JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

THERMAL SYSTEM ENGINEERING STREAM

Design of Biogas Plant for Injera Baking Stove Using Food Waste as Feedstock

(A Case Study of Assosa University)

A Thesis Submitted To the School of Graduate Studies of Jimma Institute of Technology in Partial Fulfillment of the Requirements for Award of Degree of Masters in Thermal System Engineering

By: Siraj Mohammed

Advisor: Balewgize A.Zeru (Asst.prof)

Co-advisor: Desta Goitem (Ass .Proff)

February 2020

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DECLARATION

I declare that this thesis entitled **“Design of Biogas Plant for Injera Baking Stove Using Food Waste as Feedstock”** is my original work done at Jimma Institute of Technology during the year 2019 as part of Master of Science degree in Thermal System Engineering and has not been presented for a degree in any other university.

Student: Siraj Mohammed	………………	………………..
Name	Signature	Date

CERTIFICATE

We certify that the thesis entitled “**Design of Biogas Plant for Injera Baking Stove Using Food Waste as Feedstock”** was done by Siraj mohammed.

Venkata Ramaya (proff)	………………	……………….
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Jimma University

Jimma Institute Of Technology

Faculty Of Mechanical Engineering

Thermal System Engineering Stream

Approval sheet

As a member of the Examination Board of the final Master of science open defense, we certify that we have read and evaluated the thesis that is prepared by Siraj mohammed entitled "**Design of Biogas Plant for Injera Baking Stove Using Food Waste as Feedstock" .**

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ABSTRACT

In rural communities and Ethiopian university, wood is the most sources of fuel for baking injera and cooking. The burning of wood in open fires is causing a number of health problems but is also deteriorating for the rural household economy as well as for the local and global environment. When looking for sustainable energy systems that are environmentally friendly, clean and versatile, Biogas plays a significant role. Moreover, converting food waste into Biogas helps to generate energy and reduce greenhouse gas emission by avoiding food waste from going to landfill since methane is a greenhouse gas, if it is not properly handled, can create global warming and cause health problem. Women and children are the main groups exposed to indoor smoke produced while cooking. The overall aim of this thesis project is to use biogas stove burner injera baking, to avoid the problems that are caused due to burning of fossil fuels and to assure the environmental sustainability.

Injera is the staple bread in Ethiopia; almost all Ethiopian people on a daily basis perhaps consume it.Current number of student found in Assosa university those use the ASU cafeteria are around 6000, as the result of such increment, high amount of food wastes from cafeteria and kitchen can be collected. Collecting data have been made using interview and direct measurement of the waste using balance, meter, and different literatures. The food waste and water were mixed in a ratio of 1 to 4 to optimize the biogas yield. The appropriate amount of waste and total influent per day that delivered from the cafeteria was 1100kg per day, 5500 kg respectively. Then after analyzing the data the digester, which has volume capacity 148.25 m3, and 110 m3 per day total biogas produced, energy that can be produced from the biogas 715.5 kWh of power of per day.

From the performance evaluation made the gas generated per day from food waste the potential of the biogas in reducing firewood dependence of Injera baking process can be evaluated. Biogas stove having a gas consumption rating of 0.5083m3/h for baking was designed for Injera baking. So amout of gas generated 110m3 per day from food waste can bake 2536 of injeras and 788.5kg/day wood was saved, wich is 21% of wood consumed per day , wood saved was approximated ETB 945960 per year and amount GHGs emitted to the environmental saved by using biogas stove was 25444475.5kg/annuam. Biogas burner was analytically designed.In addition, the total investment cost of the plant 541839ETB, and the payback period of the plant is 0.57 years for baking of injera. and the total installed cost could be analyzed.

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Finally, I would like to pass my heartfelt gratitude to my family and wife for their support and encouragement for the successful completion.

CONTENTS

LIST OF FIGURE

LIST OF TABLE

NOMENCLATURE

Symbol

A	Area
A_P	Area of the port
CFD	Computational Fluid Dynamics
CH4	Methane
CO2	Carbon Dioxide
Cp	Specific heat
d	Diameter
DP	Diameter of Each Port in m
E	Energy
ETB	Ethiopian currency
FS	The Fixed Solids
H2S	Hydrogen Sulfide
HRT	Hydraulic Retention Time
K	Kelvin
LSL	Lower Slurry Level
m	Mass
MSW	Municipal Solid Waste
NBP	National Biogas Program
Np	Number of Ports
OLR	Organic Loading Rate
Q	Heat transfer
Re	Reynolds number
t	Time
T	Temperature
TS	Total Solids Content

V	Velocity
VFA	Volatile fatty acids
VS	Volatile Solid
Mm	Viscosity of Mixture

Greek letters

μ	Viscosity
ρ	Density
ρ_m	Density of The Mixture

Subscripts

s	surface
amb	Ambient

Geez words

Injera	an Ethiopian traditional bread
Mitad	Ethiopian cooking appliance
Teff	Ethiopian grain

CHAPTER ONE

INTRODUCTION

1.1 Background

In today's fast-growing world, the rate of accumulation of waste is rising at an unexpected rate. As urbanization proceeds to take place, the 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.

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 [1].

Biological wastes mainly consist of high levels of cellulose, lipids, starch, proteins that are a good alternative for the technological production of energy without having influence with the fast-growing need for the world's consumption of food supply. An important step towards a sustainable waste management system is to augment the waste reduction, reuse and recycle fashion with technologies that actually reduce solid waste accumulation. 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 [1].

The anaerobic digestion of organic matter consisting of three main phases which are hydrolysis, acidogenesis, and methanogenesis. It should be noted as well that acetogenesis also take place in the digestion, just not as critical as the three main processes. In each of the processes, a specific group of microorganisms are involved. These organisms are commensal in relation, which means there are in need of each other for the breaking down and conversion of the product of the previous microbe.

The first process is hydrolysis. Hydrolysis is the process of breaking down large and complex feedstock molecules into smaller and simpler structures. This process is done by facultative aerobic bacteria which uses oxygen in the feedstock and water and the function equally well both in the presence and absence of oxygen. Hydrolysis usually takes place at a temperature around 37 °C. During hydrolysis, polymers such as carbohydrates, lipids, protein, and nucleic acids are broken down into mono and oligomers like glucose, glycerol, pyridines, and purines. Hydrolytic microorganisms excrete hydrolytic enzymes, converting biopolymers into simpler and soluble compounds [2]. The second step of the process is acidogenesis. This process is basically similar to fermentation and even uses similar types of microbes.

The acidogenic bacteria converts the monomers and oligomers into acetic acid, hydrogen and carbon dioxide. Another respiration pathway is the conversion of simple sugars, amino acids, and fatty acids into volatile fatty acids and alcohols which will, later on, undergo acetogenesis and converted into acetic acid. Volatile fatty acids (VFA) such as butyric acid and propionic as well as acetic acid are methanogenic substrates. After acidogenesis, acetogenesis takes place, where products from acidogenesis which cannot be directly converted into methane by methanogenic bacteria's will be converted into methanogenic substrates. VFA and alcohols are oxidized to become acetate, hydrogen and carbon dioxide. Along with acidogenesis, the production of hydrogen becomes high and this will cause the partial pressure of hydrogen to increase [3].

Hydrogen can be considered as a waste product of acetogenesis and it inhibits the metabolism of acetogenic bacteria. During methanogenesis, hydrogen is converted into methane and that reduces the partial pressure of hydrogen and no longer inhibits the acetogenic process. Acetogenesis and methanogenesis usually runs parallel as symbiosis of one another.

Finally, methanogenesis converts methanogenic substrates into methane via two pathways. First, acetic acid is converted into methane and carbon dioxide. The other pathway is the conversion of hydrogen together with carbon dioxide producing methane and water. Methanogenesis is the most critical step in the entire anaerobic digestion process as it is the slowest biochemical reaction of the process. Not to mention, the microorganisms involved are very sensitive thus, its performance is severely influenced by operating conditions. Temperature, pH, feeding rate and composition of feedstock are just some of the factors that must be monitored closely. Organic overloading, pH fluctuations, and oxygen entry may terminate the generation of methane all together [2].

Biogas is a renewable energy source that can be harvested from organic wastes like food waste. Biogas consists mainly of methane (CH4) and carbon dioxide (CO2) and it can be utilized as a renewable energy source in combined heat and power plants, as a vehicle fuel, or as a substitute for natural gas. This energy release allows biogas to be used as a fuel; it can be used for any heating purpose such as cooking. It can also be used in a gas engine to convert the energy in the gas into electricity and heat. The methane in the biogas can also be utilized in industrial processes and as a raw material in the industry. Production and utilization of biogas has several environmental advantages such as:

- It is a renewable energy source. ·
- It reduces the release of methane to the atmosphere compared to e.g. traditional manure management or landfills.
- It can be used as a substitute for fossil fuels. ·
- A high-quality digestate that can be used as a fertilizer is produced simultaneously with biogas.

Waste

The utilization of new renewable energy sources such as biogas to decrease our dependence on fossil fuels has been an important goal worldwide during the past years. The composition of biogas strongly deviates from that of standard natural gas, which results in a low caloric value of biogas [4].

Biogas produced from anaerobic digestion often has high amounts of sulfur, which is what causes an uncomfortable smell. This is only very problematic if the intent is to use the biogas in a fuel cell because the sulfur will poison the fuel cell. There are sulfur scrubbers available to remove the sulfur if the intent is to use the biogas in a fuel cell, but this adds significantly to cost. If the gas is just to be burned as cooking fuel or in a generator, then sulfur production is not necessarily a problem [5].

1.2 Biogas in Ethiopia

Biogas was first introduced in Ethiopia by Ambo Agricultural College around 1957 to supply the energy for welding agricultural tools. During the 1970s, two biogas plants were introduced by the Food and Agriculture Organization (FAO) as pilot projects to promote the technology. During the last two decades, around 1000 biogas plants were deployed in Ethiopia with sizes ranging between 2.5 and 200m3 for households, communities, and insti- tuitions. During this period, different models were used (e.g. fixed-dome, Indian floating-drum and bag digesters). However, there are no multiple consultants across local capacity to up-scale the technology nor sustains it. Hence, just 40% of the aforementioned biodigesters are still operational [6].

1.3 Biogas Stove

The people in Ethiopia rely on Injera as their primary source of food. Injera is a flatbread made from Teff that is baked upon a griddle, which is most often heated by means of an open wood fire. Baking Injera both accounts for over 50% of all primary energy consumption and 75% of all household energy consumption. Due to the shortage of firewood in growing Ethiopian communities, baking Injera on open fire is becoming increasingly expensive. Women and young children have to walk many miles a day to collect firewood to feed their families [7].

The use of biogas for cooking and heating begins with an efficient stove. Biogas stoves are relatively simple appliances, which can be manufactured by local blacksmiths or metalworkers. Stoves may be constructed from mild steel or clay. Clay burners are widely used in China and their performances have been satisfactory [8].

By buying fuel-efficient stoves, commercial clients and households can reduce their firewood consumption by approximately 60% and make a considerable saving on their financial budget. At the current market prices, the fuel-efficient stoves have a payback time between 2 and 3 months for an average household family [7].

1.4 Statement of the Problems

Our country is facing a big problem with the accumulation of food waste released from cafeterias and other sectors. Especially, there is a huge accumulation of food waste in the Ethiopian universities. Assosa University, which is one of the Ethiopian universities, contributes a lot to this phenomenon. There is a huge discharge of food waste as the university contains many students that consume their food in the provided cafeteria. The food leftover in the cafeteria is causing major environmental and health problems, starting from the bad smell that influences the health of human beings to the serious environmental problems causing by the releasing of greenhouse gases. In addition to that, the land of university is filling with food waste and the university is investing more money to sanitize the environment.

Biomass combustion in cafeteria for Injera baking purpose using traditional three-stone fireplace that lacks any provision for smoke exhaust exposes particularly women to smoke containing harmful products. Prolonged exposure to smoke is responsible for coughing, wheezing, acute respiratory infection, chronic obstructive lung disease, adverse pregnancy outcomes, and lung cancer. In addition, using firewood affects human and environment

The best option to alleviate this problem could be to find sustainable remedy such that to transform all those food waste to biogas energy and replacing biomass energy for baking of Injera.

The figures below illustrate how much wood is accommodated in the cafeteria area and the smoke that is out from the kitchen.

Figure 1: Assosa campus cafeteria kitchen while baking injera from firewood

Figure 2: Food and kitchen waste removal in Assosa campus cafeteria.

1.3 Objectives

1.3.1 General Objectives

The main objective of this research work is the design of biogas digester for the Injera baking stove by using food waste in the Assosa University cafeteria in replacement of biomass firewood.

1.3.2 Specific Objectives

The specific objectives of this research are the following

- To determine the biogas energy generated from biomass or food waste available.
- To design the biodigester using the resource obtained from food waste.
- To design and size gasholder.
- To calculate the amount of energy saved by using gas generated.
- To design the stove burner for injera baking process.
- To analysis the cost of the biogas plant systems.

1.4 Significance of the Study

Assosa University will gain and was an environmentally friendly alternate energy source for Injera baking utilities and used as energy source emplace of biomass. Assosa university cafeteria will get reliable energy source for baking after successful completion of the research and implementation of the result.

1.5 Scope of the Study

The study will be conducted considering the food wastes that will be collected from the Main Cafeteria and cooking kitchen. It will be conducted Analytical design.

1.6 Methodology

Identifying this problem is very important for the university as well as for the community especially for hotels, rural areas, and some other campuses. After identifying the problem important to the design and installation of the biogas digester stove. The technical information obtained from the currently existing biogas digester, journals, websites, and other related sources. In the conceptual design phase, possible solutions and one winning solution would pass for further design step and the process continues until the optimum solution obtained.

A generic design methodology shown in the flow chart provided below.

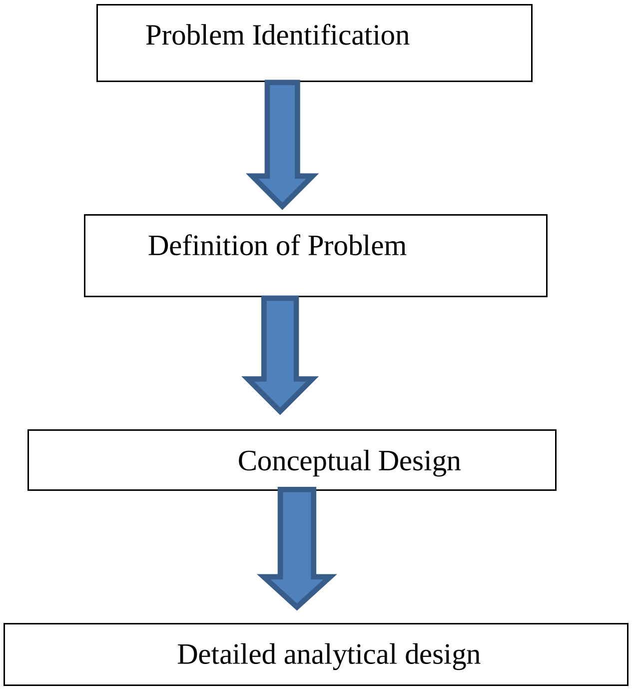

Figure 3: The hierarchy flow of methodology

CHAPTER TWO

LITERATURE REVIEW

There are suggestions that biogas used for heating bath water in Assyria as long ago as the 10th century B.C. and that anaerobic digestion of solid waste may well have been applied in ancient China. However, well-documented attempts to harness the anaerobic digestion of biomass by humans date from the mid-nineteenth century, when digesters were constructed in New Zealand and India, with a sewage sludge digester built-in, UK to fuel street lamps in the 1890s [9].

Biogas technology was introduced in Ethiopia as early as 1979 when the first batch type digester was constructed at the Ambo Agricultural College. In the last two and half decades around 1000 biogas plants, ranging in size from 2.5 m^3 to 200 m^3 were constructed in households, communities, and governmental institutions in various parts of the country. Up to 2008, approximately 40% of the biogas plants that were constructed are not operational due to a lack of effective management and follow-up, technical problems, loss of interest, reduced animal holdings, leave of ownership, water problems, etc [10].

2.1 Biogas

Biogas is derived from landfills, agricultural wastes and other sources of biomass. Thus, it is an environmentally- friendly renewable fuel. Biogas is mainly composed of methane (CH4) and carbon dioxide (CO2), with smaller amounts of oxygen, nitrogen and volatile organic compounds. Depending on the source of biogas, the fraction of CO2 present in biogas ranges from 30% to 60% by volume [11].

Biogas was produced when certain microorganisms digest organic matter in the absence of oxygen to become biogas, which mainly consist of methane, carbon dioxide, and other inertly available gases. Biogas production has four key components that are feedstock, microorganisms, environmental control, and reactor configuration or technological design [12].

There are several types of biogas stoves in use across the world. It is very easy to utilize biogas for direct combustion but for cooking purposes. Those can be utilized in a natural gas burner with some modification, i.e. orifice enlargement and intake air restriction, with attendant modification of the fuel delivery and control system .Since 1989 biogas burns in a clean way so no harmful gas is released during combustion and two-flame burners are the most popular type [13].

I.Itodo.et al (2007) designed, constructed and evaluates the performance of biogas stove using a $3m^3$ continuous- flow Indian type biogas plant at the Teaching and Research Farm, University of Agriculture, Makurdi, Nigeria. The biogas plant was operated with cattle dung as feedstock in the ratio of 1 part of dung to 2 parts of water at a retention time of 30 days and daily loading rate of 100 kg of slurry [8].

P. Taylor et al (2010) also design and develop a community biogas stove for baking chapatti (bread) or other food items on a hotplate for canteen or community purpose. 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 stove, to meet the energy requirement for cooking application at domestic as well as at the community level [14].

2.2 Characteristics of Biogas

The composition of biogas depends upon feed material also characterized based on its chemical composition and the physical characteristics which result from it. It is primarily a mixture of methane (CH4) and inert carbon dioxide gas (CO2)) with small amounts of hydrogen (H2), nitrogen (N2), hydrogen sulfide (H2S), oxygen (O2), water (H2O) and saturated hydrocarbons (i.e. methane, propane). Biogas is about 20% lighter than air has an ignition temperature in the range of 650 to 750^{0}C. An odorless and colorless gas that burns with blue flame similar to LPG gas. It's caloric value is 22 Mega Joules (MJ) /m3 and it usually burns with 60 % efficiency in a conventional biogas stove. This gas is useful as fuel to substitute firewood, cow-dung, petrol, LPG, diesel and electricity depending on the nature of the task and local supply conditions and constraints [15].

Table 1: Physical characteristics of biogas [1]

Characteristics	Value/behavior
Color when it ignites	blue
Smell	Rotten eggs
Calorific value kwh/m3	4-7.5

Table 2: Biogas composition for various feedstock's [1].

Components	Biogas from Household waste	Biogas from wastewater treatment plants	Biogas from Agricultural waste	Biogas from Food industry waste
CH4% vol	50-60	6-75	60-75	68
CO2% vol	34-38	19-33	19-33	26
H2O% vol	(at 40oc)	6(at 40oc)	6(at 40oc)	6(at 40oc)
H2S mg/m3	100-900	100-400	3000-10000	400
NH3 mg/m3	-	-	50-100	-

2.3 Feedstock's For Biogas Production

Biogas generated from organic matter including manure, food waste, municipal solid waste, biodegradable waste or any other biodegradable feedstock under anaerobic condition [16].

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 of TS content above which the material is no longer slurry, 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 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**.**

Manure is an easy choice for anaerobic digestion because it generally has a neutral pH and a high buffering capacity (the ability to resist changes in pH); contains a naturally occurring mix of microbes responsible for anaerobic degradation. However, it is a lower- energy feedstock because it is predigested in the gastrointestinal tracts of the animals [16].

Biogas from Municipal Solid Waste

Anaerobic digestion of municipal solid waste can lead to biogas generation since this waste contains organic compounds, which 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. Municipal solid waste (MSW) is the waste produced in a society with the exclusion of agricultural waste and industrial wastes. MSW comprises of residential waste, institutional waste and commercial waste [17].

Biogas From food waste

Food waste is rich in organic matter. Subjecting this waste into anaerobic digestion provides high-quality biogas. Converting food waste of universities is crucial both environmentally as it decreases carbon emission and bad smiles and economically as it needs low construction and operation costs. The TS percentage and VS percentage of Ethiopian food (Injera) is 39.43% and 93.78 respectively 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, AAU, food waste mixed with human excreta was used to generate the biogas.

Table 3: Composition of Teff Injera [1].

Component	Composition (%w/w)
Carbohydrates	86.4
Proteins	11.3
Lipids	2.3

2.4 Process of Biogas Production

Currently, biogas production is one of the most promising renewable energy sources in Ethiopia. Anaerobic digestion is one of the effective methods of treating food waste and it is an effective way of generating biogas. The provision of bioenergy tackles both energy poverty and avoids polluting the environment; as a result, biogas production technology has led to the development of the number of biogas appliances for different purposes. Design and development of a cylindrical fixed dome bio-digester for cooking purpose was done in the condominium houses in Debiza site in Debre Markos Amhara Region. The size of the biogas plant is $53m^3$ and the input materials are different wastes such as human excreta, kitchen and food wastes from a total of 357 peoples living in four buildings of 120 residents [1].

2.4.1 Anaerobic Digestion

In anaerobic digestion, bacteria degrade organic materials in the absence of oxygen, converting it into a methane and carbon dioxide mixture. The digestate or slurry from the digester is rich in ammonium and other nutrients used as an organic fertilizer.

Anaerobic digestion considered a complex process; the digestion itself based on a reduction process consisting of a number of biochemical reactions taking place under anoxic conditions. Methane formation in anaerobic digestion involves four different steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis [18].

Hydrolysis

Hydrolysis is a reaction that breaks down the complex organic molecules into soluble monomers (constituents). Enzymes excreted from the hydrolytic and fermentative bacteria (cellulose, protease, and lipase) catalyze this reaction. End products of this reaction are soluble sugars, amino acids, glycerol and long-chain carboxylic acids [19].

Acidogenesis

In the acidogenesis step, fermentative bacteria or anaerobic oxidizers utilize the soluble organic molecules from hydrolysis. These microorganisms are both obligate and facultative anaerobes. In a stable anaerobic digester, the main degradation pathway results in acetate, carbon dioxide, and hydrogen. The intermediates, such as volatile fatty acids and alcohols, play a minor role. This degradation pathway gives higher energy yield for the microorganisms and the products utilized directly by methanogenic microorganisms. However, when the concentration of hydrogen and formate is high, the fermentative bacteria will shift the pathway to produce more reduced metabolites. The products from the acidogenesis step consist of approximately 51% acetate, 19% H2/CO2, and 30% reduced products, such as higher VFA, alcohols or lactate. Acidogenesis step is usually considered the fastest step in anaerobic digestion of complex organic matter [20].

Acetogenesis

In the third stage, known as acetogenesis, the rest of the acidogenesis products, acetogenic bacteria into hydrogen, carbon dioxide and acetic acid transform i.e. the propionic acid, butyric acid, and alcohols. Hydrogen plays an important intermediary role in this process, as the reaction will only occur if the hydrogen partial pressure is low enough to allow thermodynamically the conversion of all the acids. Such lowering of the partial pressure is carried out by hydrogen scavenging bacteria, thus the hydrogen concentration of a digester is an indicator of its health [21].

Methanogenesis

In the last stage, the methanogenic bacteria (methogens) produce methane by consuming acetic acid, hydrogen, and some carbon dioxide. Around 66% of methane is formed from acetic acids by means of acetate decarboxylation and the remaining 34% of methane is formed from carbon dioxide reduction [22].

2.5 Parameters That Influence Biogas Production

Factor affecting efficiency and biogas yield in anaerobic digestion of organic solid waste are temperature, organic loading rate (OLR), Hydraulic retention time (HRT) and Carbon to Nitrogen ratio (C: N) and PH Value.

Temperature

Temperature is one of the critical parameters that often influence biogas yield. Failure to properly control the reaction temperature may lead to a decrease in process efficiency and indirectly affect the rate of reaction, the solubility of heavy metals and carbon dioxide as well as buffering. Theoretically, the rate of reaction will increase with the increase of the ambient temperature. Thus, the production of biogas also will increase. There were three temperature ranges in the anaerobic digestion, which are:

1) Psychrophilic: 0-15˚C, β)
2) Mesophilic μ 15-45 ˚C,
3) Thermophilic: 45-65 ˚C.

Most conventional digester employed mesophilic temperatures of approximately 35°C in the system. However, thermophilic temperatures ranging from 55°C to 60°C are worth considering, as it will give off more biogas over a shorter time. Many literature highlight the advantages of the thermophilic system over the mesophilic system. In terms of reaction rates, thermophilic temperatures offer a faster reaction rate over a shorter time and hence, higher gas yield [23].

Ph Value

In anaerobic digestion, all life processes are carried out at well-designed values of pH. The pH of the optimal hydrolytic stage is between 5 and 6. For methane production stage, the optimal pH value varies between 6.5 and 8. If the pH value decreases below 6, methane production is strongly inhibited. In the hydrolytic stage, the acidogenic bacteria require a pH in the range of 5.5-7.0 and final stages methanogenic. The pH must meet the requirements of the populations of microorganisms that coexist in the digester. The temperature of the reaction medium influence the pH value, while the temperature increases the carbon dioxide decrease [24].

Organic Loading Rate (OLR)

The loading rate is defined as the amount of raw materials fed per day per unit volume of digester capacity. An important parameter affects gas yield. If the plant is overfed, acids will accumulate and methane production will be inhibited since micro-bacteria cannot survive in acidic situations. Similarly, if the plant is underfed, the gas production will also be low because of alkaline solution, which is also not a favorable condition for anaerobic bacteria [25].

Hydraulic Retention Time (HRT)

Retention time defined as the theoretical time of the particle or volume of liquid added to a digester and remained in it. Similarly, retention time also defined as the length of time that volatile solid (VS) remain in the reactor. Hydraulic retention time (HRT) refers to the average range that the complex compound retained in the digesters, in contact with the biomass and decomposes into metabolic products such as monosaccharides, polysaccharides, and amino acids.

The retention time can only be accurately defined in batch-type facilities. For continuous systems, the mean retention time is approximated by dividing the digester volume by the daily influent rate [26].

Carbon to Nitrogen ratio (C/N)

The relationship between the amount of carbon and nitrogen present in organic materials expressed by the carbon/nitrogen (C/N) ratio. A suitable C/N ratio plays an important role in the proper proliferation of the bacteria for the degradation process.

It is necessary to maintain the proper composition of the feedstock for efficient plant operation so that the C: N ratio in feed remains within the desired range. It is generally found that during anaerobic digestion microorganisms utilize carbon 25 to 30 times faster than nitrogen. Thus, to meet this requirement, microbes need a 20 to 30:1 ratio of C to N with the largest percentage of the carbon being readily degradable. Waste material that is low in C can be combined with materials high in N to attain the desired C: N ratio of 30:1. Some studies also suggested that C: N ratio varies with temperature. Use of urine-soaked waste [27].

Stirring

Optimum stirring substantially reduces the retention time. Stirring is very important for completing the 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.

Stirring is more important for large-scale biogas plants. Steel rods could do stirring for digester contents of small plants manually from substrate introducing pipe, while large-scale plants require a more sophisticated stirring system for gas recirculation as mechanical stirrer. Good mixing of organic wastes with water before introducing the slurry into the digester enhances the digestion process [28].

Total Solids

Total solids mean the amount of solid particles in the unit volume of the slurry and they usually expressed in the percentage form. The percentage of total solid should be between 5% and 12% while other source reported that the best biogas production occur when total solid is ranged from 7% to 10% because of avoiding solids settling down or impeding the flow of gas formed at the lower part of digester. Therefore, dilution of organic substrate or wastes with water to achieve the desirable total solids percentage is required.

2.6 Basic Types of Biogas Plant

Biogas plants can be classified based on:

- Feeding Method
- Type of construction
- According to geometrical shapes
- According to orientations of inlet and outlet
- And according to buried position

Based on feed method they are classified as:

- Batch feed plants
- Semi-continuous
- Continuous feed plant

Batch plants are filled completely and then emptied after a fixed retention time. The major disadvantage, their gas output is not steady. To achieve a uniform rate of biogas production, several digesters must be operated in parallel i.e. filled at staggered intervals. Batch plants are suitable for digesting straw, fibrous material with high solids content, usually in areas with low annual rainfall, and for use as simple demonstration plants. Continuous feed plants are those in which there is a continuous through-flow of biomass, resulting in a near-constant volume of slurry in the digester. Such plants are feed once or twice a day [29].

The advantage of continuous feed plants is that the bacteria receive a regular supply of substrate and are therefore able to generate a more constant supply of biogas. The problem is that buoyant constituents tend to form a stiff layer of scum that impedes biogas production and may even plug up the plant. That drawback can be countered by installing suitable agitators and lengthening the retention time. Continuous feed biogas plants are sized on the basis of the desired retention time for the organic material, in combination with the digester load, which in turn is a function of the existing temperature and type of substrate. Based on the type of construction biogas is classified as:

- Fixed dome plants
- Floating drum plants
- Plastic covered bag plants

Fixed domed and floating drum biogas plants are two basic types of tested biogas plants that have gained widespread acceptance [30].

2.6.1 Fixed dome plant

A fixed dome plant comprises a closed, dome-shaped digester with an immovable, rigid gasholder and a displacement pit (expansion chamber). The gas collected in the upper part of the digester. Gas production increases the pressure in the digester and pushes slurry into the displacement pit, from where the slurry flows back to the digester as soon as gas is released. The volume of the expansion chamber is equal to the volume of gas storage.

Gas pressure is created by the difference of slurry levels between the inside of the digester and expansion chamber. When gas is extracted, a proportional amount of slurry flows back into the digester. The gas pressure does not remain constant in a fixed dome plant but increases with the amount of stored gas. Consequently, a special purpose pressure controller or a separate floating gasholder is needed to achieve a constant supply pressure. The digesters of such plants are usually made of masonry, with paraffin or bituminous paint applied to the gas-filled area in order to make it gastight [30].

The digester is filled through the inlet pipe up to the bottom level of the expansion chamber. The level of original filling is called the zero line. Under the anaerobic condition, biogas is produced. The following figures (4, 5, 6 and 7) show the basic element and some models of this design

Advantages fixed dome plant:

- It has low cost compared to floating drum type as it uses cement and no steel.
- It has no corrosion trouble (problem)
- Heat insulation is better as construction under the beneath the ground, the temperature is constant.
- The design is compact, it saves space of construction
- Less need of maintenance

Drawback fixed dome plant:

- Gas production per cubic meter of the digester volume is less.
- Gas pressure fluctuates substantially and is often very high. This makes complicates gas utilization
- Plant often not gas light (porosity and cracking often cause irreparable leaks.)

Fixed dome plant is only recommended in cases where experienced biogas technicians are available for building them, and when the user is amply familiar with how the plant operates [31].

2.6.2 Floating drum plant

The main components of this design are nearly the same as that of fixed dome design, but the difference is in the system of biogas collection. In this design, the biogas collected inside mild steel drum that adjusted over the top of the digester. This drum moves up and down according to the biogas pressure rise up under gas pressure, that is; when the quantity of biogas increases, the drum moves up and as the biogas consumed it is moved down [28].

Figure 8 shows a schematic diagram for a water jacket floating drum design show one of the applied floating drum plant.

Advantage:

- Floating drum plants are easy to understand and operate
- They provide gas at a constant pressure
- Volume of stored gas visible directly
- Few mistakes in construction

Drawback:

- High construction cost of floating drum
- Many steel parts liable to corrosion, resulting in short life(up to 15 years)
- Maintenance intensive due to the necessity of periodic painting & rust removal.
- If fibrous substrates are used, the gasholder shows a tendency to be “stuck” in the resultant floating scum.

Floating drum plants can be recommended as mature, easy to operate, functionally capable means of producing biogas, particularly when reliability is demand more than inexpensiveness. Water jacket plants are universally applicable and especially easy to maintain [28].

Fixed dome design costs less than floating drum design and it is of less repair requirements. Floating drum design provides biogas with a stable rate or pressure while the biogas rate in fixed dome design is variable [28].

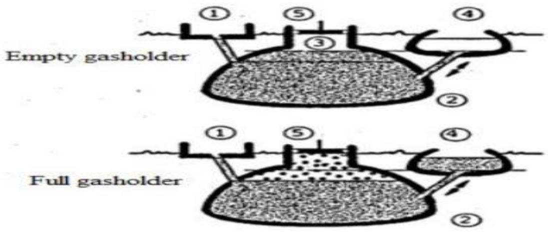

Figure 4: Basic function of a fixed dome biogas plant, 1 Mixing pit, 2 Digester, 3 Gasholder, 4 Displacement pit, 5 Gas pipe[28]

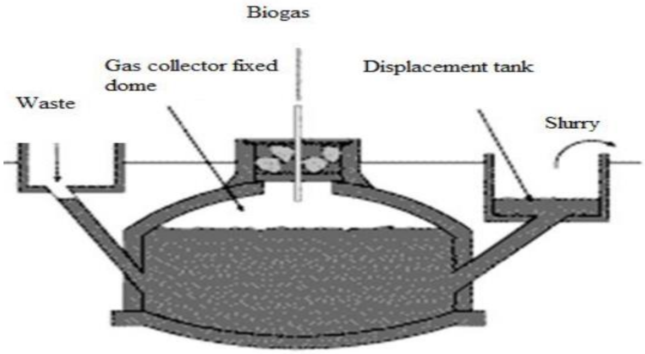

Figure 5: Chinese fixed dome plant [30]

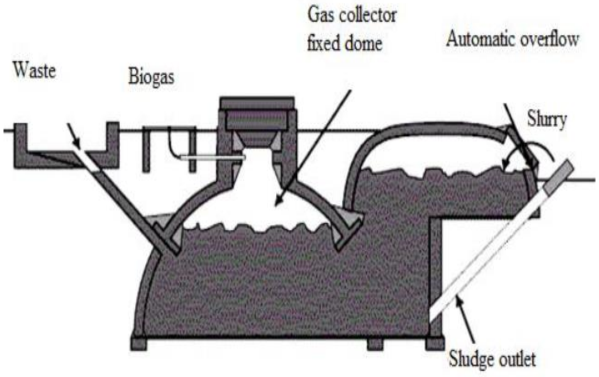

Figure 6: Fixed dome plant Camartec design [30]

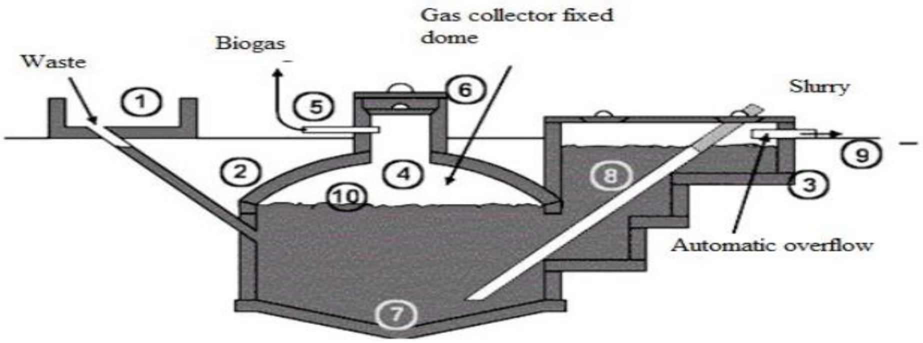

Figure 7: Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap, 2.Digester, 3. Compensation and removal tank, 4. Gasholder, 5. Gas pipe, 6.Entry hatch, with gastight seal, 7. Accumulation of thick sludge, 8. Outlet pipe, 9. Reference level &10. Supernatant scum, broken up by varying level [28]

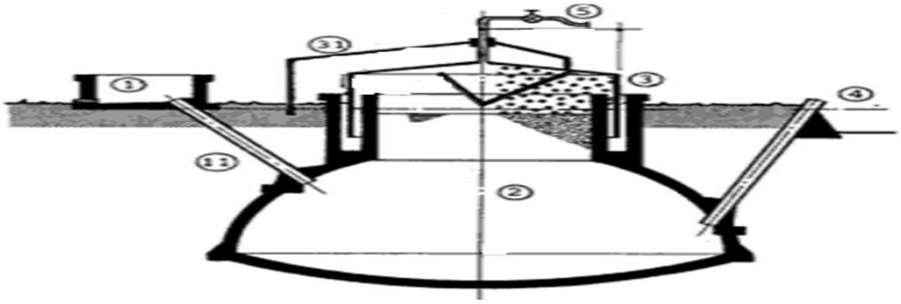

Figure 8: Floating drum plant 1.Mixing pit, 11. Fill pipe, 2.Digester, 3.Gasholder, 31. Guide frame,4. Slurry store, 5.Gas pipe

2.7 Biogas Combustion

Biogas is typically comprised of an average of 50-75% methane and 25-50% carbon dioxide with trace amounts of water vapor, hydrogen sulfide, nitrogen, oxygen, and ammonia. Methane in biogas reacts with oxygen in air and triggers a series of steps in which the saturated compounds (those with a net-zero valence number) of carbon dioxide and water are the main and preferred products. Other products in significant quantities include H2, O2, N2, NO_2, OH, and CO. These are only some of the products since chemical equilibrium requires a statistical distribution of the infinite number of molecular configurations of carbon, hydrogen, and oxygen [32].

2.8 Use of Biogas

Nowadays, the utilization of Biogas as one of the potential fuel for fossil fuel replacement is gaining increased public attention. Biogas is cheap and renewable energy source because it is produced from organic waste like garbage, food scraps, manure and industrial waste [33].

Under the right conditions, a biogas plant will yield several benefits for the end-users, the main benefits are [26]:

- Production of energy for lighting, heat, electricity
- Improved sanitation (reduction of pathogens, worm eggs, and flies)
- Reduction of workload (less firewood collecting) and biogas stoves has a better cooking Performance
- Environmental benefits (fertilizers substitution, less greenhouse gas emission)
- Improved indoor air quality (less smoke and harmful particle emission of a biogas stove compared to wood or dung fuels)
- Economic benefits (substitution of spending on expensive fuels and fertilizer)

2.8.1 Uses of Biogas in Ethiopia

Many Ethiopians face quality of life and livelihood challenges associated with sub-optimal sanitation, dependence on biomass energy, and decreasing agricultural productivity. To mitigate these livelihood challenges, the government of Ethiopia has recognized the need for a national policy framework, which encourages the uptake of biogas technology [34].

Biogas technology offers a wide range of benefits, which include economic, health, social, and environmental ones. To move towards an economy freed of the environmental and health concerns resulting from the excess use of biomass energy.

Biogas technology was introduced in Ethiopia in 1979. Even if biogas technology has a multitude of advantages to rural households society and for forming a sustainable environment, the wider dissemination of the technology is limited until the National Biogas Program (NBP) is launched in 2008. To implement the technology widely, it needs encouraging households. Because in lacking technical and financial support to rural households who are more or less unaware of the technology difficult to use it consistently the Ethiopian government has been actively pursuing a range of renewable energy options over the past five years, including support for smallholder biogas expansion [35].

2.9 Injera Baking System in Ethiopia

Preparation of Injera has a long process; it usually takes two to four days from mixing to cooking. It can be produced from almost any staple grain, with sorghum, millet, and teff being the most common in Ethiopia. The teff flour mixed with water and left to ferment for two to four days, but can take less than this time in warmer locations. Starter (leftover batter from the previous baking time) added to trigger fermentation. Approximately four to six hours before baking, a layer of bitter fermentation product has removed and hot water also added to reactivate fermentation, then the batter was poured on top of the hot baking pan surface.

To bake Injera, the heat supplied to the baking pan comes from burning fuelwood, dung or agricultural residue in biomass cookers, by heating electrical resistance in the electric baking pan and by means of heating heat transfer fluids for solar-powered baking pan. This heat is then conducted through the baking pan to the surface where the batter is cooked. The heat supplied to the Injera baking pan had used for raising the temperature of the batter on the pan surface from room temperature (20 to 25oc) to around the boiling point of water. (In Addis Ababa, boiling point of water is about 92^0c). Conventional baking pans are 58 - 60cm in diameter [36].

Injera baking is the most energy-intensive process and it requires a temperature ranging from 180^0C-220℃. To bake Injera, the heat supplied to the baking pan comes from burning fuelwood, dung or agricultural residue in biomass cookers, by heating electrical resistance in the electric baking pan [37]. The following methods will describe the methods of Injera backing usually applied in Ethiopia.

Injera Baking Using Open Fire System

In most of the households of the country, Injera baking is carried out using an open fire (three stone, "Gulecha") baking system and the fuel is biomass. The heat supplied to the mitad in this system is lost through a variety of paths such as: through the sides, through the exhaust gases from the fuel, through convective and radiative heat losses from the pan surface. The fraction of energy that flows into the Injera batter is very limited and therefore this technique is inefficient and wasteful; it is unhealthy because of carbon inhalation to the lungs and irritation of eyes [38].

Figure 9: Open fire Injera baking system [38]

Mirte Injera Stove

It is prefabricated stove from cement and local aggregate such as sand panels or the oven was made by pressing clay around the mold. The stove is suitable for mass production by casting light concrete. Each Mirte saves approximately 5 kg of wood per Injera baking session for an average household. Most household bakes Injera twice a week. Thus, the Mirte saves on average per household of nearly 260 kg of wood per year. This is a significant savings for the average Ethiopian urban household. However, the Mirte saves commercial Injera bakers over 3.5 tons of fuelwood per year. Even though the Mirte stove is better and efficient compared to the open fire baking system; it has the following drawbacks: Since it uses biomass (wood or animal dung), it has a contribution to deforestation and limits the advantage of dung as plant fertilizer. It may also produce smoke and may result in producing pollution if baking is in the door [39].

Figure 10: Mirte Injera Baking Stove [38]

Electrical Injera Baking Pan /Mittad

The other type of technology for Injera baking is an electric "Mitad"; which is mainly used by people in the urban and near urban areas where electric power is available. Thus, the majority of the population (more than 80%) in Ethiopia uses wood or biomass fuel for Injera baking.

Disadvantages of electrical baking system:

- The electric baking system is used only for the urban areas where electricity is available so that many rural people do not have access to the electricity network.
- There is high-energy loss through the sides and bottom of the baking assembly, and it requires high maintenance and labor cost [40].

Figure 11: The electric baking system

2.10 Biogas Injera Baking Stove

Matured biogas production technology has led to the development of a number of biogas appliances used for lighting, electricity, and cooking. The most hopeful among them is the biogas stove, to achieve the energy necessary for cooking application at domestic as well as at the community level.

Dejene et.al (2014) designed biogas stove used for Injera baking application. The stove designed by covering the flame under an insulated material, the demand for energy needed during baking, and the amount of gas supplied from the biogas plant. The gas burner used to supply pressure equally on the holes of the burner port. Heat transfer analysis between burner and mitad by radiation, convection heat transfer between flame and wall and heat flow through insulation also determined [7]**.**

B. Mulugeta et .al (2017) he was improved the Injera baking burner analytical design and optimization of biogas burner with CFD simulation. From his study result, he observed and proposed that the optimum manifold diameter is 26cm to distribute heat uniformly throughout the baking pan. As per this manifold diameter 5cm, thickness with 60cm diameter of insulation and 54cm diameter with 13mm thickness of baking pan obtained, which is almost equal with the size of the local standard hotel injera 50cm in size [41].

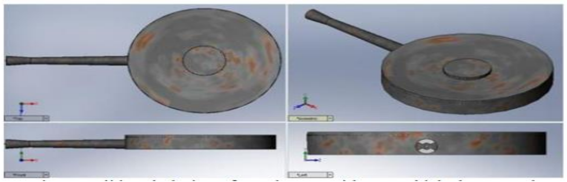

Figure 12: New burner with 2mm thick sheet Metal [41]

Stove Description

The main components of the stove are the injector, the air/gas mixing chamber, and the burner. The injector tapers into a nozzle in which gas enters into the air/gas mixing chamber. The air/gas mixing chamber opens into the burner head. If the injector moved deeper into the air/gas mixing chamber, the drift of oxygen into the burner is reduced thus reducing combustion. On the contrary, when the injector is moved out of the air/gas mixing chamber, more oxygen enters into the burner thereby increasing combustion. The frames and the stands made from angle bars. A wall made from metal sheet welded around the frame serves as a windbreaker. The stove connected to the gas-holding unit of the biogas plant by a rubber hose, which conveys biogas from the gasholder of the plant to the stove.

CHAPTER THREE

BIOGAS TECHNIQUE

3.1 Design Constraint

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 the demand for biogas and fertilizer, in addition to available substrate quantities, which determines the size of the biogas plant
- Cost of material building
- Economy of labor input for building and operating the plant.
- Knowledge and experience of the organization or person promoting the biogas plant

3.2 Sizing of Biogas plant

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

- Daily fermentation slurry feed (substrate input) (Sd),
- Retention time (RT),
- Specific gas production per day (Gd), which depends on the retention time and the feed material
- **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 material 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%.

3.3 Socio-Economic impacts of Biogas Plant

The following are some of the socio-economic impacts that resulted from constructing biogas plants:

i. Provide new job opportunities.
ii. Using renewable energy source from materials that should be disposed of, decreasing paid money for getting energy from biomass firewood
iii. Using produced biogas reduces the quantity of imported firewood and others, which saves money for university.
iv. Using digested organics for fertilizing crops reduces the used amount of manufactured fertilizers, which save money for both farmer and government. In addition, this using enhances crop production, which will increase the farmer's income.

3.4 Constraints for Biogas Technology Dissemination

The main constrains that faces dissemination of biogas technology in most societies are:

- Cost for constructing biogas plants and long the period (relatively) required for payback the capital.
- Instability of biogas production and fall of biogas production in cool months
- Experience required for constructing biogas digesters.
- Found of some toxic components (usually in trace quantities) in biogas, especially hydrogen sulfide and ammonia [42].

3.5 Parts of Biogas Plant

- Influent collecting tank
- Inlet and outlet
- Digester
- Gasholders
- Gas pipe, valves, and accessories
- Stirring facilities
- Heating systems
- Pumps

3.5.1 Mixing Pit (Influent collecting tank)

In the mixing pit, the substrate is diluted with water and agitated to yield homogeneous slurry. The fibrous material is raked off the surface, and any stones or sand settling to the bottom are cleaned out after the slurry is admitted to the digester. A sunny location can help to warm the contents before they are fed into the digester in order to avoid thermal shock due to the cold mixing water. In the case of a biogas plant that is directly connected to the stable, it is advisable to install the mixing pit deep enough to allow installation of a floating gutter leading directly into the pit [43].

The useful volume of the mixing pit should amount to 1.5-2 times the daily input quantity. It is advisable to install the mixing pit deep enough to allow installation of a floating gutter leading directly into the pit. Care must also be taken to ensure that the low position of the mixing pit does not result in premature digestion and resultant slurry formation [44].

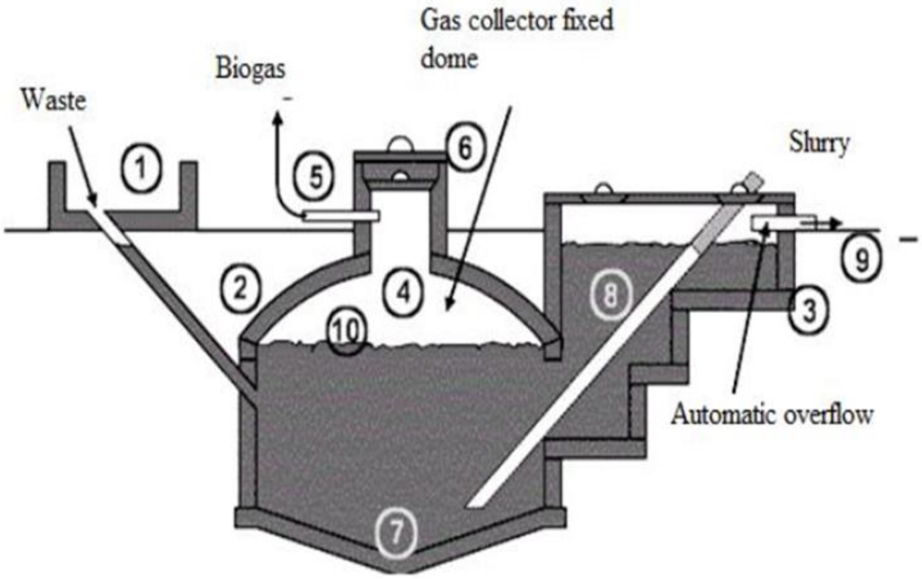

Figure 13:Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap, 2.Digester, 3. Compensation and removal tank, 4. Gasholder, 5. Gas pipe, 6.Entry hatch, with gastight seal, 7. Accumulation of thick sludge, 8. Outlet pipe, 9. Reference level &10. Supernatant scum, broken up by varying level [28]

3.5.2. Inlet and Outlet

The inlet (feed) and outlet (discharge) pipes lead straight into the digester at a steep angle. For liquid substrate, the pipe diameter should be 10-15 cm, while the fibrous substrate requires a diameter of 20-30 cm. The inlet and the outlet pipe mostly consist of plastic or concrete [44].

Both the inlet and the outlet pipe must be freely accessible and straight so that a rod can be pushed through to eliminate obstructions and agitate the digester contents. The pipes should penetrate the digester wall at a point below the lowest slurry level (i.e. not through the gas storage). The points of penetration should be sealed and reinforced with mortar. The inlet pipe ends higher in the digester than the outlet pipe in order to promote a uniform flow of the substrate. In a fixed-dome plant, the inlet pipe defines the bottom line of the gasholder, acting like a security valve to release over-pressure. In a floating-drum plant, the end of the outlet pipe determines the digester's (constant) slurry level. Inlet and outlet pipe should be placed in connection with bricklaying. It is not advisable to break holes into the spherical shell afterward; this would weaken the masonry structure.

The inlet pipe ends higher in the digester than the outlet pipe in order to promote a uniform flow of the substrate. In a fixed dome plant, the inlet pipe defines the bottom line of the gasholder (Fig.13 (1)). In a floating drum plant, the end of the outlet pipe determines the digester's slurry level (Fig.13 (2))[28].

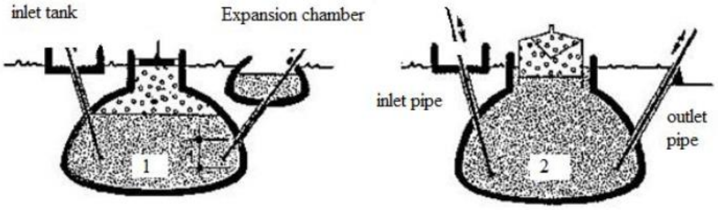

Figure 14:Inlet and outlet for fixed dome (1) and floating drum plants (2)[28]

3.5.3 Digester

Digester tank is an area where the biomass is stored and fermentation takes place. When the biomass ferments with sufficient retention time, it will produce a biogas. Digesters shape can be in different forms. Round and spherical shapes are able to accept the highest forces and distribute them uniformly [44].

Digesters can be made from any of the following materials:

- **Steel vessels-** Steel vessels are inherently gas-tight, have good tensile strength, and are relatively easy to construct (by welding).
- **Concrete vessels-** Concrete vessels have gained widespread acceptance in recent years. The requisite gas tightness necessitates careful construction and the use of gas-tight coatings, linings and/or seal strips in order to prevent gas leakage. Most common are stress cracks at the joints of the top and the sides. The prime advantage of concrete vessels is their practically unlimited useful life and their relatively inexpensive construction. This is especially true for large digesters in industrialized countries.
- **Masonry -** is the most frequent construction method for small-scale digesters. Only well-burnt clay bricks, high quality, pre-cast concrete blocks or stone blocks should be used in the construction of digesters. Cement-plastered/rendered masonry is a suitable – and inexpensive - approach for building an underground biogas digester, whereby a dome-like shape is recommended [30].

As a rule, the digesters of simple biogas plants are made of masonry or concrete. Such materials are adequately pressure resistant, but also at risk of cracking because of tensile forces. The following forces act on the digester:

- External active earth pressures (pE), causing compressive forces within the masonry
- Internal hydrostatic and gas pressures (pW), causing tensile stress in the masonry

Thus, the external pressure applied by the surrounding earth must be greater at all points than the internal forces (pE>pW) [28].

3.5.3.1 Sizing digester

The size of the biogas plant depends on the quantity, quality, and kind of available biomass and on the digesting temperature. The size of the digester, i.e. the digester volume (Vd), is determined on the basis of the chosen retention time (RT) and the daily substrate input quantity (Sd).

$$Vd = Sd \times RT \tag{3.1}$$

$$Sd = m_{biomass} + m_{water}$$

Where, Vd = Volume of digester

Sd = Daily substrate input

RT = Retention time

mbiomass = Mass of biomass

mwater = Mass of water

3.5.4 Fixed dome gasholder

A fixed dome gasholder can be either the upper part of a hemispherical digester or a conical top of a cylindrical digester (e.g. Chinese fixed dome plant). In a fixed dome plant, the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry. The following aspects must be considered with regard to design and operation:

- An overflow into the compensation tank must be provided to avoid overfilling of the plant.
- The gas outlet must be located about 10 cm higher than the overflow level to avoid plugging up the gas pipe.
- A gas pressure of 1mwc or more can develop inside the gas space. Consequently, the plant must be covered sufficiently with soil to provide an adequate counter pressure [30].

3.5.5 Gas pipe, valve, and accessories

Galvanized steel water supply pipes are used most frequently, because the entire piping system (gas pipe, valves, and accessories) can be made of universally applicable English/U.S. Pipes with nominal dimensions of (1/2") or (3/4") are adequate for small to midsize plants of simple design and pipe lengths of less than 30 m. The diameters of the pipes are depending on the required flow rate of biogas through the pipeline and the distance between biogas digester and gas appliances. Long distances and high flow rates lead to a decrease in 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 [28].

The values in Appendix A show that a pipe diameter of (1") is suitable for flow rates up to1.5m3/h and distances up to 100 m (Galvanized steel pipe). Therefore, one could select the diameter of (1") as a single size for the hole piping system of small biogas plants. Another option is to select the diameter of l" for the main gas pipe and (1/2") for all distribution pipes to the gas appliances.

When installing a gas pipe, special attention must be paid to:

- Gas-tight, less friction type joints
- Line drainage, i.e. with a water trap at the lowest point of the sloping pipe in order to empty water accumulation
- Protection against mechanical impact

The biogas coming from the digester is saturated with water vapor. This water vapor will condense at the walls of the pipeline. If this condensed water is not removed regularly, it will ultimately clog the pipeline. Hence, a water drain has to be placed in the pipeline. The position of the water drain should be vertically below the lowest point of the pipeline so that water will flow by gravity to the trap. Water can be removed by opening the drain. This has to be done periodically [30].

3.6 Pressure Developed in the Digester

The pressure of a gas mixture is equal to the sum of the pressure each gas would exert if it existed alone at the mixture temperature & volume. Dalton's law

$$pm = \sum_{i}^{k} pm(Tm, Vm) \tag{3.2}$$

The partial pressure of a gas is the pressure exerted by a particular component of a mixture of gases. It is given by [28].

$$piVi = niRT \tag{3.3}$$

Where Pi = Pressure developed by each gas of mixture

V_i = Volume of particular component of gas

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 day it is possible to find the maximum gas pressure developed in the digester dome. 110m^3/day of biogas can be produced per day (section 4.3). Based on their composition, it is possible to find a particular volume & molar number of gas.

Table 4: Night soil base biogas composition [28].

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

According to their composition, the volume of each gas in the mixture can be determined.

The volume of methane:

$$V_{CH4} = \% \ CH4 \times V_{Tb}$$
$$= 0.655 \times 110$$
$$= 72.05 m^3/day$$

The volume of Carbon dioxide:

$$V_{CO2} = \% \ CO2 \times V_{Tb}$$
$$= 0.33 \times 110$$
$$= 36.3 \ m^3 /day$$

The volume of Hydrogen Sulphide:

$$V_{H2S} = \% \ H_2S \times V_{Tb}$$
$$= 0.01 \times 110$$
$$= 1.1 m3 /day$$

Table 5: Densities, molecular weight and chemical formulas of some gases at normal Temperature and Pressure (20 ℃ and 1atm) [1].

Gas	Formula	Molecular Weight	Density - ρ -*kg/ m3*
Air	-	29	1.205
Ammonia	$NH3$	17.03	0.717
Carbon dioxide	$CO2$	44.01	1.842
Hydrogen Sulfide	$H2S$	34.076	1.434
Methane	$CH4$	16.043	0.668
Water Vapor	-	18.016	0.804

.

Density is given by:

$$Density = \frac{mass}{volume} \tag{3.4}$$

$$\rho\ CH4 = \frac{mCH4}{VCH4}$$

$$mCH4 = 0.668 \times 72.5$$

$$= \frac{48.43Kg}{day}$$

$$mole = \frac{mass}{molecular\ weight}$$

$$nch4 = \frac{mch4}{Mch4} = \frac{48.43}{16.1}$$

$$= \frac{3024mole}{day}$$

$$m\mathrm{CO2} = \rho\mathrm{CO2} \times \mathrm{VCO2}$$

$$= 1.842 \times 36.3 \frac{\mathrm{m3}}{\mathrm{day}}$$

$$= 66.86 \frac{\mathrm{kg}}{\mathrm{day}}$$

$$\mathrm{nCo2} = \frac{\mathrm{mco2}}{\mathrm{Mco2}}$$

$$= \frac{66.86}{44.01} = 1519$$

$$\mathrm{mH2s} = \rho\mathrm{H2s} \times \mathrm{VH2s}$$

$$= 1.434 \times 1.1 \frac{\mathrm{m3}}{\mathrm{day}}$$

$$= 1.5774 \frac{\mathrm{kg}}{\mathrm{day}}$$

$$\mathrm{nH2s} = \frac{\mathrm{mH2s}}{\mathrm{MH2s}}$$

$$= \frac{1.5774}{34.076} = \frac{46.2\mathrm{mole}}{\mathrm{day}}$$

The partial pressure of methane gas:

$$PCH4\ =\ nch4 \times R \times \frac{Tm}{Vm}$$

=3024×8.13×306/110000=69.99kPa

The partial pressure of a carbon dioxide gas:

$$PCo2\ \ \ =\ nco2 \times R \times Tm/Vm$$

=1519×8.31×306/110000

=35.11kPa

The partial pressure of a hydrogen sulfide gas:

$$PH2s\ \ \ =\ nH2s \times R \times \frac{Tm}{Vm}$$

=46.2×8.31×306/110000=1.06kPa

The biogas saturates with water vapor and now the total pressure inside the digester is the sum of two pressures the dry gases and the water vapor:

At 33°C temperatures, we can obtain by interpolation:

At 30°C p1=31.8mmHg

At 37°C p2= 47.07mmHg

ΔT = 7°C, Δp = 15.27mmHg

ΔT = 3°C, Δp = x = 6.54mHg

At 33°C temperatures,

p_{H2o} = 31.8+ 6.54+=5.11kPa

Total pressured developed in gasholder:

$P_{total} = p_{CH4} + p_{CO2} + p_{H2S} + p_{H2O}$

= 69.34 + 35.12 + 1.07 + 5.11

= 110.64kPa

3.7 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 785-981pascal. Due to friction effect when gas flows through pipe there is loss. So properly designed pipeline is one which does not cause pressure drop of more than 196-294 pascal under any circumstances. For determining the proper size of the pipeline, 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 [28]:

$$Q = VA \tag{3.5}$$

Where, Q = Discharge (m3/s)

V = Gas velocity (m/s)

A = Cross-sectional area (m2)

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

$$\frac{p}{\rho g} + \frac{v2}{2g} + z = \text{constant} \tag{3.6}$$

Where, p = Biogas pressure (N m–2),

ρ= Biogas density (kg m–3),

v = Biogas velocity (m s–1),

g = Acceleration due to gravity (9.81 m s–2) 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 to allow for energy loss due to friction in the pipe:

$$\frac{p}{\rho g} + \frac{v2}{2g} + z + hf = constant \tag{3.7}$$

Where, h_f= head loss due to friction

3.8. 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 effects such as valves, sudden changes in the area of flow and bends. The overall head loss is a combination of both these categories.

3.8.1.Head loss in straight pipes

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

$$hf = \frac{fLv2}{2gd} \tag{3.8}$$

Where, hf = 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 <2300)

$$f = 64/\mathrm{Re} \qquad (3.9)$$

ii. For turbulent flow ($Re > 2300$)

$$f = \frac{0.3164}{\mathrm{Re}^{0.25}} \qquad (3.10)$$

Where Re= VD/γ

V = Velocity of gas

D = Diameter of pipe

γ = kinematic viscosity

At p = 1.013bar, and T = 300K Assuming the biogas kinematic viscosity equal to air

$\gamma = 1.568\times10\text{-}5\mathrm{m}^2/\mathrm{s}$

From the continuity equation

$$Q = AV \qquad (3.11)$$

14.5 hours usage time, discharge is 14*0.534=7 m3 /hr. section (5.3)

$$7 = 5.07\times10^{-4}\times V$$

$$V = 4.64\mathrm{m/s}$$

$$Re = 0.0254\times\frac{4.64}{1.568}\times 10 - 5$$

$$= 7517$$

$Re \geq 2300$, Implies turbulent flow

$$f = \frac{0.3164}{7517^{0.25}}$$

$$= 0.033$$

$$\mathrm{Hf} = \frac{\mathrm{fLV}^2}{2\mathrm{gd}}$$

$$= \frac{0.033 \times 25 \times 4.64 \times 4.64}{2 \times 9.81 \times 0.0254}$$

= 35.6

3.8.2 Head loss Due to Sudden Changes in Area of Flow

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

Figure 15: A sudden expansion [28]

hmE = (V12-V22)/2g (3.12)

Where h_{mE} = minor loss due to expansion

V1 =Velocity at cross-sectional area 1

V2 =Velocity at cross-sectional area 2

g = gravity

In this design, there is no sudden expansion of pipe. Since the main gas pipe is divided into the appliance gas pipe or for each baking process.

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

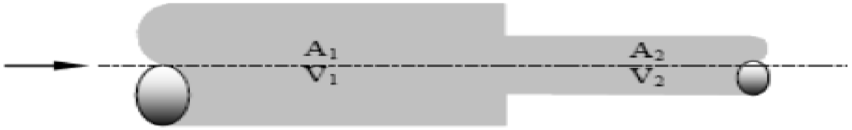

Figure 16:A sudden contraction [28]

$$hmc = \frac{kV2^2}{2g} \qquad (3.13)$$

Where h_{mC} = minor loss due to sudden expansion K= loss coefficient

Table 6: Loss Coefficient for Sudden Contractions [28]

A2/A1	0	0.1	0.2	0.3	0.4	0.6	0.8	1.1
K	0.50	0.46	0.41	0.36	0.30	0.18	0.06	0

From the continuity equation:

$$A1V1 = A2V2$$

$$\frac{4.64 \times \pi \times 0.0254^2}{4} = \frac{V2 \times \pi \times 0.0127^2}{4}$$

V2 =18.56 m/s

$$Hmc = \frac{KV^2}{2g}$$

$$= (0.385 \times 18.56 \times 18.56)/(2 \times 9.81)$$

By interpolating the value of K since area ratio is 0.25

= 6.7 m

3.8.1.3. Head loss due to Bends

The head loss due to a bend is given by expression

$$hmb = \frac{kBv2}{2g} \qquad (3.14)$$

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 15

$h_{mb}=k_B v^2/2g$

$$hmb = \frac{kBv2}{2g}$$

$$hmb = \frac{0.5 \times 4.64 \times 4.64}{2 \times 9.81}$$

= 8.22m

3.8.4. Head loss due to Valves

The head loss due to a valve is given by expression

$h_{mv} = k_v v^2/2g$ (3.15)

h_{mv}= Minor loss due to valve

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

Table 7: Typical valves of loss coefficients for gate and globe valves [28].

Valve type	**KV**
Globe valve, fully open	10.0
Gate valve, fully open	0.2
Gate valve, half-open	5.6

For gate value, fully open K_V = 0.2 average number of valves = 4

$$hmv \ = \frac{kv2}{2g}$$

$$h_{mv} \ = \ \frac{0.2\times4.642}{2\times9.81}\times 3$$

$=1.31$ m

Total head loss

$h_{fT} = hf + hmE + hmC + hmB + hmV$

$=35{,}6 + 0 + 8.22+ 6.7+ 1.31$

$= 51.8$m

Total pressure loss in pipes

$P_{fT}=\rho fLV^2/2d=\rho g h_{fT}$

$=1.2\times9.81\times51.8$

$= 0.478$kPa

CHAPTER FOUR

BIOGAS SYSTEM DESIGN

4.1. Design Procedure

The current number of student those who use the ASU cafeteria are around 6000, as the result of such increment, high amount of kitchen and food wastes can be collected. The appropriate amount of waste available and its type should be known before starting the design of the digester. Hence, collecting data have been made using interview and direct measurement of the waste using balance, meter, and different literatures. Then after analyzing data analytical design of digester and injera baking biogas stove.

4.2 Data Analysis

The solid wastes in the cafeteria are two types as mentioned earlier.

Table 8: Type of solid wastes available and its description in the cafeteria

No	Kinds of waste	Description
1	Food waste	Food waste consists of fruit, food scrap obtained from student waste after meals.
2	Kitchen waste	Kitchen waste consists of vegetable waste Alternatively, peel obtained from the preparation of food.

4.2 Solid Organic Waste

The maximum amount of solid organic waste obtained per day that contains both biodegradable and no biodegradable from direct measurement using balance recorded as follows for only six days in 2011 E.C

Table 9: Recorded of food waste per day for consecutive six days at Assosa university cafeteria

No	Date	Number of waste per Bermel (barrel)
1	22/08/11	10
2	23/08/11	7
3	24/08/11	10
4	25/08/11	9.5
5	26/08/11	8
6	27/08/11	8.5
		Average =8.8

4.2 Design and Sizing Biodigester

The size of the biogas plant depends on the quantity, quality, and kind of available biomass and on the digesting temperature. The size of the digester, i.e. the digester volume (Vd), is determined on the basis of the chosen retention time (RT) and the daily substrate input quantity (Sd).

The number of days the organic material stays in the digester is called the retention time. There are two significant retention times in an anaerobic digester: solids retention time (SRT) and hydraulic retention time (HRT). The SRT is the average time the bacteria (solids) are in the anaerobic digester. The HRT is the time the liquid is in the anaerobic digester. The process of degradation requires at least 10-30 days in mesophilic conditions, while in thermophilic environment HRT is usually shorter [45].

The size of the digester, i.e. the digester volume V, was determined based on the chosen retention time RT (27days) and the daily substrate input quantity Q. The volumes of thermal hydrolyzer equal with the volume of the digester. The working volume of the digester (Vw) = daily substrate input x hydraulic retention time [1].

$$V_d = Sd \times RT \quad (4.1)$$

$$S_d = mbiomass + mwater$$

Where, V_d = Volume of digester

S_d = Daily substrate input

RT = Retention time

$m_{biomass}$ = Mass of biomass

m_{water} = Mass of water

On average per day, an 8 barrel of food waste discharged from the ASU cafeteria. The barrel has 140-liter capacity. The density of food waste Teff Injera is $1175\frac{Kg}{m3}$ [1].

1 Bermel (barrel) =140L (estimation)

Then amount food waste three cafeteria=8×140L=1120L

Kitchen waste in ASU campus weights =100L.

Total amount of food waste=1120L+100L=1220L

Mass =1175kg/m^3 x 1.22 m^3=1433.5 Kg i.e. 1433.5 kg of food waste is discharged from the cafeteria of daily .1100kg/day of food waste was taken as a basis to minimize the cost of the construction. TS of 100-gram sample is 40%, the sample and water were mixed in 1 ratio 4 to obtain optimum biogas. TS of the

1100 kg food waste= 0.4 x 1100= 440 kg. To make the mixing ratio 1 to 4, 4×1100kg = 4400 kg water added.

So the total influent per day = amount of water + amount of food sample =4400+ 1100 = 5500 kg.

5500kg/day x 27days =148500kg=148.5m3

4.3 Total Biogas Produced

The total biogas produced from food waste calculated as follows [46]:

Total biogas produced = Daily input of the food waste × biogas production rate, (K=0.1)[46]. (4.2)

$$1100\ \text{Kg/day} \times 0.1\ (\text{m3})/\text{Kg} = 110\,\frac{m3}{day}$$

Therefore, we will have an average of 110 m^3 of biogas produced every day. The energy value of biogas is given as 6.0- 6.5 KWh/m^3[47].

The energy that can be produced from the biogas produced calculated from this value will be:

=110x 6.5

=721.5kWh of power per day.

4.4 Establishing the plant parameters

The degree of safe-sizing certainty can be increased by defining a number of plant parameters:

4.4.1 Specific gas production (Gp)

The daily gas generation rate per m3 digester volume Vd is calculated according to the following equation.

$$Gp = G \div Vd\ [(\text{m3/day}) / \text{m3}] \qquad (4.3)$$

= 110/148.5 = 0.7407/day

4.4.2 Digester loading (L_d)

The digester loading Ld is calculated from the daily total solids input TS/d or the daily volatile solids input VS/d and the digester volume Vd [43]. Organic loading rate is determined as a counter check for the digester volume. The Ratio of volatile solid to total solid is 90% [46].

$$L_{dT} = TS/d \div Vd\ [\ \text{kg/(m3 d)}\ ] \qquad (4.4)$$

$$L_{dV} = VS/d \div Vd\ [\text{kg/ (m3 d)}] \qquad (4.5)$$

So L_{dT} =0.4×1100/148.5

=2.96 kg/m3/day

LdV =0.36×1100/148.5

=2.667 kg/m3/day

Therefore, 5.627 kg substrate / m3 / 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 substrate Kg /m3 [46].

4.5 Selecting the Type of Biogas Plant

Part of digester below the ground level subjected to heavy compressive load due to the earth pressure, which increases with depth. In this design due to hydrostatic pressure, cylindrical digester selected. Deenbandhu fixed dome plant with a little modification is best suited. Deenbandhu, the successor of the Janata plant in India, with improved design, is more crack-proof and consumes less building material than the Janata plant with a hemispherical digester. Other reasons that support this choice are:

Constructing the digester underground reduces the negative impacts resulted from atmospheric temperature changes,

- Availability of construction materials such as cement, sand, small stones, etc. It distributes forces uniformly on surface area
- Deenbandhu fixed dome plant application is well disseminated in Ethiopia [48].

4.6 Sizing of digester

The anaerobic digester sizing is determined by the amount of food waste per day (daily feed), the retention time and volume of the digester. The biogas plant size is dependent on the average daily feedstock and expected hydraulic retention time of the material in the biogas system. Capacity of the plant designed based on the availability of raw materials.

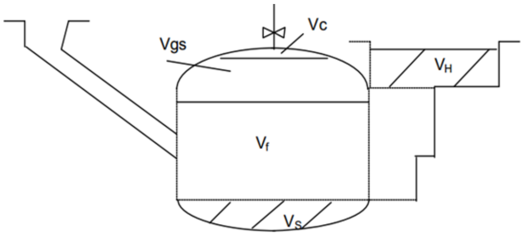

Figure 17: Cross-section of a digester

Volume of gas collecting chamber layer= VC

Volume of gas storage chamber Vgs, V1 = Vc+ Vg

Volume of fermentation chamber = Vf = V3

Volume of sludge layer, Slurry = V2

R1 and R2 is the crown radius of the upper bottom spherical layer of the digester

S1 and S2 art the surface area of the lower dome respectively

f1 and f2 are the maximum distance of upper and lower dome

Therefore the total volume of the digester $(\mathrm{v}) = \mathrm{VC} + \mathrm{vgs} + \mathrm{v2} + \mathrm{v3} = \mathrm{v1} + \mathrm{v2} + \mathrm{v3}$

Geometrical Dimensions of the Biogas Digester

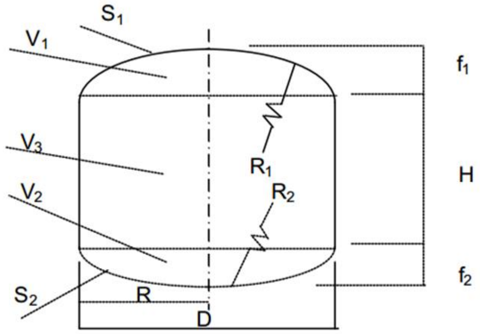

Figure 18: Geometrical dimensions of the biogas digester

Basic Assumptions of Biogas Digester Design:

Volume of the Digester [49]

$\mathrm{Vc} \leq 5\%\,\mathrm{V}$

$\mathrm{Vs} \leq 15\%\,\mathrm{V}$

$\mathrm{Vgs} + \mathrm{Vf} = 80\%\,\mathrm{V}$

$\mathrm{Vgs} = \mathrm{VH}$

$\mathrm{Vgs} = 0.5 \times 0.95\mathrm{V} \times \mathrm{K},$

Where K = 0.3, Gas production rate/m3 digester volume per day.

Geometrical Dimensions of the Digester [49]**.**

$\mathrm{D} = 1.3078 \times \mathrm{V}1/3$

$\mathrm{V1} = 0.0827\,\mathrm{D3}$

$\mathrm{V2} = 0.05011\,\mathrm{D3}$

$\mathrm{V3} = 0.3142\,\mathrm{D3}$

$\mathrm{R1} = 0.725\,\mathrm{D}$

$\mathrm{R2} = 1.0625\,\mathrm{D}$

$$\mathrm{f1} = \frac{\mathrm{D}}{5}$$

$$\mathrm{f2} = \frac{\mathrm{D}}{8}$$

$$\mathrm{S1} = 0.911\ \mathrm{D2}$$

$$\mathrm{S2} = 0.8345\ \mathrm{D2}$$

4.7 Design of Digester

The anaerobic digester sizing is determined by the amount of food waste per day (daily feed), the retention time and volume of the digester. The biogas plant size is dependent on the average daily feedstock and expected hydraulic retention time of the material in the biogas system.

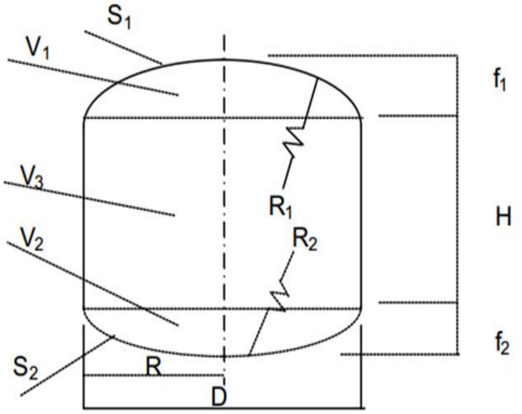

Figure 19: Geometrical dimensions of the biogas digester [28]

From Geometrical Assumptions:

From section 3.4 working volume of the digester is 148.25 m3

$$"Vgs + Vf = 0.8V = 148.5 = VW"$$

$$\mathrm{V} = \frac{148.55}{0.8}$$

=185.5 m^3

Where V is the total volume of the digester (V) = $V_1+V_2+V_3$

$$\mathrm{D} = 1.3078 \times v1^{1/3}$$

$$\mathrm{D} = 7.45\ \mathrm{m}$$

$$\mathrm{V3} = \frac{\pi\, \mathrm{D}^2 \mathrm{H}}{4},$$

where $\mathrm{V3} = 0.3142\, D^3 = 130.36\ \mathrm{m}^3$

$$H = \frac{4 \times V3}{3.14 \times \mathrm{D2}}$$

$= 3\ \mathrm{m}$

Taking the values of H and D to the assumptions, we will get:

$R1 = 0.725\, D$

$= 0.725 \times 7.45m$

$= 5.4m$

$R2 = 1.0625\, D$

$= 1.0625 \times 7.45m$

$= 7.9m$

$$f1 = \frac{D}{5}$$

$$= \frac{7.45m}{5}$$

$= 1.5m$

$$f2 = \frac{D}{8}$$

$$= \frac{7.5m}{8}$$

$= 0.93m$

$VC = 0.05\, V$

$= 0.05 \times 185.5\ m3$

$= 9.3\ m3$

$V2 = 0.05011\, D3$

$= 0.05011 \times (7.45)3$

$= 20.72m3$

$\mathrm{S1} = 0.911\ \mathrm{D2}$

$$= 0.911 \times (7.45)2$$

$$= 50.5 \text{ m2}$$

$$S2 = 0.8345 \text{ D2}$$

$$= 0.8345 \times (7.45)2$$

$$= 46.3 \text{ m2}$$

Calculation on Volume of Hydraulic Chamber:

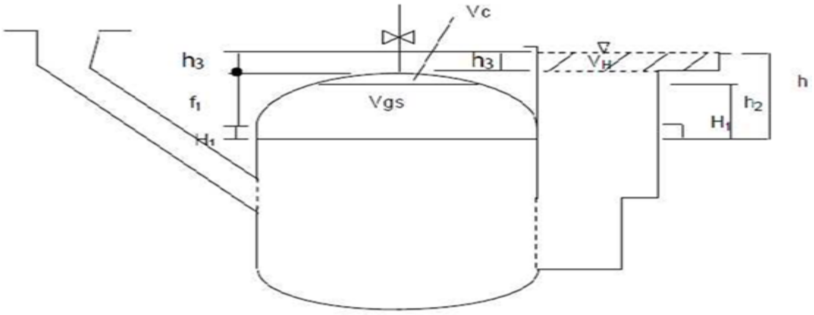

Figure 20: Geometrical dimensions of hydraulic chamber

$$Vgs = 0.5 \times (0.8V + Vs) \times K,$$

Where Kr= 0.3 = gas production rate per m3 digested $\frac{\text{vol}}{\text{day}}$ [50].

$$Vgs = 0.5 \times (0.8V + vs) \times 0.4$$

$$= 35.5\, m3$$

$$Vgs + Vf = 0.8V$$

$$Vf = 0.8V - Vgs$$

$$= (0.8 \times 185.5) - 26$$

$$= 113\, m3$$

$$V1 = [(VC + Vgs) - \pi\, D2\, H1],$$

where V1 = 34.2m3 and D = 7.45m

$$\text{H1} = \frac{4 \times [(\text{VC} + \text{Vgs}) - \text{V1}]}{\pi \text{D}^2}$$

$$= \frac{4 \times [(9.3 + 35.5) - 34.2]}{3.14 \times 7.45^2}$$

$$= 0.8\text{m}$$

$$h = 0.8\,H$$

$$= 0.8 \times 3\text{ m} = 2.4\text{ m}$$

$$h = h3 + f1 + H1$$

$$h3 = h - (f1 + H1)$$

$$h3 = 0.1\text{m}$$

$$Vgs = V\,H$$

$$Vgs = 3.14 \times (DH)^2 \times \frac{h3}{4},$$

where $Vgs = 26.5\text{ m3}$

$$DH^2 = \frac{Vgs \times 4}{3.14 \times h3}$$

$$DH^2 = \frac{26.5 \times 4}{3.14 \times 0.2}$$

$$DH = 13\text{ m}$$

Where DH is diameter of hydraulic chamber

4.8 Mixing Pit

Cylindrical shape was selected based on its advantage i.e. it increases the efficiency of mixing. The diameter and height of the cylindrical mixing pit were assumed to be equal. The volume of the mixing pit was designed to be equal with the daily input of the food waste after it gives a 10% safety factor [1].

$$V = \pi Di2hi/4 + 0.1V, \qquad (4.6)$$

Where V is the daily input of the food waste, the daily substrate input is 5.5 m^3

So, $V = 5.5\text{ m3} + 0.1 \times 5.5\text{ m3} = 6.25\text{ m3}$.

Since the diameter and height are equal $V=\pi Di3/4$, $Di= (6.25\times 4\text{ m}^3/\pi)^{1/3}= 1.82\text{ m}= hi$

Table 10: Digester component designed

Component	symbol	Volume(m3)	Dimension(m)	
			D	H
capacity of the plant	V	185.5		
working volume	Vw	148.25		
Gas collecting chamber	Vc	9.3		–
Gas storage chamber	Vgs	26.4		
Fermentation chamber	Vf = V3	113		
Mixing Pit	D		1.9	
Volume of slurry	V2	27.8		
Hydraulic chamber			13	2.08

CHAPTER FIVE

DESIGN OF BIOGAS STOVE

Cooking is an essential daily household activity and it consumes significant quantities of energy and human effort. Considering the hazardous effect and the awkward nature of cooking with wood and fossil fuel, an alternative energy source for cooking that is renewable will be a welcome development. Biogas produced from anaerobic digestion of organic biodegradable waste can be used as an alternative fuel source for domestic cooking. Biogas comprises mainly of methane (CH4), carbon (IV) oxide (CO2), and other constituents such as Hydrogen Sulphide (H2S), and water vapor (H2O), among others. Gas produced because of fermentation process contains a high calorific value and can be used for cooking and lighting purpose. Cooking with biogas will help to reduce the amount of unwanted gases released into our ecosystem. Biogas burns in a clean way, so no harmful gas is released during combustion [51].

Biogas stove is a relatively simple appliance for direct combustion of biogas. Its burner is a premix and multi-holed burning ports type and operates at atmospheric low pressure. A typical biogas stove consists of gas supply tube, gas tap/valve, gas injector jet, primary air opening(s) or regulator, throat, gas mixing tube/manifold, burner head, burner ports (orifices), pot supports and body frame [52].

5.2 Design Parameters

Several design parameters were taken into account for efficient and optimum design, such as the air required for complete combustion, injector orifice, primary aeration, flame port, and mixing tube and throat.

5.2.1 Injector

An injector needs to be carefully designed and positioned in order to control the amount of gas and air used by a burner. The size and shape of the injector orifice control the gas flow rate and hence heat input for a given gas composition and supply pressure [53].

5.2.2 Discharge from an orifice

In physical terms, an injector uses to convert potential energy from high-pressure gas supply into the kinetic energy of an emerging gas jet. Mathematically, therefore, by conservation of energy and assuming no losses at the nozzle, we have (per unit mass):

$$\frac{1}{2}V^2 = \ gh\ Or\ \dot{V} = \ Aj\sqrt{2gh} \qquad (5.1)$$

$V^{\cdot} - \ Volumetric\ gas\ flow\ rate\ from\ the\ orifice\ (m3\ s-1)$

Aj - jet area (m^2)

g -acceleration due to gravity

h -column of gas required to exert gas pressure at the orifice

Gauge pressure is given as

$$p = h\rho g_{g} \qquad (5.2)$$

$Where;\ \rho = density\ of\ biogas\ (1.15 kg/m3)$

From equation 1 and 2 [54].

$$Q = 0.046101 Aj \sqrt{\frac{P}{S}} \qquad (5.3)$$

Where: $Q = $ gas flow rate $(m3\ h - 1)$

$Aj = area\ of\ orifice\ (mm2)$

$p = gas\ pressure\ before\ orifice\ (10 mbar)$

$s = specific\ gravity\ of\ biogas\ gas\ (0.94)$

Relative density (specific gravity) of methane and Carbon dioxide (with air density =1 kg/m3) is 0.554 kg/m3 and 1.519kg/m3 respectively. Volumetric content of biogas is 60% methane and 40% carbon dioxide; based on the volumetric content specific gravity of biogas expressed as:

$$s = \left(0.554 \frac{kg}{m3} \times 60\%\right) + \left(1.519 \frac{kg}{m3} \times 40\%\right)$$

$$= 0.94\ kg/m3$$

In practice, the flow of gas after orifice is less than before orifice because of frictional losses and the vena-contract effect. It is usual to represent these two terms as a coefficient of discharge, CD such that:

$$Q = 0.046101 Aj CD \sqrt{(P / S)} \qquad (5.4)$$

CD = coefficient of discharge for the orifice is taken 0.9 [55].

5.2.3 Biogas Combustion

For complete combustion, enough quantity of air is required. Sufficient air will help to release the potential heat contained in the biogas fuel. However, inadequate air supply would lead to loss of potential heat as a result of incomplete combustion [51].

The combustion of gas involves mixing air with fuel gas, adding heat in the form of a pilot and burning the resultant air-gas mixture. The chemical reaction of combustion of biogas (containing 60 % methane and 40 % carbon dioxide) and air (oxygen and nitrogen) mixture shown below

$$0.6CH4\ +\ 0.4CO2\ +\ 1.2O2\ +\ 4.5N2\ \rightarrow\ CO2\ +\ 1.2\ H2O\ +\ 4.5N2\ +\ Energy \tag{5.5}$$

Thus, one volume of biogas requires 5.7 volumes of air or the stoichiometric requirement is1/ (1+5.7) = 0.149, i.e., 14.9 % volume of biogas is required in air.

Characteristics of biogas important from the viewpoint of designing an efficient stove or a lamp mentioned in table bellows.

Table 11: Properties of Biogas Relevant for Designing a Stove or A lamp [56].

Property	Value
Methane And Carbon Dioxide Content	60% And 40 %
Calorific Value	22MJ/m^3
Specific Gravity	0.940
Density	1.2Kg/m3
Flame Speed Factor	11.1
Air Requirement For Combustion	5.7 M^3/m^3
Combustion	40cm/Sec
Inflammability In Air	6-25%

Biogas will burn over a narrow range of mixtures from approximately 9% to 17% of biogas in air. If the flame is `too rich', i.e., has too much fuel, then it will burn badly and incompletely, giving carbon monoxide (which is poisonous) and soot (carbon particles). Burners are usually run "slightly lean", with a small excess air, to avoid the danger of the flame becoming rich [54].

In partially aerated burners, air mixed with the gas before burning. The amount of primary air added to the gas before the flame is varies depending on the design of the burner, but is usually around 50% of the total air requirement.

5.2.4 Aerated flame

As gas comes out through the injector, primary air is entrained into the stream and is mixed in the mixing tube with the gas before it comes out of the burner port. The unburned gas is heated up in an inner cone and starts burning at the flame front. The cone shape is a result of laminar flow in a cylindrical mixing tube, the mixture at the center of the tube is moving at a higher velocity than that at the outside. The main combustion zone is where the gas burns in the primary air and generates the heat in the flame. The Outer mantle of the flame is where combustion is completed with the aid of the secondary air that is drawn into the flame from the sides.

The combustion products (carbon dioxide and steam) are at a high temperature, so rise vertically away from the flame, transferring heat to the air close to the top of the flame. It is this air moving vertically away that draws in the cooler secondary air to the base of the flame. The size of the inner cone depends on the primary aeration. A high proportion of primary air makes the flame much smaller and concentrated, giving higher flame temperatures [53].

5.2.5 Air entrainment

The mechanism of air entrainment has been studied experimentally and theoretically for many years, and is of vital interest to the domestic aerated burner designers because the quantity of primary air taken up has a considerable effect on burner port design requirements, flame stability, shape and temperature, and, ultimately, the design of the combustion chamber itself.

The gas emerging from the injector enters the end of the mixing tube in a region called the “throat”. The throat has a much larger diameter than the injector does, so the velocity of the gas stream is much reduced.

The velocity $\boldsymbol{vj}$ of the gas in the orifice is given by:

$$Vj = Q/3.6 \times 10-3Ajms-1, with\ Q\ in\ m3h-1\ and\ Aj\ in\ (mm)2 \qquad (5.6)$$

Velocity reduction in the throat is expressed as:

$$vt = vj\ Aj/At \qquad (5.7)$$

Ignoring the vena contractor effect and friction loss the gas pressure just after the nozzle then becomes:

$$Pt = Pj - \rho \frac{vj^2}{2g}\left[1 - \left(\frac{dj}{dt}\right)^4\right] \qquad (5.8)$$

The value of Pj is around atmospheric pressure as the throat is open to the air. This pressure drop is sufficient to draw primary air by the air inlet parts to mix with the gas in the mixing tube [53]

The primary aeration depends on the entrainment ratio (r) which is determined by the area of the throat and the injector. Throat size

The flow rate of the mixture in the throat Qm is the sum of the flow rate of the gas and the entrained air

$$Qm = Qgas(1 + r) \qquad (5.9)$$

Where r is the entrained air to gas volume ratio, then: $\mathrm{r} = \frac{\mathrm{Qair}}{\mathrm{Qgas}}$

The pressure drop due to the flow of the mixture down the mixing tube should be checked, by first calculating the Reynolds number.

$$R = \frac{\rho m dt vt}{\mu} = \frac{4\rho m Qm}{\pi \mu m dt} \qquad (5.10)$$

Where ρm and μm density and viscosity of the mixture specified as follows:

$\rho m = 1.15Kg/m3$ And

$\mu m\ =\ 1.71\ \times\ 10 - 5\ Pa\ s$ At a temperature of 30^{o}C

The pressure drop ΔP given by:

$$\Delta P\ = f/2\ \rho mvt{\wedge}2\ \ lm/dt = f/2\ \rho m\ 16Qm/\pi 2dt5\ lm \qquad (5.11)$$

$Where: f\ = \frac{Re}{64}$, When $Re\ <\ 2000$ and

$$f\ = \frac{0.316}{Re^{3/4}} \quad \text{When } Re\ >\ 2000 \qquad (5.12)$$

The pressure drop should be much less than the driving pressure. Most burners are designed to have a throat that gives aeration greater than optimum, with a device for restricting the airflow, so the optimum aeration can be set for a given situation.

5.2.6 Mixing tube

The mixing tube and diffuser as one unit obtained by experiment. The effect on air entrainment of mixing tube length both downstream and upstream of the throat from practical result the distance from the throat entrance to the injector should be about 2 to 2.5 times the throat diameter, and that mixing tube length should be about 10 to 12 throat diameters [53].

5.2.7 Burner Ports

The big advantage of a gas burner is that the heat can be directed to where it is needed, by designing the burner properly. When a biogas/air mixture has ignited, the flame front produced propagates through the remaining unburnt gases at a rate dependent on the mixture composition, pressure, and temperature. The burning velocity is a fundamental property of the mixture and is linked to the overall chemical reaction rate in the flame. Burning velocity defined as the velocity normal to the flame front, relative to the unburnt gas, at which an infinite one-dimensional flame propagates through the unburnt gas mixture. Biogas has a stoichiometric flame speed of only 0.25 m/s burning velocity [14]**.**

The mixing supply velocity vp given by:

$$vp\ =\ \frac{Qm}{AP} \ll\ 0.25ms - 1 \qquad (5.13)$$

Where: Ap (the total burner port area in $m2$)

$$=\ np\ \frac{\pi dp2}{4} \qquad (5.14)$$

np - Number of ports

dp − Diameter of each port in m

5.2.8 Flame Stability

Biogas flame is cone-shaped and consists of an inner cone and an outer mantle as shown in Figure 13 When biogas, air mixture reaches the burner ports and burnt with a 16 pilot heat, it forms a cone-shaped blue flame. The cone shape of the flame is a result of laminar flow in a cylindrical mixing tube. As gas comes out of the injector, air is "entrained" into the stream and is mixed in the mixing tube with the gas before it comes out of the burner port. The unburned gas is heated up in an "inner core" and starts burning at the "flame front". The cone shape is a result of laminar flow in a cylindrical mixing tube, the mixture at the center of the tube is moving at a higher velocity than that at the outside.

The main "combustion zone" is where the gas burns in the primary air and generates the heat in the flame. The "Outer mantle" of the flame is where combustion is completed with the aid of the secondary air that is drawn into the flame from the sides.

The combustion products (carbon dioxide and steam) are at a high temperature, so rise vertically away from the flame, transferring heat to the air close to the top of the flame. It is this air moving vertically away that draws in the cooler secondary air to the base of the flame. The size of the inner cone depends on the primary aeration. A high proportion of primary air makes the flame much smaller and concentrated, giving higher flame temperatures [57].

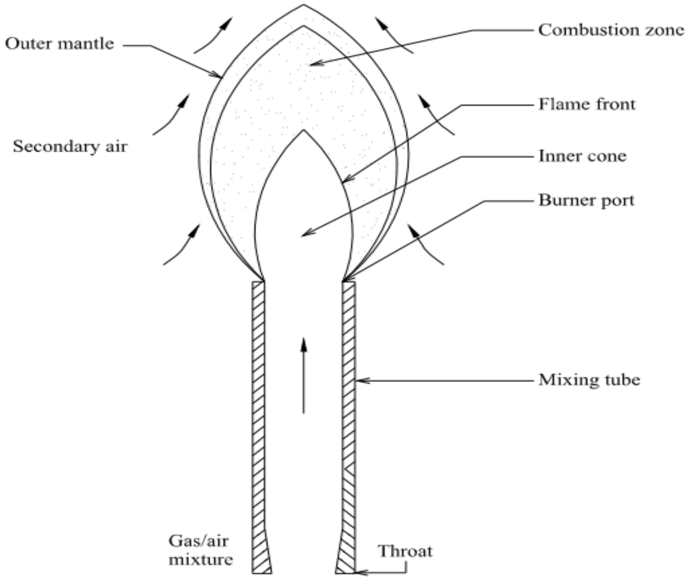

Figure 21: Biogas flame [50]

5.3 Analytical Design Analysis

5.3.1 Power Required Estimation

Considering the efficiency of the traditional stove, which is 8% the power required for the process, can be determined using the general equation of efficiency. With a calorific value (CV) of wood at 19.45 MJ/Kg and specific fuel consumption of the process 0.6054Kg of wood per Kg of one Injera. In order to bake the mass of the dough which 497.5 grams of injera, it took about 4.74 minutes including heat up, cooking and idle period [58].

Basic input data:

- Number of injera baked per day in Assosa university cafeteria is equal to 12000
- The number of traditional stoves used for the process is 65.
- Total mass of injera baked per day which is equal to (0.4975 kg×12000 = 5970 Kg)
- If 0.4975 kg took 4.74 minutes, then 5970kg takes 14.5 hours by using 65 baking stoves.
- The maximum average time it consumes for the process of baking per day is 14.5hr.
- The maximum average gas generated per day 110m^3 from biogas digester.

To determining, the power required could be first calculating the rate at which firewood is being burned for one Injera as follows

$$= (0.6054\ (kg\ of wood)/(kg\ of\ Injera) \times 5970\ Kg)/(65 \times 14.5hr)$$

= 3.82 Kg of wood/hr

Then using the same values of efficiency and calorific value of wood we can come up with the power.

$$Efficiency\ = \frac{Power\ output}{Power\ input} \tag{5.15}$$

$$Efficiency\ of\ traditional\ stove\ = \frac{Power\ output}{CV\ of\ wood \times \frac{mass\ of wood}{hr}} \tag{5.16}$$

$$0.08 = (power\ output)/(19.45MJ/kg \times 3.82Kg/hr)$$

Power output required = 1.647KW

Therefore, the Injera baking process requires or needs 1.647KW power output which is related to the reference value before 1.5KW [41].

In determining the biogas flow rate to meet the power input required for the process knowing the power required of the process being 1.647KW, calorific value of biogas 22MJ/m3 and setting optimum biogas stove efficiency of 50% can be calculated as follows;

$$Efficiency\ of\ biogas\ stove\ = \frac{Power\ output}{CV\ of\ biogas \times Qbiogas} \tag{5.17}$$

$$0.5\ = \frac{1.647\text{KW}}{22 \times \text{Qbiogas}}$$

$$Q_{\text{biogas}} = 0.536\text{m}^3/\text{hr}$$

5.3.2 Energy required

By considering, the efficiency of the traditional stove, which is 8% the energy required for the process can be determined using the general equation of efficiency. With a calorific value (CV) of wood at 19.45 MJ/Kg and specific fuel consumption of the process, 0.6054Kg of wood per Kg of Injera baked. The energy required to cook one kilogram of food will be:

$$Efficiency\ of\ traditional\ stove\ = \frac{Energy\ \ out\ put}{CV\ of\ wood \times \frac{mass\ wood\ consumed}{mass\ of\ injera}} \tag{5.18}$$

$$0.08\ = \frac{Energy\ \ out\ put}{19.45\ MJ \times \frac{0.6054\ Kg}{Kg}}$$

Energy output = 0.94209MJ/kg of Injera

Therefore, the energy required to bake one kilogram of Injera is 0.94209MJ/Kg of Injera. We can determine the volume of gas required as an input with an optimum biogas stove efficiency of 50% to achieve the energy required for the process with a calorific value of the biogas to be 22MJ/m3 as follows.

$$\text{Efficiency of biogas stove}\ = \frac{\text{Energy output}}{\text{CV of biogas} \times \frac{\text{Volume of biogas}}{\text{mass of injera}}} \tag{5.19}$$

$$0.5\ = \frac{0.94209\text{MJ} \times \text{Kg of Injera}}{22\text{MJ} \times \text{Volume of biogas}}$$

Volume = 0.0856m3/kg of Injera

Therefore, one kg of Injera need 0.08557 m3 volume of biogas.

However, the total mass of Injera baked per day in the Assosa University cafeteria was 5970 kg, which needs 0.0856m3/kg Injera×5970kg = 511.032-m3 volume of gas. However, for each stove =511m3/65 $=7.75\text{m}^3$

Then to get the amount of the gas required in one hour first calculate rate mass of Injera baked in one hour as follows: The rate of Injera baked per hour = $\frac{5970kg}{65 \times 14.5hr}$

= 6.2Kg Injera/hr

The volume gas required per hour for process of Injera baking application by using biogas stoves is equals:

Volume flows rate (Q) = 0.085m3/Kg Injera ×6.2Kg Injera/hr
= 0.535m^3/hr
One biogas stove consume = 0.534m^3/hr×14.5hr
= 7.75m^3 because each stove needs in order to operate in14.5hr.

5.3.3 The Potential of Biogas in Reducing Firewood

From the results of calculations made above and gas generated per day from food waste the potential of biogas in reducing firewood dependence of Injera baking process can be evaluated.

Biogas flow rate required for the process of Injera baking at 0.535 m^3/hr and biogas production potential of the fixed dome plant at 110m^3 the amount of time the biogas can serve the Injera baking is 110 m3/0.53m^3/hr = 206.38hr. However, the traditional baking stove burns 206.38hr × 3.81Kg of wood/hr = 788.37Kg of firewood to perform the same process. Therefore, this 788.37Kg of firewood that could have been burned can be replaced by the biogas and it accounts for 21.6% of the total 3611.49Kg/day of firewood consumption.

Also, 110 m3 per day gas generated can be bake 1285kg that means 2582 number of Injera and it accounts for 21.6% of the total 12000 baked per day because one kg of Injera need 0.0856m3 volume of biogas. And consuming 108.4m3 volume of gas using 14 biogas stove in 14.5 hr time.

5.4 Sizing the gasholder

The size of the gasholder, i.e. the gasholder volume Vg, depends on the relative rates of gas generation and gas consumption. The gasholder must be designed to[59]:

- cover the peak consumption rate gcmax (Vg1) and
- hold the gas produced during the longest zero-consumption period tzmax (Vg2)

$$Vg1 = gcmax \times tcmax = vcmax \qquad (4.7)$$

$$Vg2 = Gh \times tzmax \qquad (4.8)$$

gcmax = maximum hourly gas consumption [m3/h]

tcmax = time of maximum consumption [h]

vcmax = maximum gas consumption [m3]
Gh = hourly gas production [m3/h] = G ÷ 24 h/d
tzmax = maximum zero-consumption time [h]

All data input needed for the design of the gasholder is listed in the table bellows from section 5.32.

Table 12: list of parameters

No	Parameter	Value
1	Maximum Hourly Gas Consumption [m3/hr]	0.534×14=7.476
2	Time of Maximum Consumption [hr]	14.5
3	Maximum Gas Consumption [m3]	108.4m3
4	Hourly Gas Production [m3/hr]	110/24=4.58
5	Maximum Zero-Consumption Time [hr]	11

By using the equation 4.7 and 4.8 above:

$$Vg1 = 0.534 m3/hr \times 14.5 hr \times 14$$

$$= 108.4 m^3$$

$$Vg2 = 7.58\ m^3/hr \times 11 hr$$

$$= 83.4 m^3$$

The larger Vg-value (Vg1 or Vg2) determines the size of the gasholder. A safety margin of 10- 20% should be added: Vg = 1.15 (±0.5) × max (Vg1, Vg2)

The volume of gasholder $Vg = 1.2 \times 108.458\ m^3$

$$= 130.22\ m^3$$

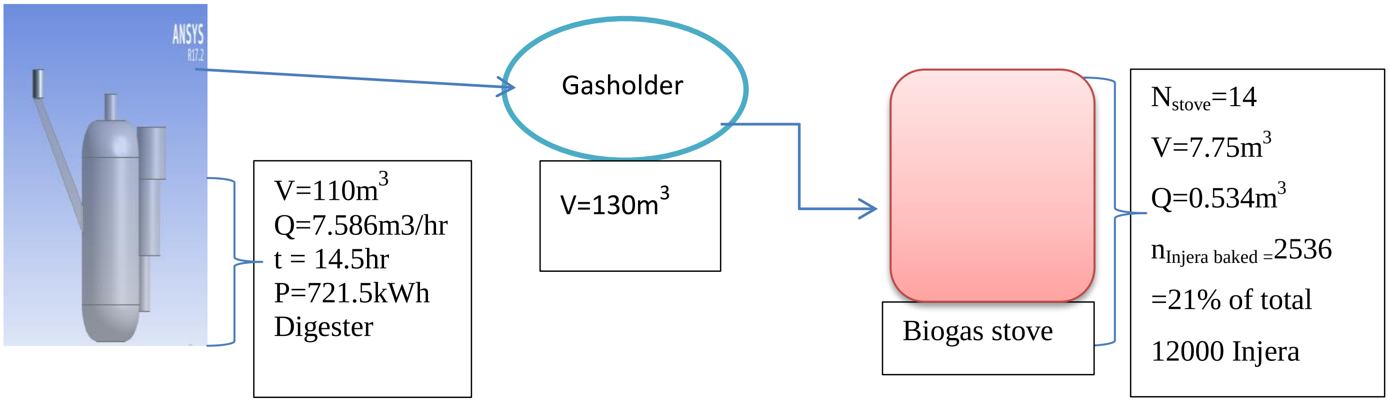

Figure 22: Layout of the biogas flow process from digester to total stoves.

5.3.4 GHG Emission Reduction

To minimize environmental air pollution minimizing the release of CO and CO2 from firewood burning which are the main GHGs and avoiding the release of CH4, this is 25 times more pollutant than CO2. For wood combustion the CO2 emission factor reported in previous studies suggested between 1560–, 1620 g/kg (gram of CO2 per kilo of wood combusted) and others such as CO, CH4, and NOx are in the range 19-136 g/Kg, 6-10 g/Kg and 0.05-0.2 g/Kg respectively [57]. Then the amount firewood combusted per day in Assosa university cafeterias are 3611.8 kg of wood is combusted per production day at Assosa University where they bake 7 days per week, ten-month by excluding two summer and using 65 traditional Injera baking stoves.

From this the considering the worst-case scenario of the traditional injera baking stove perform their tasks throughout the year without fail the annual firewood consumption will be:

Wannum = 3611.8 × 7 ×44 × 65 = 72309837.6 kg/annum,

The amount of CO2 released from the injera baking process at the Assosa university cafeteria only will be CO2 emission = 1.59×72309837.6 kg/annum=114972641kg/annum. The amount of CO released from the injera baking process at Assosa University only will be CO emission = 5604012kg/annum, The amount of CH4 released from Injera baking process at Assosa University is CH4 emission = 578478.32kg/annum. The amount of NOX released from injera baking process at Assosa University only will be CO2emission = 9038kg/annum and the total GHGs emitted for the three pollutants is:

$\text{GHG}emission = \text{CO2emission} + \text{COemission} + \text{CH4emission} + \text{NO}X\text{emission}$

$\text{GHG}_{\text{emission}}$ = 121164169.7kg/annum.With the current injera baking wood consumption pattern the amount of GHGs emitted to the environment per annum is 121164.1697kg tones.

Therefore, the amount GHGs emitted to the environmental saved by using biogas stove is 21% of total firewood burned per day, which is 25444475.5kg.

5.5 Analytical Design of Biogas Stove

The design analysis of biogas Injera backing burner involves the determination of the following important parameters like:

- Injector orifice (jet) size,
- throat size, burner port, diameter of the jet ($\boldsymbol{dj}$),
- length of the air intake holes measured from the end of the jet,
- length of the mixing pipe, number, and diameter of flame portholes, and
- height of the burner head[41].

5.4.1 Determination of injector orifice (jet) size

Material used for an injector is brass. Because the material is soft for drilling, less expensive in terms of cost, Available in the market and can withstand high temperature.

The size and shape of the injector orifice control the gas flow rate and hence heat input for a given gas composition and supply pressure. Using Cd = 0.94 and gas supply pressure of 10 mbar [55].

By using equation 5.3

$$Q \ = \ 0.046101 AjCD\sqrt{P/_{S}}$$

$$\text{dj}= \sqrt{\frac{0.535}{0.036\times0.9}}\times\sqrt[4]{\frac{0.94}{10}}$$

$$= 2.2\text{mm}$$

Where: Q (gas flow rate) = 0.535 m^3/ hr

The area of orifice jet is determined as:

The area of the injector orifice (A0) is determined as follows:

$$\text{Ao} = \frac{\pi \text{dt}^2}{4} \ = \frac{\pi(2.2)2}{4}$$

$$= \ 3.81 \times 10 - 6\text{m}2$$

The velocity of gas in the orifice (V_O) is:

Finally, using Aj= 5.51mm^2, the velocity of the biogas in the orifice jet

$$vj = \frac{Qbiogas}{Aj\times3.6*10-3}$$

=39.9ms-1

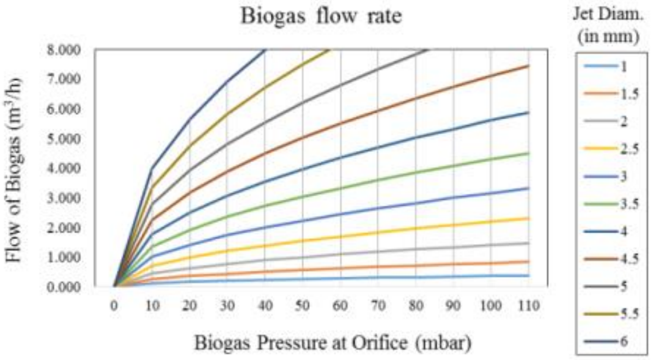

Figure 23: The graph of biogas flow rate versus pressure at orifice

5.4.2 Determination of throat size

From the composition of biogas, the stoichiometric air requirement is 5.7, and then the entrainment ratio (r) should be half of the air requirement, which is equal to 2.85.

The flow rate of the biogas and air mixture at optimum aeration is given by equation (5.9)

$$Qm \ = QBiogas(1 + r \ )$$

$$= 0.532 \text{ m3/hr } (1+2.85)$$

$$= 5.8 \ \times 10 - 4 \, m3/s$$

Throat diameter (td) is calculated using Prig's formula including orifice diameter as follows[53]:

$$dt = \left(\frac{r}{\sqrt{s}} + 1\right) dj$$

$$= (2.85/\sqrt{0.94}+1) \times 2.2\text{mm}$$

$$= 8.6\text{mm}$$

However, it is better to use the stoichiometric value of primary air of 5.7 directly rather than using r = 2.85 to get better aeration and control using primary airflow adjuster.

$$= (\frac{5.7}{\sqrt{0.94}} + 1) \times 2.2\text{mm}$$

$$= 15.13\text{mm}$$

Therefore, the better design diameter of the throat will be 15.13mm. Then the throat area becomes 179.79mm^2. The air inlet ports must have an area similar to that of the throat [41].

Length of the mixing pipe can be calculated as:

$$Lm = 12 \times 15.13\text{mm}$$

$$= 181.56\text{mm}$$

The gas pressure in the throat (P_t) can be calculated as:

$$Pt = \ Pj \ - \ \rho \frac{vj^2}{2g} \left[1 - \left(\frac{dj}{dt}\right)^4 \right]$$

$$Pt = 105pa \ - \ 1.2 \frac{39.9^2}{2 \times 9.81} \left[1 - \left(\frac{2.2}{15.13}\right)^4 \right]$$

$$= (10^5 - 99.9) \text{ pa}$$

$$= 99912.7 \text{ Pascal}$$

The value of Pj is 10^5Pasical as the throat is open to the air. This pressure drop is sufficient to draw primary air by the air inlet parts to mix with the gas in the mixing tube[53].

Calculating the Reynolds number should be used to check the pressure drop due to the flow of biogas and air mixture in the mixing tube:

$$R = \frac{\rho m d t v t}{\mu} = \frac{4 \rho m Q m}{\pi \mu m d t}$$

$$= \frac{4 \times 1.15 \times 5.8 \times 10 - 4}{\pi \times 1.71 \times 10 - 5 \times 15.13 mm}$$

$$= 3282.47$$

Where ρm and μm density and viscosity of the mixture specified as follows:

$\rho m = 1.15 Kg/m3$An

$\mu m = 1.71 \times 10 - 5\ Pa\ s$ At a temperature of 30°C

Re >2000 (flow of biogas and air mixture in the mixing tube is turbulent),

So the friction loss is calculated as:

$$\mathrm{f} = \frac{0.036}{Re^{1/4}} = 0.00475$$

Pressure drop (ΔP) could be calculated as follows:

The pressure drop ΔP given by:

$$\Delta P = \frac{f}{2} \rho m v t^2 \frac{lm}{dt} = \frac{f}{2} \rho m \frac{16 Q m 2}{\pi 2 d t 5} lm$$

$$= \frac{0.0045}{2} 1.15 \frac{16 \times 0.000535}{\pi 2 \times 0.0156\ 5} \times 0.181$$

$$= 2.05 \mathrm{pa}$$

However, this pressure drop is much lower than the driving pressure or the pressure in the throat which is = 99912.7 Pascal.

5.4.3 Burner Port Design

Burner port is at which the gas flows from it and burnt. It is more affected by high temperature and the material selected for this purpose stainless steel resists a temperature of flame.

Biogas has a stoichiometric flame speed of only 0.25 m/s Burning velocity. The mixture supply velocity (vp) using equation (5.13) is vp =≪ 0.25ms-1.

The total burner port area will be chosen as:

$$A_P > = \frac{\boldsymbol{Q_m}}{\mathbf{vp}}$$

$$A_P > 5.8 \times 10 - 4/0.25$$

$$= 0.00232$$

Assume 30% area was added;

$$A_P = 0.00232 \times (1+30\%) \times m^2$$

$$= 3016.4mm^2$$

Fulford (1996) and Itodo (2007) in their study used 5mm and 2.5mm diameter holes respectively. However, a problem of flame lift was recorded at a diameter of less than 2.5 mm [53]. Using 2 mm port diameter to minimize the problem of flame lift, the total number of required ports will be:

$$\mathrm{Np} > \frac{4\mathrm{Ap}}{\pi d_p^2}$$

$$\mathrm{Np} = 4 \times 0.003016/\ (3.14 \times\ (0.002)2)$$

$$= 960$$

Using the flame stabilization, it should be possible to reduce this number of burner ports by up to 1/5 [41], so ~192 holes may be sufficient.

Among these 192 holes, 152 holes can be used for the outer manifold, with a hole diameter of 2mm and 4.5 mm gaps between holes, arranged in a circular pattern, gives a total outer circumference of 146× (2 + 4) = 876 mm. So that the centers of the holes will be placed around a circle of the outer diameter (D=876 mm/π) =278mm (~27.8 cm).

Then the remaining 40 holes can be used for the inner manifold diameter, with a hole diameter of 2mm and 4mm gaps between holes, arranged in a circular pattern, gives a total inner circumference of 40 × (2 + 4) = 240 mm. So that the centers of the holes are then placed around a circle of inner diameter (d= 240 mm/ π) =76.4mm (~7.6cm).

Table 13: parameters of burner stove

Biogas Flow Rate	0.535 m^3/hr
Jet Diameter	2.2mm
Throat Diameter	15.6mm
Mixing tube length	181mm
Area of orifice Injector	3.81mm^2
Velocity of Biogas In The Orifice	39.9ms-1
Port Diameter	2mm
Number of Burner Port	152
	40
Manifold Diameter	278mm outer
	76.4mm inner

CHAPTER 6

COST ESTIMATION

The table 16 below displays the key results of cost analysis using EES software for the construction of biogas plants in Assosa University with 148.5m3 volume capacity. As far as the costs of a biodigester are concerned, there are two major categories, which are construction cost, operation, and maintenance cost.

6.1 Construction cost (2019 price)

The construction costs include everything that is necessary for the installation of the biodigester in the specified area or in Assosa University. The construction cost and bill of quantities of 148.5m^3 sizes of the anaerobic digester is given in the following table 10.

Table 14: Total investment cost of the biogas plant

No.	Item	unit	cost/unit	quantity	Total cost
A	Construction Material				
1	Stone	m3	150	120	18000
2	Cement -100kg Bag	bag	300	231	69375
3	Gravel 1x2	m3	500	90	45000
4	Coarse Sand	m3	160	20	3200
5	Fine Sand	m3	50	26	1300
6	Inlet Gi Pipe 30 Cm Dia,Length 10m	piece	120	2	1200
7	Acrylic Emulsion Paint	lit	60	30	1800
Subtotal I					139875
B	Accessories				
8	Gas Pipe	m	75	20m length&1/2"dia	1500
9	Main Gas Pipe (Galvanized Steel)	m	200	14	2800
10	Main Gas Valve(Ball Value 1")	pcs	100	14	1400
11	Male-Female Socket Dia 0.5" Gi With Aluminum Threads	pcs	20	28	560
12	GI(Galvanized Iron) 90 Degree	pcs	20	58	1160

	Elbow				
13	T Socket 0.5" Dia, For Water Trap	pcs	30	28	840
14	Water Drain	pcs	40	14	1060
15	Gas Tap	pcs	40	18	720
16	Gas Rubber Hose Pipe 0.5" Dia, And 2 Clamps	pcs	20	30	60
17	Stove	pcs	3500	14	49000
18	Pressure Manometer	pcs	150	20	3000
19	Paint	gal	500	35	17500
Subtotal II					79600
	Labors	Unit	Cost/unit	quantity	Total cost
20	For Skilled Labor	number	200	10person*60day	120000
21	For Unskilled Labor	number	100	12person*20day	24000
Subtotal-III					144000
C	Total cost of installation				363375
22	Maintenance cost and others				105689
	Person taking care of thedigester	days	35	365	12775
23	Operation Cost	months	2000	2	60000
	Total investment				541839

6.2 Annual Operation and Maintenance Cost (2019 price)

The operation and maintenance costs consist of wage and material costs for the collection and feeding of the substrate, water supply, and operation of the plant, supervision, maintenance, and repair of the plant, storage of the effluent. The operation cost is assumed mainly to the salary of the operator i.e. a person who controls the biogas plant but the cost of feedstock is negligible, as it does not need to purchase. The annual operating period was estimated to be 10 months (excluding the two summer months).

6.3 Saved Cost

The amount of wood saved by using of fourteen-stove biogas burner with the current price of 4 ETB/Kg and 788.37Kg /day of wood saved per 10 months approximated as follows:

= 788.37Kg /day ×4ETB/Kg= 3153.2ETB/day

= 788.37Kg /day ×300day/years×4ETB/Kg = 945,960 ETB/years

Then the payback period can be easily estimated by the following formula [1].

Payback period = Total investment/ fuel or biomass cost saved

=541839/945,960 ETB/years

= 0.57

Table 15: Total cost of the fuel per year used in Assosa University

Fuel source	Quantity of biomass saved by biogas in 788.37Kg /day	Cost PerUnit In ETB	Total cost saved/day in ETB	Total cost saved per year in ETB	Payback period in years
Biomass	1	788.3*4	3153.2	945,960	0.5
				945,960	

Table 16: Calculation of payback period

Time in year	Cumulative cash flow	Cash flow(biomass saved)
0	-541839	-541839
1	404121	945,960
2	1350081	945,960
3	2296041	945,960

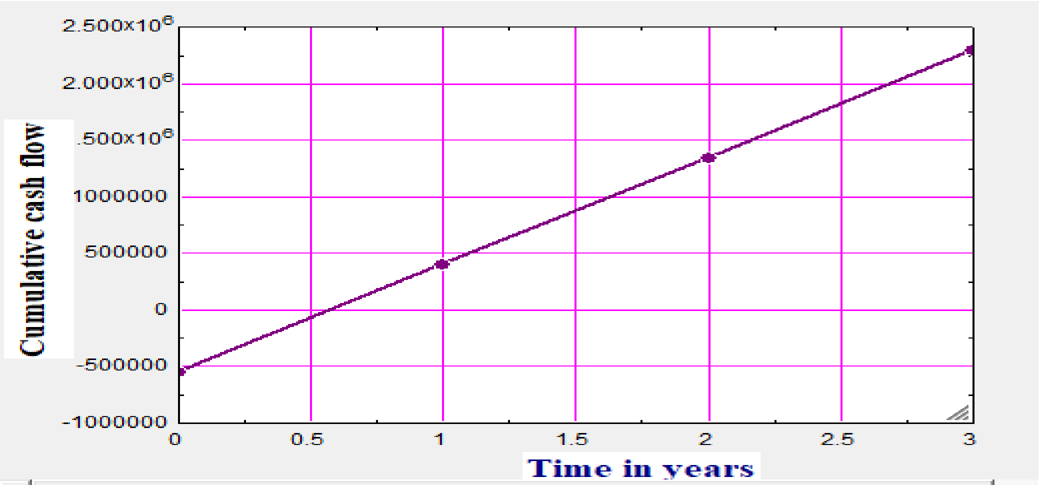

Figure 24: Number of years versus cumulative cash flow

From figure 18 we can understand that the payback period of the biogas plant is 2.1 years. This means that after 2.1 years Assosa University will start a profit from the biogas plant. The current fuel source which is a firewood will be replaced by the biogas and hence biogas will be used for baking applications on the campus.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Biogas plants convert food wastes to biogas and the biogas is a clean renewable energy, which will be used in different forms of environmentally friendly energy sources. The aim of the study was to solve the main problem of the workers those using firewood during Injera baking in the Assosa university cafeteria and environmental pollution. So all data needed for these research works are analyzed the amount of food waste that supplied per day was 1100kg.

After analyzing, the data total gas produced from food and kitchen wastes per day was $110m^3$/day. This gas produced using energy conversion gives 715 kWh of power per day. Having the daily input of food waste, retention time, different parameters of the biogas digester, the size of the biogas digester was analyzed. The capacity volume of the digester that designed was 148 m^3, From the performance evaluation gas generated per day from food waste the potential of biogas in reducing firewood was 788.5kg/day, that means 21% of total wood consumed per day, 2536 number of Injera could be baked by using fourteen biogas stove with in 14.5 hours and the amount GHGs emitted to the environmental saved by using biogas stove is 21% of total firewood burned per day, which is 25444475.5kg. The biogas stove having gas consumption rating of 0.5083m3/h was designed for Injera baking application.

In addition, the total investment cost of the plant 541839ETB, the amount of wood used for baking was approximated 945960ETB per year and the payback period of the plant is 0.57 years. This means Assosa University will start profit from biogas after six months and firewood, which is the current fuel source, or biomass, will be replaced by the biogas for baking of injera.

7.2 Recommendation

Some of the improvements that should be included in the future research work would be:

1. There should be a serious need for proper collection, and characterization of food waste and investigating their potential as a source of renewable energy in the university.
2. The digestate should be further studied.
3. For further study, Parameters that affect the production of biogas are analyzed experimentally or other simulation software.
4. The amount of biogas produced shall be upgraded if one wants to use the biogas for the application of electricity generation
5. Heat transfer distribution between the burner and the stove would be studied.

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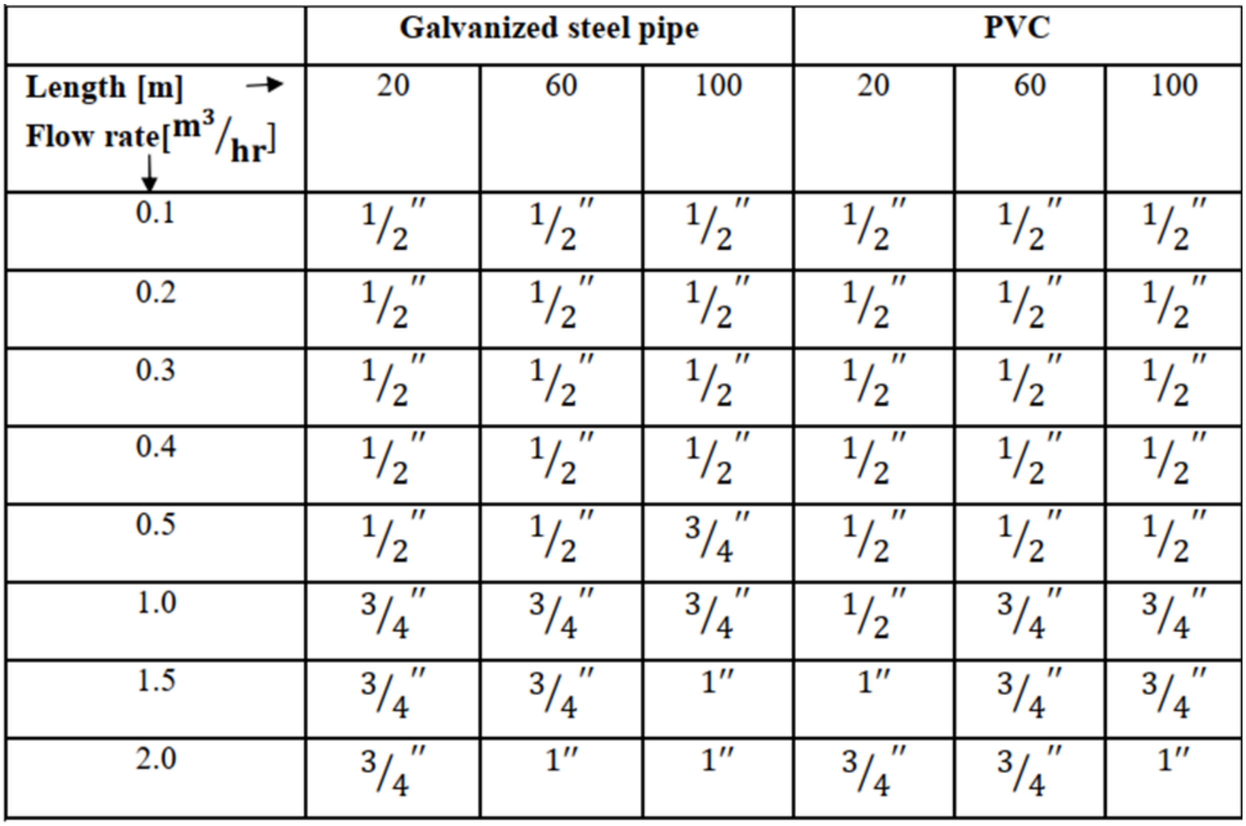
APPENDIX A

Figure 25:Appropriate pipe diameter for different pipe lengths and flow rate (maximum pressure loss < 5mbar) [43].

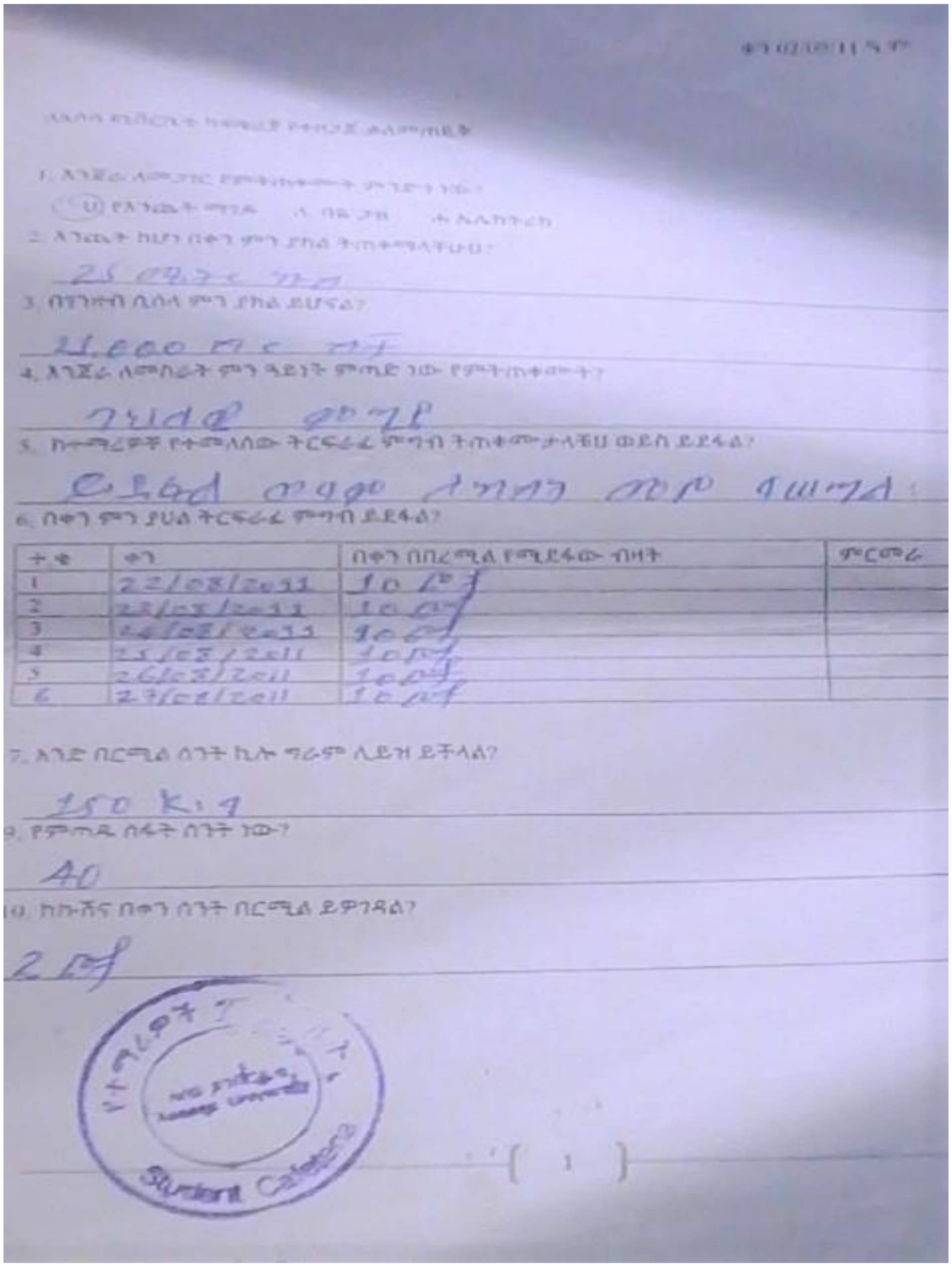


	Galvanized steel pipe			PVC		
Length [m] → Flow rate[m^3/hr] ↓	20	60	100	20	60	100
0.1	1/2″	1/2″	1/2″	1/2″	1/2″	1/2″
0.2	1/2″	1/2″	1/2″	1/2″	1/2″	1/2″
0.3	1/2″	1/2″	1/2″	1/2″	1/2″	1/2″
0.4	1/2″	1/2″	1/2″	1/2″	1/2″	1/2″
0.5	1/2″	1/2″	3/4″	1/2″	1/2″	1/2″
1.0	3/4″	3/4″	3/4″	1/2″	3/4″	3/4″
1.5	3/4″	3/4″	1″	1″	3/4″	3/4″
2.0	3/4″	1″	1″	3/4″	3/4″	1″

Figure 26: Water vapor pressure at a specific temperature [28].

Temp (^{o}C)	Vapor Pressure (mmHg)	Temp (^{o}C)	Vapor Pressure (mmHg)
-10	2.15	40	55.3
0	4.58	60	149.4
5	6.54	80	355.1
10	9.21	95	634
11	9.84	96	658
12	10.52	97	682

13	11.23	98	707
14	11.99	99	733
15	12.79	100	760
20	17.54	101	788
25	23.76	110	1074.6
30	31.8	120	1489
37	47.07	200	11659



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ለአሶሳ ዩኒቨርሲቲ ካፍቴሪያ የተዘጋጀ ቃለመጠይቅ

1. እንጀራ ለመጋገር የምትጠቀሙት ምንድን ነው?
[✓ ሀ) የእንጨት ማገዶ] ለ. ባዮ ጋዝ ሐ. ኤሌክትሪክ

2. እንጨት ከሆነ በቀን ምን ያክል ትጠቀማላችሁ?
25 ሜትር ኩብ

3. በገንዘብ ሲሰላ ምን ያክል ይሆናል?
21,000 ብር ነው

4. እንጀራ ለመስራት ምን ዓይነት ምጣድ ነው የምትጠቀሙት?
ባህላዊ ምጣድ

5. ከተማሪዎቹ የተመለሰው ትርፍራፊ ምግብ ትጠቀሙታላችሁ ወይስ ይደፋል?
ይደፋል [illegible] [illegible] [illegible] [illegible]

6. በቀን ምን ያህል ትርፍራፊ ምግብ ይደፋል?

ተ.ቁ	ቀን	በቀን በበርሚል የሚደፋው ብዛት	ምርመራ
1	22/08/2011	10 [illegible]	
2	23/08/2011	10 [illegible]	
3	24/08/2011	10 [illegible]	
4	25/08/2011	10 [illegible]	
5	26/08/2011	10 [illegible]	
6	27/08/2011	10 [illegible]	

7. አንድ በርሚል ስንት ኪሎ ግራም ሊይዝ ይችላል?
150 K.g

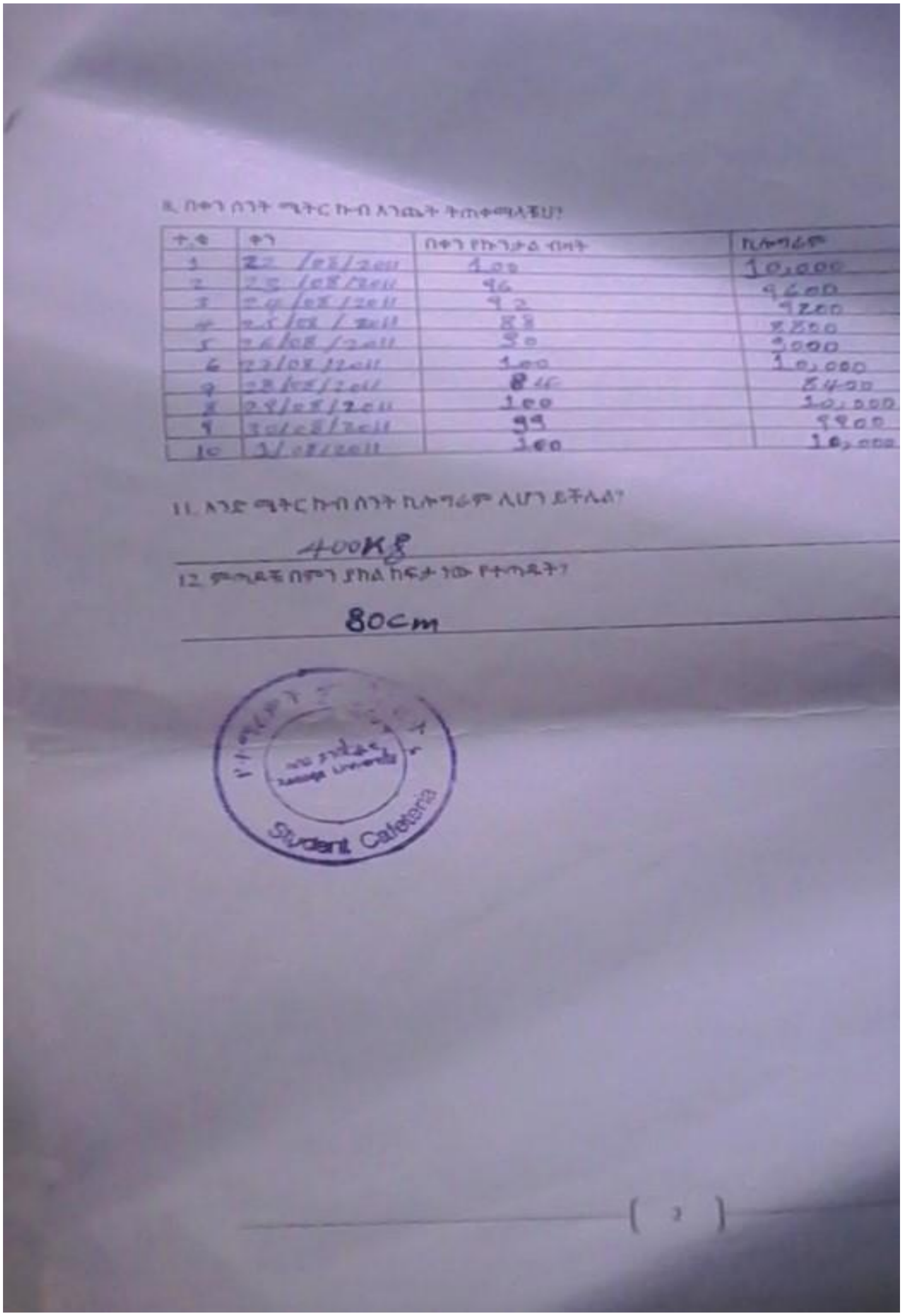
9. የምጣዱ ስፋት ስንት ነው?
40

10. ከኩሽና በቀን ስንት በርሚል ይወገዳል?
2 [illegible]

Student Cafeteria

1

B.Data recorded from Assosa university cafeteria, which is the amount of food waste



8. በቀን ስንት ሜትር ኩብ እንጨት ትጠቀማላችሁ?

ተ.ቁ	ቀን	በቀን የኩንታል ብዛት	ኪሎግራም
1	22/08/2011	100	10,000
2	23/08/2011	96	9600
3	24/08/2011	92	9200
4	25/08/2011	88	8800
5	26/08/2011	90	9000
6	27/08/2011	100	10,000
7	28/08/2011	84	8400
8	29/08/2011	100	10,000
9	30/08/2011	99	9900
10	1/08/2011	100	10,000

11. አንድ ሜትር ኩብ ስንት ኪሎግራም ሊሆን ይችላል?

400Kg

12. ምጣዶቹ በምን ያክል ከፍታ ነው የተጣዱት?

80cm

Student Cafeteria

(3)

B. Amount of firewood used in cafeteria