

# CHAPTER FOUR

## Results and Discussion

### 4.1 Physiochemical characteristics of food waste

During the experimentation the following result of physiochemical characteristics were obtained (for full calculation of the result see Appendix C).

Table 6 Results of physico-chemical characteristics of food waste sample

Parameters	Amount in %
Total solid	90.49
Volatile solid	71.38
Moisture content	9.51
Fixed solid	19.11

From the above table, the total solid, which is the amount of solid part present in the sample food waste, was 90 of 100 gram. This means that 10% of the sample food waste is water or moisture. The volatile solid, which is the amount of organic content of the FW, was 71.38% and this organic content is useful to generate biogas after anaerobic bacteria utilize it.

### 4.2 Optimum mixing ratio

From this experiment the following result was observed.

Table 7 Result of anaerobic digesters with varying amount of food waste

Slurry number	Food waste in gram(g)	Water in milliliter(ml)	Expansion for balloon
1	100	500	High
2	50	500	Low

From the table the expansion of the balloons represents the amount of biogas produced. From the table result it was observed that there should be an optimal mixing ratio of food waste and water to get high amount of biogas production. Observing Slurry number-1, and 2, there was high and low expansion of balloons (biogas production) when the mixing ratio of food waste with water were 1:5 and 1:10 respectively.

Table 8 Result of different anaerobic digester with varying amount of water

Slurry number	Food waste (g)	Water in milliliter	Expansion of balloon
1	200	500	Low
2	200	800	High

From the above table, it was observed that the 200 gram of food waste generates more gas when it was mixed with 800 ml of water. But for the other set up (200g with 500ml), the expansion of the balloon was less compared with the aforementioned. Generally, the amount of biogas collected in the balloon was varied with different slurry concentration prepared. By running six series experiment, it was then concluded that the optimal mixing ratio of food waste and water to be 1:4.

There was observed that expansion of balloon at digester with sample manure is higher than that of without manure. This shows that co-digester can greatly improve biogas production process.

### 4.3 Biogas result

The result obtained from experiment carried out by adding inoculant to slurry prepared by mixing of food and water in a ratio of 1:4 was recoded as follow:

Table 9 the amount of gas measured using syringe protocol method

Days	Gas produced ml
1	0
6	8.3
13	10
19	7.6
23	5.7

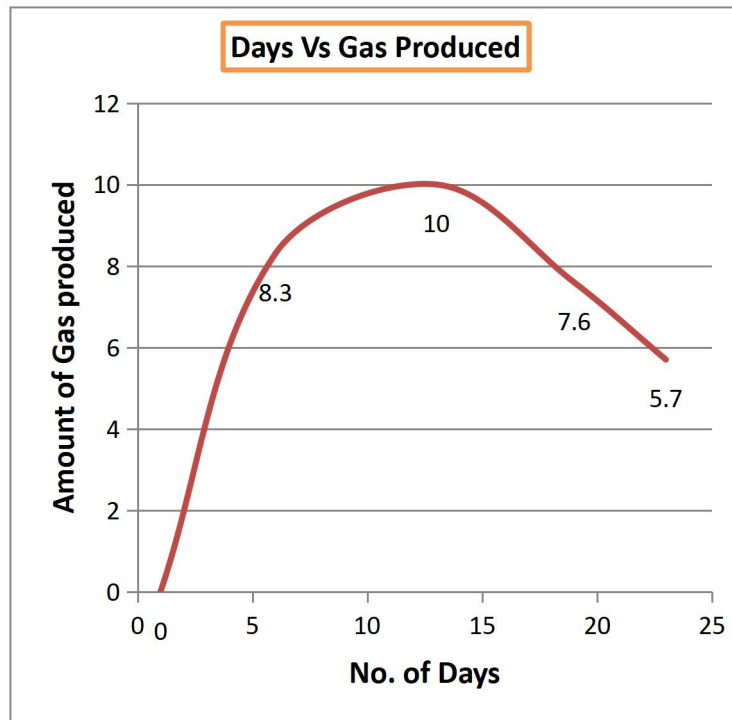


Figure 9 amount of biogas produced

Figure 9 shows the amount of biogas produced within 23 days. The amount of biogas produced was increased from day 6 onwards because of better formation of methanogens bacteria inside the anaerobic digester. But lower production of biogas was also observed particularly after 23 days. In observation, the size of the balloon expansion of the experiment with inoculant was higher than without inoculant. The parameter that made the biogas produced to be higher in the Experiment with inoculant is due to the availability of inoculant as those are source of microorganism that help to degrade the organic content of the feedstock. As we have tried to compare our results with different literatures we have seen that little difference in physico-chemical characterization result because we have introduced other vegetable peels waste and the sample was dried well to enhance its size reduction. It only affects positively in biogas results because vegetable peels waste itself is an organic matter with having high biogas content.

Biogas is a renewable fuel produced from the anaerobic digestion of organic feedstocks including municipal waste, farm waste, food waste, and energy crops. Raw biogas typically consists of methane (50–75%), carbon dioxide (25–50%), and smaller amounts of nitrogen (2–8%). Trace levels of hydrogen sulfide, ammonia, hydrogen, and various volatile organic compounds are also present in biogas depending on the feedstock. Life cycle assessment studies have shown that deploying biogas technologies can effectively reduce greenhouse gas (GHG) emissions and, therefore, reduce the climate impact of energy consumption. Biogas production and utilization practices also help diversify energy systems while simultaneously promoting sustainable waste management practices. California is promoting biogas utilization by mandating the low carbon fuels, offering grants to develop biogas production facilities, and providing assistance in accessing pipeline infrastructure. (Yin Li et al., 2019)

To make biogas suitable for use, the methane has to be separated from the carbon dioxide. This involves the use of membranes: filters that stop the methane and let the CO<sub>2</sub> pass through. Methods for separating CO<sub>2</sub> from biogas include: absorption by chemical solvents, physical absorption, pressure swing adsorption (PSA), cryogenic separation, membrane separation, and CO<sub>2</sub> fixation using biological methods. (Birgir et al., 2021)

## CHAPTER FIVE

### Material and energy balance

#### 5.1 Design and sizing of biodigester

##### Design Constraints

When selecting a design, the following operating requirements need to be considered.

- Type and composition of organic material, which determines the choice of process.
  - Knowing demand for biogas and fertilizer, in addition to available substrate quantities, which determines the size of the biogas digester.
- Cost of material building
  - Economy of labor input for building and operating the plant.
  - Pressure development and
  - Pressure drop or head loss
  - Digester heat requirement and heat loss

#### 5.2 Sizing of bio digester

To calculate the size of a biogas digester, certain characteristic parameters are used. These are as follows:

Daily fermentation slurry feed (substrate input) ( $S_d$ ), Retention time (RT), Specific gas production per day ( $G_d$ ), which depends on the retention time and the feed material. The size of biogas digester depends on the quantity, quality and kind of available biomass and on the digesting temperature. The digester volume ( $V_d$ ), is determined on the basis of the chosen retention time (RT) and the daily substrate input quantity ( $S_d$ ). The following additional concepts and parameters are also used in the theoretical literature:

Dry matter (DM): The water content of natural feed materials varies. For this reason the solids or dry matter content of the feed material is used for exact calculation. Organic dry matter (ODM or VS): Only the organic or volatile constituents of the feed materials are important for the digestion process. For this reason, only the organic part of the dry matter content is considered. Most favorable ODM value desired is 8%.

General assumptions for the design of the digester are as follows:

One kg of food waste produces 0.04 m<sup>3</sup> of biogas.

- ✓ Hydraulic Retention Time (HRT) of 20 days ensures that most of the pathogens are destroyed.
- ✓ The amount of food waste per day = 0.6kg/d. Therefore, the total amount of food waste per day = 0.6 \* 1680 = 1008kg/d.
- ✓ Amount of food per person per day = 1L/d = 0.001m<sup>3</sup>. Therefore, the total amount of food wastes per day = 1L \* 1680 = 1680L/d = 1.68m<sup>3</sup> /d.
- ✓ One student uses 0.4 liter of water for hand cleaning.
- ✓ The diameter (d) and height (h) of mixing pit are equal (d=h).
- ✓ Take 10% allowance (safety factor) to calculate dimensions of the digester
- ✓ Specific biogas moisture content = 0.07 m<sup>3</sup> /kg
- ✓ Specific biogas moisture Species content = 0.028 m<sup>3</sup> /kg
- ✓ Total daily content of specific biogas yield = 0.35m<sup>3</sup> /kg
- ✓ Size of septic tank is 95 – 180m<sup>3</sup>
- ✓ Inlet pipe diameter is 110 – 150 mm
- ✓ Distance of septic tank from the nearest block is 3m the minimum distance Daily substrate Input can be taken as Sd = 0.4kg / person-day
- ✓ Total discharge for the 2 café is determined from the input data  
 $TSD = 12 \times 0.4 \times 140 = 672 \text{ kg / day}$ .

Therefore, the daily biomass input is 672 kg.

Total solid content of night soil is, TS = 0.2

Volatile solid content of night soil is, VS = 0.15

The underground temperature is assumed to be 30°C for which is found in tropical zone. The amount of biogas generated each day is calculated on the basis of the specific gas yield of the substrate and the daily substrate input. The estimation can be based on (GTZ, 1989):

a) Volatile Solids Content (VS)

$$G_d = V_s \times G_y$$

b) Weight of Moist Mass

$$G_d = W_{\text{biomass}} \times G_y \text{ (moist)}$$

c) Standard Gas yield values per waste Unit

$$G_d = n_{\text{waste}} \times G_y \text{ (species)}$$

Where,  $G_d$  = Daily biogas generated

$G_y$  = Specific biogas yield

Nwaste=Number of waste Unit As a rule, it is advisable to calculate according to several different methods, since the available basic data are usually very imprecise, so that a higher degree of sizing certainty can be achieved by comparing and averaging the results.

d) Flow rate of daily Gas Production

$$a) Gd = VS = Gy = 0.2 \times 672 \times 0.38 = 51.072 \text{ m}^3 / \text{day}$$

$$b) Gd = W_{biomass} \times Gy (\text{moist}) = 672 \times 0.07 = 47.04 \text{ m}^3 / \text{day}$$

$$c) Gd = n_{waste} \times Gy (\text{species}) = 1680 \times 0.028 = 47.04 \text{ m}^3 / \text{day}$$

Averaging the daily biogas yield:

$$Gd = \frac{51.072 + 47.04 + 47.04}{3} = 48.384 \text{ m}^3 / \text{day}$$

Digester volume is determined on the basis of the chosen retention time and daily substrate input quantity. The retention time, in turn, is determined by the digesting temperature. Practical experience shows that a retention time is 20 days. For a night soil biogas digester, a longer retention time (20-40 days) is needed so that the pathogens present in human feces are destroyed. Extra-long retention times can increase the gas yield by as much as 40%. Since Wolkite University found in somewhat cold tropical region and to ensure complete degradation of slurry, retention time of 20 days is assumed. There is 672kg weight of moist biomass Dry matter (Dm) of fresh discharged =  $W_{biomass} \times TS = 672 \times 0.2 = 134.4 \text{ kg} / \text{day}$

To make favorable condition for fermentation the concentration of organic dry matter Should be 8% i.e. 8kg Organic dry matter should be available in 100kg influent.

$$8 = 100$$

$$134.4 = x$$

$$X = \frac{134.4 \times 100}{8} = 1680 \text{ kg} / \text{day}$$

$$M_{water} = 1680 \times 672 = 1008 \text{ kg} / \text{day}$$

The density of slurry approximately to  $1000 \text{ kg} / \text{m}^3$ , the volume of daily discharge of substrate is:

$$V_s = m_{slurry} / \text{density slurry} = 1.68 \text{ m}^3 / \text{day} \text{ Hence, volume of digester:}$$

$V_d = S_d \times RT = 1.68 \times 65 = 109.2 \text{ m}^3$  Since the biogas will be stored in pressure vessel outside digester, the volume required for digester can be as small as possible. Therefore, the digester

$$\text{Volume (Vd) is: } = 109.2 - 48.384 = V_d = 60.8 \text{ m}^3$$

### 5.3 Dimension of the Main Parts of the Digester

#### Dimension of mixing pit:

The mixing pit of the digester should have a size slightly greater than the daily input and better if no corners. To calculate the dimensions of the digester cylindrical shape is selected based on its advantage as explained on geometrical shape of digester with retention time of day. The diameter (d) and height (h) of mixing pit are equal (d=h).

$V = \pi d^2 h / 4$ , Where V is t

In addition volume can be written in terms of diameter as follows.

$V = \pi h d^2 / 4 = \pi d^3 / 4$ , solving the diameter (d)

$d = (4 * 1.697 / 3.14)^{1/3} = 1.29 \text{ m}$

Therefore, the mixing height (h) = d = 1.29 m

#### 5.4 Dimension of compensation tank:

The dimension of the compensation tank ( $V_{\text{tank}}$ ) is around 20% of the volume of the Digester (Slurry).  $V_{\text{tank}} = 20\% Gd = 0.20 * 48.38 \text{ m}^3 = 9.67 \text{ m}^3$  = for efficient spaces assume cubic shape with length of 'a' then: the daily substrate flow of the waste after providing 10% safety factor, then

the Volume including safety(V) ,  $V = 10\% V_o + V_o$

$V = (10\% * 1.68 \text{ m}^3 / \text{d}) + 1.68 \text{ m}^3 / \text{d} = 1.697 \text{ m}^3 / \text{d}$

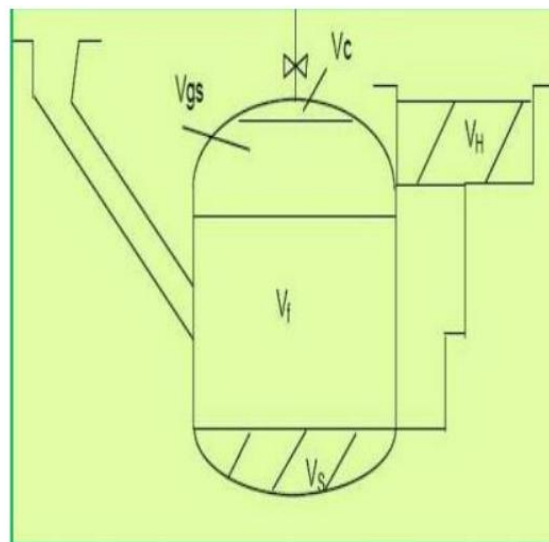


Figure 10 the cross section of digester specifications  
Reference (article or book)

1. Volume of gas collecting chamber at the top layer= $V_c$
  2. Volume of gas storage chamber  $V_{gs}, V_1=V_c+V_{gs}$
  3. Volume of fermentation chamber= $V_f=V_3$
  4. Volume of sludge layer= $V_2$ , slurry volume  $V_2+V_3$
  5.  $R_1$  and  $R_2$  are the crown radius of the upper and the bottom spherical layer of the digester respectively.
  6.  $S_1$  and  $S_2$  are the surface area of the upper and lower dome respectively
  7.  $f_1$  and  $f_2$  are the maximum distance of upper and lower dome Therefore the total volume of the digester ( $V$ ) = $V_c+V_{gs}+V_2+V_3=V_1+V_2+V_3$ , substituting  $V_1=V_c+V_{gs}$
- Geometrical dimensions of the cylindrical shaped biogas digester

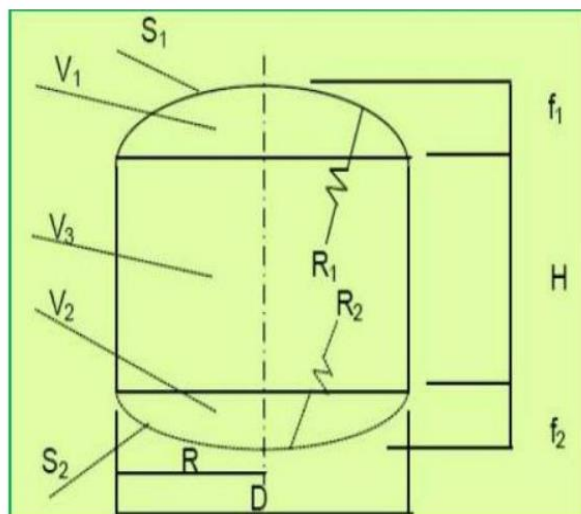


Figure 11 Geometrical dimension of the designed cylindrical fixed dome digester

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

From the above geometrical dimension correlations:

Volume of digester ( $V_D$ ) = $V_3+V_2 = (0.05011+0.3142) D^3=43m^3$  implies

$$D = \sqrt[3]{43/0.364} = 4.9 \text{ m}$$

Therefore, the value of each parameter is calculated by substituting the value of diameter in the above geometrical relation presented in table 4.2 and obtained as

$$V_1=9.72m^3, V_2=5.89m^3, V_3=36.96m^3, V_c=2.65m^3,$$

$$f_1=0.98m, f_2=0.61m,$$

$$S_1=21.87m^2, S_2=20.03m^2,$$

$$R_1=3.55m, R_2=5.21m$$

Then the total volume ( $V$ ) is:

$$V=V_1+V_2+V_3= (9.72+36.96+5.89) m^3=52.57m^3=53m^3$$



T = Temperature of mixture in Kelvin

R =Ideal gas constant

n = number of moles of component

Based on the maximum volume of biogas produced per a day it is possible to find the maximum gas pressure developed in the digester dome. 48.384 m<sup>3</sup> of biogas can be produced per a day. Based on their composition, it is possible to find particular mass of each species & molar number of gas.

Table 10 Night soil base biogas composition (Daisy & Kamaraj , 2018)

Composition	Percentage (%)
Methane	65-66
Carbon dioxide	32-34
Hydrogen sulphide	1
Nitrogen oxide	Trace
Ammonia	Trace

Density=Mass/Volume

$n_{CH_4} = \frac{m_{CH_4}}{M_{CH_4}}$ , but volume of gases is constant which is 48.384m<sup>3</sup>

$m_{CH_4} = 0.668 * 48.384 * 0.655 = 21.169 \text{ kg/day}$

mole= mass/molar waight

$n_{CH_4} = \frac{m_{CH_4}}{M_{CH_4}} = 21.169 / 16.01 = 1322 \text{ Mol/day}$

$m_{CO_2} = \rho_{CO_2} * V_{CO_2} = 1.842 * 48.384 * 0.33 = 29.41 \text{ kg/day}$

$n_{CO_2} = \frac{m_{CO_2}}{M_{CO_2}} = 29.41 / 44.11 = 666.74 \text{ mol/day}$

$m_{H_2S} = \rho_{H_2S} * V_{H_2S} = 1.434 * 48.384 * 0.01 = 0.693 \text{ kg/day}$

$n_{H_2S} = \frac{m_{H_2S}}{M_{H_2S}} = 0.693 / 34.076 = 20.33 \text{ mol/day}$

Table 11 Water vapor pressure at specific temperature

Temp(°C)	Vapor pressure(mmHg)	Temp(°C)	Vapor pressure(mmHg)
-10	2.15	40	55.3
5	4.56	60	149.4
10	6.54	80	355.4
11	9.21	95	655.1
12	10.9	96	658
13	11.34	97	775
14	11.9	98	788
20	12.78	99	1043
25	17.54	100	1078
30	23.8	101	1434.9
35	31.8	110	1489

At 33°C temperature, we can obtain by interpolation

At 30°C P1=31.8mmHg

At 37 °C p2=47.07mmHg

$\Delta T=7^{\circ}C$ ,  $\Delta p=15.27mmHg$

$\Delta T =3^{\circ}C$ .  $\Delta p=x=6.54mmHg$

At 33°C temperature:

Total pressure developed in the gasholder:

$$P_{TOTAL} = P_{CH4} + P_{H2S} + P_{CO2} + P_{H2O}$$

$$P_{total} = 69.34 + 35.12 + 1.07 + 5.11 = 110.64kpa$$

### 5.5 Heat requirement for Bio Digesters

During cold weather digester operation, the mixed-liquor-heating requirements will be Used for temperature rising of the digester. The total amount of energy required for Maintain the mixed-liquor at the desired operating temperature is the sum of:

- (a) Heat losses through the digester walls, roof and floor; and
- (b) Heat required raising the temperature of the digester influent to the desired operating temperature. In order to assess the accuracy of using heat-transfer theory to estimate digester heating requirements, the heating requirement necessary to replace wall, roof and floor losses and to raise the temperature of the raw human waste effluent.

### Design parameters

The following lists are the basic design parameters that have to be met for the proper heating of the human manure in the digester.

Table 12 design parameters of heat calculation.

Operating temperature of digester	33°C
Volume of biogas digester	48.38m <sup>3</sup>
Assume average temperature of human waste	22°C

The total digester heating requirements can be represented by the following equation:

$$Q_1 = Q_T + Q_L \dots \dots \dots (1)$$

Table 13 Calculation of total resistance to heat flow and heat loss

Wall	17.64	0.15	1.7	concrete
Roof	3.13	0.25	1.7	concrete
floor	3.0	0.12	1.279	20 cm stone 15 cm concrete

Where,  $Q_T$  = Rate of heat transfer to raw human influent

$Q_L$  = Rate of heat loss through digester walls, floor and roof

#### A) Calculation of influent heating ( $Q_T$ )

Energy required to heat influent manure to reach the required operating temperature inside the digester was calculated as

$$Q_T = m \cdot C_p \cdot (T_2 - T_1)$$

$m$  = mass of influent added

Current input substrate temperature,  $T_1 = 22^\circ\text{C}$

Operating temperature of dig estate,  $T_2 = 33^\circ\text{C}$

Therefore,  $Q_T = m \cdot C_p \cdot (T_2 - T_1)$

$$= 8992 \times 4.19 \times (33 - 22) = 414441.3\text{J}$$

#### B) Calculation of heat loss ( $Q_L$ )

All heat losses from the digester were assumed to be by conductive heat transfer. The general equation for steady-state one dimension conductive heat transfer is:

$$Q_L = (T_2 - T_1) / R_{\text{TOTAL}}$$

Where,  $R_{\text{Total}}$  = total resistance to heat flow

T3 = ambient temperature

T2= desired digester slurry temperature

Total resistance to heat flow =  $L/(K*A)$

Where, L= Length of path flow

K= Thermal conductivity of the material of the path

A= Area normal to path flow

Resistance to heat flow due to wall,

## 5.6 Pressure drop in a gas pipe

The pressure system of the gas must be controlled whenever designed gas distribution system. Biogas is available at a gauge pressure of about 981pascal in conventional biogas plants and for efficient use in burners and lamps it should be available at the point of use at a pressure of not less than 785-981 Pascal. Due to friction effect when gas flows through pipe there is loss. So properly designed pipe line is one which does not cause pressure drop of more than 196-350 Pascal under any circumstances. For determining the proper size of the pipe line, the gas is considered as incompressible fluid during the flow its density changes to a very small extent. For an incompressible fluid through a pipe:

$Q=VA$  where, Q=the discharge flow rate (m<sup>3</sup> /s)

V=Gas velocity (m/s)

A=cross sectional area (m<sup>2</sup>)

Pressure drop of the gas is computed using Bernoulli's equation

$$\frac{P}{\rho g} + \frac{v^2}{2g} + Z = \text{Cost}$$

Where, p=biogas pressure (N/m<sup>2</sup>) during the production of biogas from food waste

$\rho$ =biogas density (kg/m<sup>3</sup>)

V=biogas velocity (m/s)

g=acceleration due to gravity (m/s<sup>2</sup>) and

Z=head (m)

Bernoulli's theorem essentially states that for an ideal gas flow, the potential energy due to the pressure, plus the kinetic energy due to the velocity of the flow is constant. In practice, with gas flowing through a pipe, Bernoulli's theorem must be modified. An extra term must be added total low for energy loss due to friction in the pipe:

$$\frac{P}{\rho g} + \frac{v^2}{2g} + Z + \Delta f$$

Where,  $hf$  = head loss due to friction

## 5.7 Head Loss

The head loss in a pipe circuit falls into two categories:

- a) That due to viscous resistance extending throughout the total length of the circuit
- b) That due to localized affects such as valves, sudden changes in area of flow and bends. The overall head loss is a combination of both these categories.

A. Head loss in straight pipes. The head loss due to friction in pipes may be obtained by using the Darcy-Weisbach's equation.

$$h_f = fLV^2 / 2gd$$

Where,  $h_f$  = head loss due to friction

$f$  = Friction factor depending upon the surface of the pipe (dimensionless)

$L$  = Length of the pipe in meters

$V$  = Velocity of gas

$d$  = Diameter of pipe

Friction factor for pipe: The value of friction, for smooth pipes, may be obtained by using the following expression:

i. for laminar flow =  $Re \leq 2300$

$$f = 64/Re$$

ii. For turbulent flow =  $Re \geq 2300$

$$f = 0.3164 / 0.25Re^{0.25} = \text{Where, } Re = VD/\gamma$$

$V$  = velocity of gas

$D$  = diameter of pipe

$\gamma$  = kinematics of viscosity

At  $p = 1.013 \text{ bar}$ , and  $T = 300 \text{ K}$  assuming the biogas kinematic viscosity equal to air

$$\gamma = 1.568 \times 10^{-5} \text{ m}^2/\text{s}. \text{ From continuity equation, } Q = AV$$

Eight hours usage time, discharge is  $5.4 \text{ m}^3/\text{hr}$ . (sec)

$$5.4 = 5.07 \times 10^{-4} \times V, V = 2.96 \text{ m/s}$$

$$Re = \frac{0.0254 \times 0.29}{1.568 \times 10^{-5}} = 4794.89$$

$$Re \geq 2300, f = \frac{0.3164}{4.995 \times 10^{0.25}} = 0.038$$

$$H_f = \frac{f \times L \times V^2}{2gd} = \frac{0.038 \times 25 \times 2.96^2}{2 \times 9.81 \times 0.0254} = 16.7 \text{ m}$$

B. Head loss Due to Sudden Changes in Area of Flow

1. Sudden Expansion: The head loss at a sudden expansion is given by:

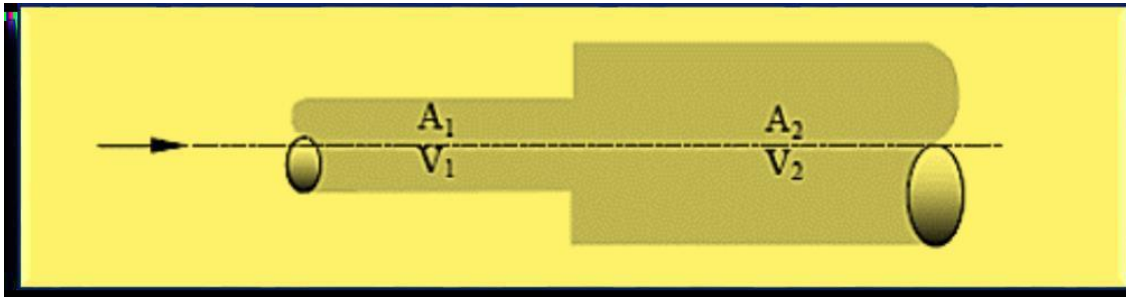


Figure 13 A sudden expansion

$$h_{me} = \frac{V_1^2 - V_2^2}{2g}$$

Where,  $h_{me}$  = minor loss due to expansion

$V_1$  = velocity at cross sectional area 1

$V_2$  = velocity at cross sectional area,  $g$  = gravity

In this design there is no sudden expansion of pipe. Since the main gas pipe is divided in to the appliance gas pipe.

2. Sudden contraction - The head loss at a sudden contraction is given by

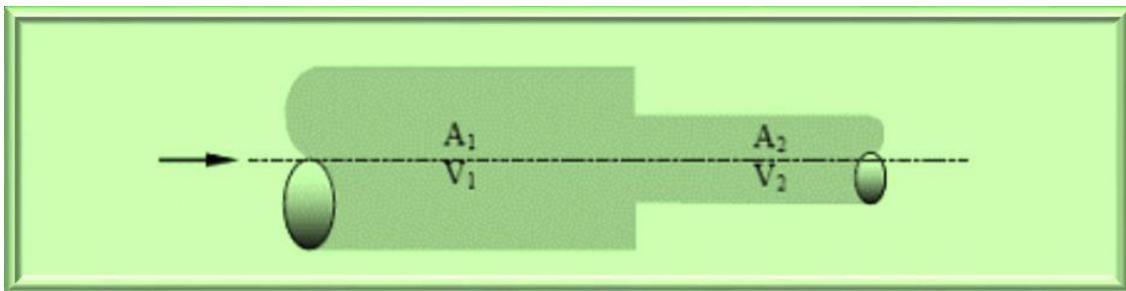


Figure 14 A sudden contraction

$$h_{mc} = \frac{KV_2^2}{2g} \quad \text{Where, } h_{mc} = \text{minor loss due to sudden expansions, } K = \text{loss coefficient}$$

From continuity equation:

$$A_1 V_1 = A_2 V_2$$

By interpolating the value of  $k$  since area ratio is 0.25.

C. Head loss due to Bends

The head loss due to a bend is given by expression. Where,  $h_{mB}$  = minor loss due to bending of pipe,  $KB$  = a dimensionless coefficient which depends on the bend radius/pipe radius ratio and the angle of the bend.  $KB = 0.5$  for elbow connection and considering the average number elbow 20.

$$h_{mb} = \frac{KbV^2}{2g} = \frac{(0.5 \times 2.962)}{2} \times 9.81 = 4.46\text{m}$$

D. Head loss due to Valves

The head loss due to a valve is given by expression

$$h_{mv} = \frac{K_v V^2}{2g} = , h_{mV} = \text{Minor loss due to valve}$$

$K$  = Loss coefficient depends upon the type of valve and degrees of opening

Table 14 Typical values of loss coefficients for gate and globe valves

Valve type	$K_v$
Globe valve fully open	10
Gate valve fully open	0.2
Gate valve half open	5.6

$$h_{mv} = \frac{K_v V^2}{2g} = (0.5 \times 2.962) / 2 \times 9.81 = 4.46\text{m}$$

Total head loss (Hft)

$$h_{ft} = h_f + h_{mE} + h_{mC} + h_{mB} + h_{mV} = 16.7 + 0 + 2.75 + 4.46 + 4.46 = 28.37\text{m}$$

### 5.8 Compression of Biogas

Compressing biogas reduces storage requirements, concentrates energy content, and increases pressure to the level needed to overcome resistance to gas flow. Sometimes the production pressure of a biogas source does not match the pressure requirements of the gas utilization equipment.

Compression can eliminate the mismatch and assurance the efficient operation of the equipment. Moreover; large biogas systems rely on compression to reduce the size of the gas storage facility or to transport the biogas to a pipe line. The choice of either a blower or compressor depends on the amount of pressure increase needed (James L. Waish et al., 1988).

### 5.9 Parameters for Selection of Compressor

In order to determine what type of compressor system is needed to accomplish the job, a variety of detailed data is needed to be discerned.

As a minimum, a precise understanding of the following data is required:

- Gas being handled
- Flow rate
- Suction and discharge pressure
- Site elevation (or local barometric pressure)
- Suction temperature
- Capacity

Capacity: To size a compressor the capacity must be stated as the volume of gas flow at the compressors suction condition. This volume is normally referred to as inlet cubic meters per hour (Nm<sup>3</sup> /hr.).

Calculating Compression ratio

Compression ratio (R) is the ratio of discharge pressure to suction pressure:

$$R = \frac{P_d}{P_s} \quad R_1 = \frac{P_1}{P_s} \quad R_2 = \frac{P_d}{P_s}$$

(Remember  $P_d$  &  $P_s$  must be "absolute" values A single stage compressor has only a single R value. A two stage compressor has three R values.

$R$  = Total compression ratio for the compressor

$R_1$  = Compression ratio for the first stage

$R_2$  = Compression ratio for the second stage

$P_s$  = Suction pressure

$P_d$  = Discharge pressure

$P_i$  = Inter stage pressure- the pressure between the 1st and 2nd stage of the compressor.

### 5.10 Choosing one stage or two stage Compressor

The choice of the proper number of compression stages is largely based on the compression Ratio: Here are some guidelines for choosing the proper number of stages:

Table 15 Compression ratio vs. Proper number of Stages (Source: NPC, 2018)

R value	No, Of stages
1-3	Single stage
3-5	Single stage occasionally two stage
5-7	Single stage occasionally single stage
7-10	Two stage
10-15	Usually two stage occasionally three stages
15+	Three stages

In this work, the Compressor fulfills the following criteria may be select from catalogue for Compression purpose.

- ◆ The gas being handled is biogas
- ◆ Flow rate = 120 .96m<sup>3</sup> /hr. for compressor selected from catalogue
- ◆ Suction pressure: The pressure at the compressor inlet expressed  $P_s = 1.106$  bar
- ◆ Discharge pressure: The pressure at the compressor discharge expressed  $P_d = 11$  bar

Suction temperature =33°C Power =11kW

$$R = \frac{P_d}{P_s} P_s = 1.106 \text{ bar} + 1.013 \text{ bar} = 2.12 \text{ bar-a}$$

$$P_d = 11 \text{ bar} + 1.013 \text{ bar} = 12.013 \text{ bar-a}$$

$$R = 12.013 / 2.12 = 5.67$$

### 5.11 Energy Density and Storage Volume

As biogas is compressed to higher pressures, its mass is pushed into smaller volume. This raises the energy density of the gas and reduces the required storage volume. Note that the energy densities are much higher for biogas that has the H<sub>2</sub>S, CO<sub>2</sub> and water vapor removed (100% methane). The higher compression ratio, the costs associated with compressing biogas will increase. For adiabatic compression, with no heat transfer across the system boundary ( $Q = 0$ ), the thermodynamic relation is given by (W.Z.Black & J.G.Hartley, 1995):

$$P_1 V_1^k = P_2 V_2^k$$

Where,  $k$  = adiabatic ratio = for bio gas

$V_1$  = Initial volume of biogas that the plant produces per day.

$P_2$  = Compressed raw biogas pressure (11 bar) selected from catalogue

$V_2$  = Compressed volume substituting the values

$V_1 = 43.2 \text{ m}^3 / \text{day}$ ,  $P_1 = 110.64 \text{ kpa}$ ,  $P_2 = 1100 \text{ kpa}$ ,  $V_2$ ?

$K = C_p / C_v = 1.3$  for bio gas  $P_1 V_1^k = P_2 V_2^k$

$$110.62 * 43.2^{1.3} = 1100 * V_2^{1.3}$$

$$V_2 = 7.38 \text{ m}^3 / \text{day}$$

### 5.12 Power Needed for Compression

The energy required for compression represents a major operating cost of a biogas system. Accordingly, estimating the energy requirement becomes an important component of the system design effort. Estimates are usually based on adiabatic compression process (compression without cooling) since such a calculation estimates the maximum energy required for compression in a frictionless compressor (James L.Waish et al., 1998). Mathematically, the relationship between the system pressures, the compressor capacity, and the energy required for compression in a Frictionless, adiabatic compressor can be stated as:

$$W = C_1 R T_1 \left\{ \left( \frac{P_2}{P_1} \right)^{C_2} - 1 \right\}$$

Where,  $W$  = Shaft work required for compression (horsepower)

$$C_1 = \frac{K}{K-1}, C_2 = \frac{K-1}{K}$$

$K$  = Ratio of specific heats of the biogas  $k = C_p/C_v = 1.3$  for biogas

$R$  = Gas constant for the biogas

$T_1$  = Initial (suction) temperature (K) = 33°C = 306.15k

$P_1$  = Initial (suction) pressure (kpa) = 110.6kpa

$P_2$  = Final (discharge) pressure (kpa) Values for 60% CH<sub>4</sub>, 40%CO<sub>2</sub> biogas = 1100kpa

(From catalogue

$$W = 1.3/(1.3-1) \cdot 8314.3 \cdot 306.15 \left\{ \left( \frac{11}{1.106} \right)^{1/(1.3-1)} - 1 \right\} = 7.71 \cdot 10^3 \text{ kJ/kg}$$

The value of “ $W$ ” represents the amount of energy required to compress biogas of a known composition adiabatically. However, compressors are never 100% efficient because of friction and heat transfer that occur during the compression process and therefore the actual energy required will be greater than computed using the preceding equation. It should be noted that manufacturers’ literature will indicate different efficiencies for almost every compressor. Confusion can be avoided by asking the manufacturer of the compressor being analyzed for the actual energy consumption of the equipment.

## CHAPTER SIX

### Economic and financial analysis of biogas

Biogas is a renewable energy which is eco-friendly and minimizes expenditure on the foreign exchanges on the import of fossil fuels. The primary reason that biogas plant is not yet used for households is due to lack of awareness and availability of resources such as firewood, Charcoal, Kerosene, Electricity and etc. even though they are expensive. Any decision for or against the construction and operation of a biogas plant depends on various technical criteria as well as on a number of economic and utility factors. Users want to know what the plant will offer in the way of profits (cost benefit analysis) and advantages like reduced work load, more reliable energy supplies or improved health.

#### 6.1 Determining Biogas demand

There are different approaches to estimate gas demand for cooking. The following alternative methods of calculation are useful (GTZ, 1989).

A. Determining biogas demand on the basis of present consumption:

This involves measuring the present rate of energy consumption in the form of Fire Wood Charcoal, Kerosene, and Electricity etc. Basic data: Assume for five person family size

Table 16 Present energy consumption (Source: field survey, 2018)

Source of energy	Monthly fuel consumption	
	Unit	Price (averagely) in birr
Fire wood	(30-50) kg	60
Charcoal	(40-80) kg	150
Kerosene	(8-10) m3	180
Electricity	-	85
Total = Birr 475		

Equivalence of biogas demand The equivalent demand of biogas can be determined using the following factors for the fuel to be substitute.

1 kg of Fire Wood = 0.2m<sup>3</sup> biogas  
1 kg of Charcoal = 0.5m<sup>3</sup> biogas  
0.6liter of kerosene=1m<sup>3</sup> biogas (Source: GTZ, 1989)

Hence, the biogas to be produced 48.2m<sup>3</sup> per day can serve the cooking energy requirement for student's cafeteria per day .This indicates that the substrate collected from the 12 blocks can serve the cooking energy requirements for student's cafeteria. Construction of Materials and their Costs after asking many experienced people those who are working in Rural Energy Development and promotion Center of Ethiopia, the costs for constructing the proposed design (i.e.96m<sup>3</sup> ) biogas plant may be estimated as follows.

Table 17 Requirement and cost for constructing the proposed design based on current price

No	Requirement	quantity	Price in birr		Total price
			Unit price		
1	Digging operation	109.2 m3	28		3058
2	Cement bags	150	350		52500
3	Gravel	45m3	400		15800
4	Rigid plastic pipe	20m	75		1500
5	Gas pipe	250 length & ½ " Diameter	50		2500
6	Main gas pipe (galvanized steel)	1" diameter and 20m	75		1500
7	Gas valve & Connector	00pcs	80		800
8	Mold/cast	5m3	3200		48000
9	Paint	12 gal	420		5040
10	Brick	1250	2.5		31250
11	Mason	4 persons 60 days	150		36000
12	Installation work	2 persons 14 days	150		4200
13	Biogas stove	10	500		5000
14	Biogas burner	10	100		1000
15	Biogas compressor	1	20000		20000
	Total birr				230,348
	Contingency%				11,498.5
	Total money in birr				241,848.5

## 6.2 Financial Analysis

Projects are assumed to be economically feasible if the Net Present Value (NPV) is positive, the internal rate of return (IRR) is  $\geq 20\%$  and a payback period of  $\leq 7$  years (Government of Georgia,2018).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. For example, it is difficult to put a money value for the benefit of decrease environmental population. This indicates that even if the financial analysis shows zero net benefit of constructing a biogas plant, it should be interpreted as having positive net benefits owing to the un priced factors. 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:

$$B_a = B_{ab} + B_{af} - C_a$$

Where,  $B_a$  = Annual benefit

$B_{ab}$  = Annual benefit from biogas

$B_{af}$  = Annual benefit from organic fertilizer

$C_a$  = Annual cost Organic Fertilizer

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

$O_m = L_a - C_b$  Where,  $O_m$  = Organic matter gets out from digester

$L_a$  = Loaded amount of substrate

$C_b$  = Organic matter converted in to biogas

$$O_m = L_a - C_b = 0.2 \times 672 \times 30 \times 12 - 0.15 \times 672 \times 30 \times 12 = 12096 \text{ kg per year}$$

Manufactured fertilizer of the lowest price available in the local markets is Urea fertilizer which sales to farmer by about 900 Birr per 100kg .By selling the organic matter gets out of the digester by 5% Urea price, and then the price of 900kg:

$$O_{fp}=0.05 \times 900 \times 9 \times 12 = \text{Birr } 4860 \text{ per year}$$

### Annual Cost

Annual cost for operating a biogas plant may come from replacing some used equipment (mainly gas valve, gas transporting pipe and etc.), i.e. is maintenance cost & operational cost. The main operational cost is the cost of compressor power for the system. The power required for compressor is 11Kw for selected compressor. If this compressor is operates for 24 hour, it will come 264kWh. This amount of energy has provided from Ethiopia Electric Light and Power Authority (EPCO) or the plant itself. We know that 1 m<sup>3</sup> biogas can generate 1.25kilowatthours of electricity (Table 6.2). Hence in terms of electricity 1m<sup>3</sup> biogas generates 1.25kwhrs of electricity, so that 48.2m<sup>3</sup> biogas can generate 54kwhrs of electricity. Then in 24hrs can generate 1296kw of electricity. To use the power obtained from the plant, it needs a lot of preliminary things which lead us to additional cost due to raw biogas, is not ready use.

Therefore, it is better to use the power of EPCO. Currently, EPCO charges for power as follows:

- a) For less than 50 kWh it charges 0.273 Birr/kWh
- b) 50 to 100 kWh it charges 0.354 Birr/kWh
- c) For greater than 100 kWh it charges 0.4993 Birr/kWh accordingly:

$$C_{op} = 264 \times 30 \times 12 \times 0.4993 = \text{Birr } 47,453.472 \text{ per year}$$

As the result, the annual income:

$B_a = B_{ab} + B_{af} - C_a$  Where,  $B_{ab} = \text{Birr } 184,800$  for 40 households from saving of charcoal, Fire wood, electricity and kerosene from table 5.4

Annual cost ( $C_a$ ) = maintenance cost +operational cost

$$= 47,453 + 20,967 = \text{Birr } 68,420 \text{ (Table 5.4)}$$

$$B_a = 184,800 + 4,795 - 68,420$$

$$B_a = \text{Birr } 121,175$$

### 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.

### **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.

Simple Payback Period Simple payback period is time period required to recover the original investment 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:

$$Spp = I_c / A_s$$

Where,  $S_{PP}$  = Simple payback period

$I_c$  = Initial cost

$A_s$  = Annual saving (benefits)

### **6.3 Economic Analysis**

Some of benefits and costs of biogas plants are not limited to the users (student's cafeteria) but also some communities those live in the compass. If a large number of biogas plants are installed in Wolkite University, the non-users will also be benefited avoidance of environmental pollution and conservation of forest in area. Such benefits and costs that increase even outside of the user is a subject matter of economic analysis and not of financial analysis. A single biogas plant does not significantly affect the economy as a whole. Economic analysis measures the effect of biogas Program me on the fundamental objectives of the whole economy. For example,

Table 18 Financial analysis of a 109 m3 biogas plant (in Birr) for an assumed 40 households

Year	1	2	3	4	5 to 15
Benefits in birr indirect priced saving charcoal	60,600	60,600	60,600	60,600	60,600
Saving fire wood	26,000	26,000	26,000	26,000	26,000
Saving kerosene	65,8000	65,8000	65,8000	65,8000	65,8000
Saving electricity	34,400	34,400	34,400	34,400	34,400
Selling organic fertilizer	5,795	5,795	5,795	5,795	5,795
Total	196,595	196,595	196,595	196,595	196,595

The net present value, benefit cost ratio and simple payback period are given as follows.

1. The present costs during the lifetime of the project: - is determined by

$$P_c = I_c + A(p/A, r, n)$$

$I_c$  = initial cost = 241,846.5 from table 5.4

$A$  = Annual Cost = maintenance cost + operational cost = 68,420

$$P_c = I_c + A(p/A, r, n)$$

$r$  = discount rate

$$P_c = 241,846.5 + 68,420 = 12\%$$

$$P_c = \dots \text{Birr } 707,858.78$$

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

$$P_b = A \frac{(1+r)^n - 1}{(1+r)^n}$$

Where,  $A$  = Annual benefits

$P_b$  = Total benefits during the life time of the project

$$P_b = 1339019$$

4) The Net Present Value (NPV):-

Cumulative discounted cash position at the end of the project.

It is determined by  $NPV = P_b - P_c$

The annual saving is:  $A_s = A_b - A_c = 189,595 - 68,420 = \text{Birr } 121,175$

5) The simplest payback period

$(spp) = I_c / A_s = 241846.5 / 121175 = 2 \text{ year}$

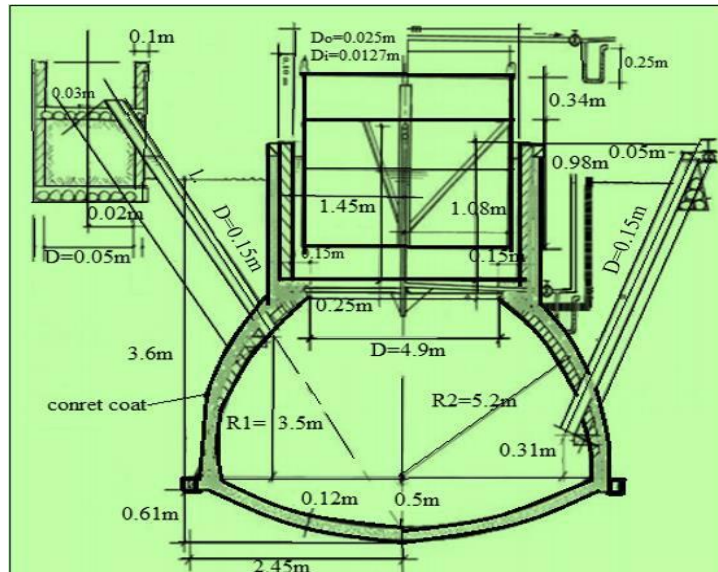


Figure 15 Final Drawing sheet of fixed dome plan

#### 6.4 Environmental impact of biogas

Energy demand must be managed to cope not only with energy but with environmental problems, as well. The energy production from renewable sources is one of the main issues to reduce environmental damage and greenhouse gases emissions, as climate agreements encourage non fossil fuel use in the future. Landfill gas is a flammable and potentially harmful gaseous mixture consisting mainly of  $CH_4$  and  $CO_2$  with trace amounts of volatile organic compounds. The air quality deterioration derived from LFG can be controlled by combustion (gas turbines) and chemical cleaning (Borjesson and Berglund, 2006). While methane is a very promising energy resource, the non-methane components of biogas (hydrogen sulfide, carbon dioxide, and water vapor) tend to inhibit methane production and, with the exception of the water vapor, are harmful to humans and/or the environment. For these reasons, the biogas produced should be properly “cleaned” 25 using appropriate scrubbing and separation techniques. In addition, the methane itself represents a serious danger, as it is odorless, colorless, and

difficult to detect. Methane is also highly explosive if allowed to come into contact with atmospheric air at proportions of 6 to 15 percent methane. For these reasons, it is recommended that buildings be well ventilated; and alarms and gas-detection devices should be used.

# CHAPTER SEVEN

## Conclusion and recommendation

### 7.1 Conclusion

From the result of experiments carried out and from the simulation developed, there is a clear indication that food waste could contribute a substantial potential as source of energy biogas. The anaerobic digester had a hydraulic retention time of 25 days and operated at 47<sup>0</sup>C, which was at termoophylic conditions. From the simulation, it was observed that a total of 93.187kg/day biogas is produced from a feed rate of 497.882kg/day. The biogas yield was optimized by mixing food waste with water in 1:4 ratios and by introducing cow dung as inoculant. Carefully controlling of the operation parameters (Temperature, pH, types of substrate, HRT, anaerobic environment) of the anaerobic digester optimizes the biogas yield. To conclude as the payback period of the biogas plant is low, this project is economically feasible.

### 7.2 Recommendation

Wolkite University shall give an emphasize in this project and implement it as it has many advantages such as source of energy, environmental safety, erecting of the biogas plant is cheap. Before processing food waste in an anaerobic digester, pretreatment options such as sorting, drying and heating to enhance the performance of the digestion process should be evaluated. In addition, the anaerobic digestion should be run under conditions suitable for methanogenesis to increase the methane concentration in the produced biogas.

- ❖ The digestate should be further studied.
- ❖ The amount of biogas produced shall be upgraded if one wants to use the biogas for the application of electricity generation. .
- ❖ There should be a serious need for proper collection, and characterization of food waste and investigating their potential as source of renewable energy in all Ethiopian Universities

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## APPENDIX

### Appendix A: Composition of biogas

Component	Concentration(by volume)
Methane (CH <sub>4</sub> )	55-60 %
Carbon dioxide (CO <sub>2</sub> )	35-40 %
Water (H <sub>2</sub> O)	2-7 %
Hydrogen sulphide (H <sub>2</sub> S)	20-20,000 ppm (2%)
Ammonia (NH <sub>3</sub> )	0-0.05 %
Nitrogen (N)	0-2 %
Oxygen (O <sub>2</sub> )	0-2 %
Hydrogen (H)	0-1 %

### Appendix B: calculations

#### CO<sub>2</sub> subscriber capacity:

$(2.5 \text{ g CO}_2/1 \text{ kg H}_2\text{O}) * (1\text{mol CO}_2/12 \text{ g CO}_2) * 22 \text{ L CO}_2 /1\text{mol CO}_2) * (0.264 \text{ gal}/1 \text{ L})$   
 $= 1.21 \text{ gal}/\text{kg H}_2\text{O}$   $(1.21\text{gal} /\text{kg H}_2\text{O}) * (10\text{gal}/\text{feed}) * 0.4\% \text{ CO}_2 = 4.84\text{gal}/\text{feed}$   
 $(4.84 \text{ gal}/\text{feed}) / (1.21\text{gal}/\text{kgH}_2\text{O}) * 4 \text{ kg H}_2\text{O required for feed} = 4 \text{ kg H}_2\text{O} * (1\text{L}/1\text{kg}) * 0.264 \text{ gal}/1\text{L} = 1.05\text{gal}/\text{feed}$

A three gallon scrubber would require the water to be changed roughly every three feeds

#### BTU Calculation:

$(11\text{b}/ \text{H}_2\text{O}) * (T_2 - T_1)F = \text{BTU}/\text{gallon}$   $6.6\text{lb H}_2\text{O} * 22.4 \text{ degrees F} = 24.64 \text{ BTU}/\text{gallon}$   
 This yield is roughly 1/3 the amount of BTU we should expect from a gallon of biogas.

#### Potential Methane yield

$(20\text{m}^3 \text{ gas}/1\text{Tonne}) * (1\text{Tonne}/2204.62\text{lbs}) * (10\text{lbs}/\text{feed}) * (1\text{gal}/0.379 \text{ m}^3) = 24\text{gal}/\text{feed}$

### Appendices C: calculation on physicochemical characteristic

#### Total solid

First 100g of food waste was measured and allowed to be dried at 105 0C. After dried the mass of the sample with the crucible became 390.49g. So, the amount of dry sample became 40g.

Initial weight= 100g, Mass of crucible=304g, Mass of crucible and wet sample (initial weight) = 146g, Mass of crucible and dry

Sample = 86g. TS%= (mass of dry sample and crucible– mass of crucible)/initial weight

TS%= (390.49-300.49)/100 \* 100 = 90%, Hence, 90% of the sample was total solid and the remaining 10% was water.

### **Moisture content**

Moisture content = 100 – TS% = 60% 100-90.49 = 9.51

### **Volatile solid**

The amount of total solid gained was allowed to dry at 550 0C in furnace for 4 hours. After dried it was measured and allowed it to be cooled at heat sucker. Hence, the organic content left or the volatile solid and the ash were calculated as follows:

Total solid= 90g=V1, Mass of crucible= 300.49= V0

Mass of ash and crucible =326.3= V3,

Mass of crucible and total solid=390.49g=V2

Volatile solid= (V2 – V3)/V1\*100=71.38% of the total solid is organic.

### **Fixed solid**

The amount of mass obtained after ignition became; % fixed solid= 100 – VS %, %FS= 19.13%