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Determining Biogas Energy Generation from Municipal Wastes and Designing an Appropriate Biogas digester (Case of Adama city)

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June, 2019

Adama

Acknowledgement

Thanks to Almighty God for the provision of every essentials that enabled us accomplish this work.

We would like to thank Adama Science and Technology University (ASTU) for accepting the research proposal, granting the requested fund and allotting additional time for accomplishing.

Further we would like to forward our thanks to different Governmental organizations in Adama and Addis Ababa city for their unreserved cooperation.

We would like to thank School of Mechanical, Chemical, and Materials Engineering for the rendered support.

Thanks to the team which has been bound together thoughtfully to bring this work to the end.

Further thanks to our families who have shared us their Conducive environment with this work carried to home.

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Acronyms

AAR----------------------Adama Assessment Report

COD---------------------------Chemical Oxygen Demand

CSA----------------------------Central Statistic Authority

EREDPC----------------------Ethiopian Rural Energy Development and Promotion Center

HRT----------------------------Hydraulic Retention Time

KVIC--------------------------Khadi and Village Industries Commission

MSE---------------------------Micro and small enterprise

MSW--------------------------Municipal Solid Waste

NBP---------------------------National Biogas Program

OECD------------------------Organization for Economic Cooperation and development

OFMSW---------------------Organic Fraction of Municipal Solid Waste

OLR---------------------------Organic Loading Rate

SNV---------------------------Netherlands Development Organization

SWM--------------------------Solid waste management

TS-----------------------------Total solids

VFA--------------------------Volatile fatty acids

VS----------------------------Volatile solids

Abstract

Fast growing cities are subjected to projected urbanization accompanied with increased number of population and income. This has resulted in increasing demand for energy and other services. Use of conventional type sources of energy such as wood, cow dung cake, charcoal etc. which are meant for domestic use have led to environmental deterioration and increased green house gas effect. Adama city is one of the fast growing cities in Ethiopia with increased number of population. It is clear that the rate of growth of population is directly proportional to solid wastes generated from the household of the urban cities such as Adama. The purpose of this study is to determine the size of energy generated from Adama Municipal biodegradable wastes and design an appropriate bio-digester suitable for the city. For this study the first step was identification of major sources of municipal biodegradable wastes; Thus, four categories such as domestic animal wastes, food wastes, household wastes, Fruit and Vegetable wastes, were identified. To determine the size of the wastes sample data collection was done. Further, data collection from literatures, documents of organizations in Adama and Addis Ababa was done. For a close study data of sample weight for each of identified major waste categories were collected for one week (or successive seven days); Average weight of wastes per day, and average weight of wastes per source per day were calculated. From this the average total weight of the biodegradable solid wastes was determined. The average total weight of biodegradable solid wastes in Adama city was found to be 1,323,938.24 kgs per day (or 1,323.938 metric tons per day). The biogas potential of the above total weight of biodegradable wastes was resulted to be in a range of 49,767.23 m^3 – 96,805.07 m^3 of biogas yield per day; The calorific value ranges from 1,094,879MJ - 2,129,711.54 MJ per day which can generate 84.6-164.6 MWh electricity per day. With this result and other parameters such as waste Total solid, Total influent etc. the total volume of the digester had been designed and was found to be 63,916.53 m^3. Having this result the location for construction of the digester, means of segregation, collection and transporting of wastes had been suggested. From this all we can conclude that the size of biodegradable waste in Adama city is very high and proper management and use will benefit the society otherwise will harm the society and environment.

Key words: Substrate, Total solid, Influent, compost, Solid waste, Biogas yield

CHAPTER 1

INTRODUCTION

1.1 Background

Energy is a crucial requirement for human life which deeply influences all aspects of human well-being such as access to water, food and its preservation, agricultural products, health, education, job, climate change, and environmental sustainability (Legros et al., 2009). Thus, the current global development challenges such as poverty, gender inequality, climate change, food insecurity, and problems of access to health care, and educational services can be addressed through sustainable, affordable, and dependable sources of energy (Bazilian et al., 2010).

The majority of the people in developing countries in general and Ethiopia in particular have no access to reliable and affordable sources of domestic energy. About 83 % of the total population in Sub-Saharan Africa and 91 % in least developed countries have no access to modern fuels. Even worse, access to modern fuels is much lower for rural people than the urban counterpart. By the year 2007, the proportions of urban population in Sub-Saharan Africa and least developed countries having access to modern fuels were 42 % and 27 %, respectively. But for the rural counterparts, the figures were merely 5 % and 3 % in the same order (Legros et al., 2009).

Ethiopia, being one of the least developed countries in Sub-Saharan Africa, suffers from a severe domestic energy problem. Among other things, the country's domestic energy problem can be manifested by the relatively very low per capita energy consumption and the dominance of traditional biomass fuel use. According to IEA (2015), in 2013, the per capita total primary energy supply in Ethiopia was merely 0.51 toe while it was 0.67 tons of oil equivalent (toe), 4.2 toe, and 1.9 toe for Africa, OECD countries, and the world average, respectively. The same source also indicated that the annual per capita electricity consumption in Ethiopia was only 65 kWh while it was 584 kWh, 8072 kWh, and 3026 kWh for Africa, OECD countries, and the world in the same order. Moreover, in 2009, the percentage of population who relied on traditional use of biomass fuels for cooking was 93 % in Ethiopia while it was 65 % for Africa, 77 % for Sub-Saharan Africa, and 39 % for the world as a whole (IEA, 2011).

Thus, rate of energy demand and consumption is rising and fast-growing in the world we live from time to time at exceptional rates. Ethiopia is a developing country that shares this energy demands more than usual. To meet this growing energy demands, the country is investing enormously to develop hydroelectric power by building dams over its rivers such as Awash, Gibe, Abay, Tekezie, Fincha etc; Besides, the country also relies substantially on the fuel it imports to meet its energy demand. It is obvious that Ethiopia's energy demand can be solved by developing a renewable and sustainable energy sources. The production of renewable and sustainable energy is possible from locally available materials with a reduced cost. It is clear that the locally available waste materials such as food and plant wastes are either used as fertilizer after being composed by individuals and some households or simply thrown on road sides or open areas deteriorating the conducive environment. Thus, such experience should be changed towards using wastes by capturing the energy that is stored in it.

In recent years a biogas generating technology is being employed as a favorable dual purpose technology; i.e. the biogas generated can be used to meet energy requirements while the organic residue is a useful fertilizer. Biogas is a type of renewable energy that can be produced from the biodegradable wastes.

In developing countries such as Ethiopia the majority of the people depend on solid forms of fuel such as fire wood to meet their basic energy needs for cooking and lighting. Over 60% of the total wood in developing countries is used as wood fuel in form of either charcoal, especially in the urban areas or as firewood mostly in the rural areas. This has resulted in depleting forests at a faster rate than they can be replaced. Biogas is a well-established fuel that can supplement or even replace wood as an energy source for cooking and lighting in developing countries. Currently, as the fossil-based fuels become scarce and more expensive, the economics of biogas production is turning out to be more favorable.

Many developing countries resolved their energy and waste problems by developing biogas technology. Ethiopia is one of the countries among those initiated to promote biogas technology to reduce the severe energy problem faced especially in the household energy sector since more of the energy requirement is allocated for the household energy. Thus, the promotion of biogas technology has started a long time ago (Siltan A.1989; as cited in Tadesse L. 2010).

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 25 years, around 1,000 biogas plants were constructed in households, communities, and governmental institutions in various parts of the country. For Ethiopia, livestock plays an important role as an agriculture-dependent country, where there has been little experience in biogas systems. Animal and human excreta are generally available within rural areas, and there is a potential for larger biogas digester program for cooking, lighting and other purposes within the country. Thus, currently Ethiopian Rural Energy Development and Promotion Center (EREDPC) and Netherlands Development Organization (SNV) have set up a National Biogas Program (NBP), and completed a feasibility study of a support program for domestic biogas plants in rural households in Ethiopia (Boers 2007, as cited in Tadesse L. 2010).

Municipal solid waste (MSW) generation is significantly increasing in Ethiopian urban areas and started creating enormous waste disposal problems in the recent past. In Ethiopia, MSW management is the duty of the local municipalities. The anaerobic digestion is an attractive option for energy generation from the putrescible fraction of MSW as well as for reducing the disposal problem. It has reduced environmental impact, especially with respect to the greenhouse effect and global warming (Yusuf, 2011; cited in Alemayehu G, 2014).

Amounts of municipal solid waste (MSW), and its composition, have been changing due to the changes in consumption behaviors of people along with the rapid advances of technology. A gradual increase in the amount of solid waste leads to various problems in transportation, storage, and disposal of this waste and makes efficient solid waste management complicated. MSW has great economic potential and the efficiency of waste management systems affects the potential economic value of MSW (Huseyin K.O. et. al., 2016).

Adama as being one of the fast growing towns of the country has increasing solid waste generation. According to the Central Statistical Agency, the population of Adama has a projected population size of 391,597 (C.S.A., 2009).

1.2 Statement of the problem

In developing countries over 60% of the total wood is used as wood fuel in form of either charcoal, especially in the urban areas or as firewood mostly in the rural areas; The most prominent issues in Ethiopia's domestic energy sector include heavy reliance on these solid forms of fuels to meet their basic energy needs such as cooking and lighting. At the same time, this has resulted in depleting forests at a faster rate than they can be replaced (Aremu and Agarry, 2013).

The use of biogas energy has to be prioritized in Ethiopia in the course of attempting: a) reducing deforestation and land degradation in the country; b) improving the living condition of the majority of the Ethiopian society (i.e. health and socio-economic situation of the households, including gender relations); and c) reducing the contribution of the green house gasses to climate change. Biogas is potential source of energy, particularly where there is an abundant supply of waste organic matter. It is expected that, the greater part of the potential have to be realized through community (institutional) biogas plants of large capacities. Therefore, it is imperative to intersect the growing interest of Biogas technology in Ethiopia at institutional as well as household level.

Adama, a city with a population of 391,597 (C.S.A., 2009) is one of fast urbanizing town is far from satisfying the infrastructure demand of its inhabitant. Its solid waste management is poor. Waste treatment, reduction from its source, recycling of wastes or energy recovery from the wastes are not well exercised, the main activity being done is collection and dumping of wastes at dumping site. Currently Adama Municipality and Small Private Operators collect only 42% of the solid waste generated in the city; The remaining 58 % remains uncollected. These waste often end up in roadside drainage and in open fields causing flooding in low lying areas of the city (AAR, 2016).

Adama city is given priority in this research work due the reasons indicated as under:

- ✓ It is one of the fast growing and urbanizing towns in the country where solid biodegradable waste management problem is significant;
- ✓ So far, no research has been conducted regarding its biodegradable solid waste generation rate and composition;

- ✓ It is a city comprising markets of fruits and vegetables, Urban agricultural activities (i.e. animal farming), many hotels, resorts, recreational areas, food processing industries, institutions and hospitals which can be a potential sources of wastes;
- ✓ Since Adama Science and Technology University (ASTU) located in Adama city has shown interest to support such demand-driven research of energy production from Municipal solid wastes.

Thus, this study is mainly concerned with determining the amount of energy generated from Adama city municipal biodegradable solid wastes, design of the appropriate bio-digester, devise modern waste collection methods, and select site for biogas plant.

1. 3 Objective

1. 3.1 General Objective

The general objective of the research work is to determine the amount of biogas energy generated from bio-degradable wastes (like animal manure, house hold organic wastes, etc.), design an appropriate bio-digester, devise collection and transportation mechanism of wastes, and select an appropriate site for bio-digester plant.

1.3.2 Specific Objectives

The specific objectives of the research are to:

- Identify the types of biodegradable waste materials for biogas energy generation by survey of important areas, brainstorming and checklists;
- Collect data of different biodegradable wastes identified by measuring the weights of samples.
- Determine biogas production capacity of different biodegradable wastes based on important data from literatures of previous study;
- Design an appropriate bio-digester that accommodate all the wastes;
- Select the site for constructing the designed bio-digester in cooperation with Municipal experts;
- Suggest the collection mechanisms of the wastes based on best experience from literatures;
- Suggest transportation means of the wastes to feed the constructed bio-digester based on best experience from literatures;

1.4 Significance of the Study

A successful accomplishment of this study has a great significance from the point of view of:

- Determining the size of biodegradable wastes accumulated in Adama town which might have an impact to the health of the society;
- Exploring the size of the energy generated from selected dominating biodegradable wastes;
- Getting a means of converting municipal biodegradable wastes to useful energy;
- Attracting donors to implement the conversion on the basis of information gathered by the study;
- Slowing down rate of deforestation, control of land degradation and hence mitigation of greenhouse gas emissions;
- Aspiring other institutions to conduct similar study to solve the waste burden imposed to their town.

1.5 Scope of the study

This research work having its focus on Adama city, encompasses identification of dominating biodegradable wastes, determination of the size of the biodegradable wastes from various sources such as households, commercials, institutions etc. and make analysis of the wastes; It also bound to activities including designing of appropriate bio-digester, selecting the site for construction of bio-digester, and suggesting mechanisms of waste collection and means of transporting it to bio-digester. Constructing the digester, experimental studies and scrubbing of the biogas produced is not included in this study.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Urban solid waste can be sub-divided into two major components: biodegradable and non-biodegradable. In low and lower-middle income countries, organic materials remain the main source of waste generated with more than 50% of the total solid waste generated. The higher density (mainly due to the high moisture content) of the organic materials in comparison with other waste makes compaction difficult, contributing to the low efficiency of hydraulic-compactor trucks for such type of waste.

2.2 Review on biogas Production

The production of methane during the anaerobic digestion of biologically degradable organic matter depends on the amount and kind of material added to the system. The efficiency of production of methane depends, to some extent, on the continuous operation of the system. As much as $1000m^3$ of gas (containing 50 - 70 percent methane) can be produced from $1000m^3$ of volatile solids added to the digester when the organic matter is highly biodegradable (e.g., night soil or poultry, pig, or beef-cattle fecal matter) for a period of 30 days. Combustion of about 30 litres (1 ft^3) of gas will release an amount of energy equivalent to lighting a 25-watt bulb for about 6 hours. In general, lower gas-production rates result when the wastes are less biodegradable (Onojo et al., 2013).

Among the many potential uses of digester gas are hot water heating, building heating, room lighting, and home cooking. Gas from a digester can be used in gas-burning appliances if they are modified for its use. Conversion of internal-combustion engines to run on digester gas can be relatively simple; thus the gas could also be used for pumping water for irrigation. Past experiences have shown that where methane is generated in significant quantities in rural areas of developing countries, its use is primarily for lighting and cooking (Onojo et al., 2013).

Ethiopia produces a plenty of fruits and vegetable wastes and generates a solid waste. Therefore, it becomes necessary to develop appropriate waste treatment technology for Municipal waste, animals Manure and vegetable wastes to minimize green house gas emission. One of the burning problems faced by the world today is management of all types of wastes and energy crisis. Rapid growth of population and uncontrolled and unmonitored urbanization has created serious problems of energy requirement and solid waste disposal. Vegetable market wastes contribute to a great amount of pollution; hence, there has been a strong need for appropriate vegetable waste management systems. Vegetable wastes that comprise of high fraction of putrescible organic matter cause serious environmental and health risks (Dhanalakshmi and Ramanujam, 2012).

When animal, plant vegetation and domestic wastes are allowed time, they are acted upon by anaerobic bacterial to produce a gas which is commonly referred to as biogas. This natural gas or "marsh gas" can be used as a rich source of fuel and power generation (Biogas Plants, 2010).

In many instances, the generation rate of animal waste types varies significantly in nature and in situation of relative abundance of a particular animal waste; the need for combining animal waste including human excreta from different sources may become imperative in biogas generation. Hence, the implications of combining or co digesting animal wastes for biogas production need to be properly assessed for successful implementation of such anaerobic process. Co-digestion was used by researchers to improve biogas yield by controlling the carbon to nitrogen ratio (Yusuf and Debora, 2011). Cellulosic wastes are generally known to be poor biogas producers because of their poor biodegradability. One treatment method for improving the biogas production of various feed stocks is co-digesting them with animal and/or plant wastes.

2.3 Processes of Biogas Production

The process of biogas formation is a result of linked process stages, in which the initial material is continuously broken down into smaller units. The simplified diagram of the Anaerobic digestion (AD) process, shown in Figure 1 highlights the four main process stages: Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis. Hydrolysis is the first stage of the organic waste decomposition process involving the breakdown of large organic polymer chains into smaller molecules such as simple sugars, amino acids and fatty acids (A. Schnürer and Å. Jarvis, 2010). Acidogenesis is the second stage where Fermentative bacteria (acidogenic) produce an acidic environment in the digestion tank while creating ammonia (NH_3), Hydrogen (H_2), Carbon dioxide (CO_2), Hydrogen sulphide (H_2S), shorter volatile fatty acids, organic acid (acetic, propionic acid, butyric acid, succinic acid, lactic acid etc.) as well as low alcohols (EInstruments, 2014) . However the resulting organic matter is still very large and unsuitable for methane production. Acetogenesis is the third stage where Acetogens produce acetic acid, carbon and energy sources. This process consumes hydrogen gas, thus keeping its concentration at very low levels. Methanogenesis is the final stage of AD methane production stage, where methanogens produce methane from hydrogen, carbon dioxide and acetate as well intermediates products from hydrolysis and acidogenesis (A. Schnürer and Å. Jarvis, 2010). Methanogenesis constitutes the final stage of AD in which methanogens create methane from the final products of acetogenesis (i.e. hydrogen gas, carbon dioxide and acetate) as well as from some of the intermediate products from hydrolysis and acidogenesis (Y. Liu and W. B. Whitman, cited in Edison M. 2014).

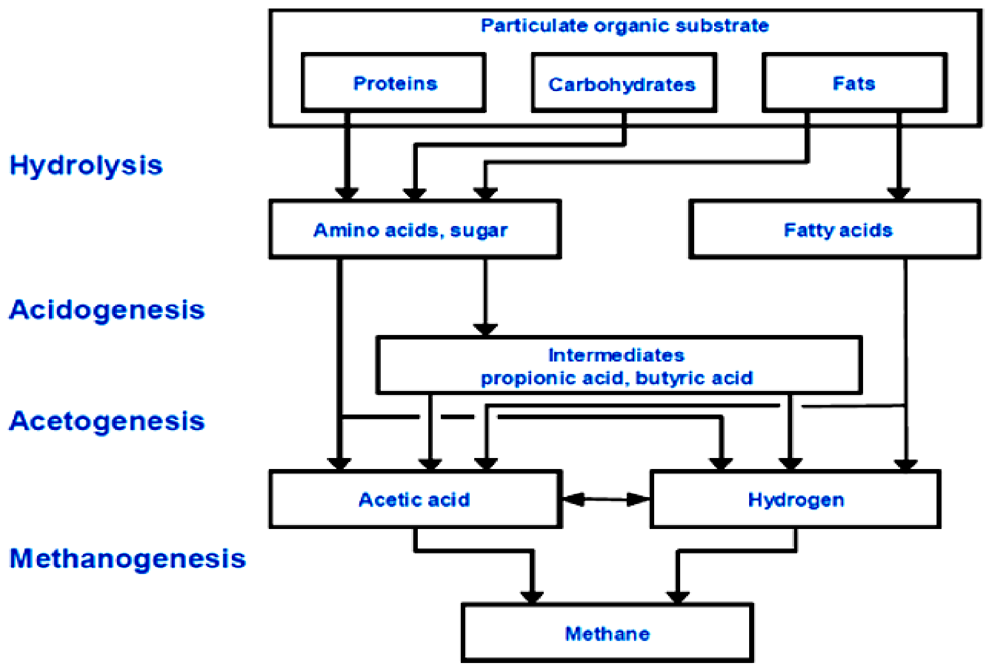

Figure 1: Anaerobic digestion process (Serna, E., 2009; cited in Ertuğrul D.Ö., 2013)

2.4 Factors Affecting Biogas Production/ Variation in Operational Parameters

The performance of biogas plant can be controlled by studying and monitoring the variation in parameters like pH, temperature, loading rate, agitation, etc. Any drastic change in these can adversely affect the biogas production. So these parameters should be varied within a desirable range to operate the biogas plant efficiently. Most researchers' results show that factors like temperature, pH, concentration of total solids, etc affect the production of the biogas.

Various factors such as biogas potential of feedstock, design of digester, inoculums, nature of substrate, pH, temperature, loading rate, hydraulic retention time (HRT), C:N ratio, volatile fatty acids (VFA), etc. influence the biogas production (Dioha et al., 2013).

2.4.1 Temperature

Temperature inside the digester has a major effect on the biogas production process. There are different temperature ranges during which anaerobic fermentation can be carried out: psychrophilic (< 30^{o}C), mesophilic (30-40^{o}C) and thermophilic (50-60 ^{o}C). However, anaerobes are most active in the mesophilic and thermophilic temperature range. The length of fermentation period is dependent on temperature (Yadvika et al., 2004; cited in Alemayehu G. 2014). The methanogenic bacteria, which facilitate the formation of biogas, are very sensitive to temperature changes and the optimum temperature for the bacteria to operate is between 33-38 ^{o}C. Temperatures below this slow down the biogas production process, while a higher temperature than necessary kills the biogas producing bacteria. This is why the structure for biogas production is generally built underground, to keep the temperature as constant as possible (Sibisi and Green, 2005; cited in Alemayehu Gashaw, 2014).

2.4.2 pH

pH is another important parameter affecting the growth of microbes during anaerobic fermentation. The optimum pH for a generally stable AD process and high biogas yield lies in the range of 6.5 – 7.5. During digestion, the processes of hydrolysis and acidogenesis occur at acidic pH levels (pH 5.5 – 6.5) as compared to the methanogenic phase (pH 6.5 – 8.2) (Khalid et al., 2011). An alkalinity level of approximately 3,000 mg /L has to be available at all times to maintain sufficient buffering capacity. Lime is commonly used to raise the pH of AD systems when the process is too acidic. To avoid drops in pH chemicals are added to the organic substrate to supply a buffer capacity. Sodium bicarbonate, sodium hydroxide, sodium carbonate and sodium sulphide are the most used chemicals (Esposito et al., 2012). Failing to maintain pH within an appropriate range could cause reactor failure although ammonia is at a safe level (Chen et al., 2008; cited in Alemayehu Gashaw, 2014).

2.4.3 Moisture

High moisture contents usually facilitate the anaerobic digestion; however, it is difficult to maintain the same availability of water throughout the digestion cycle. Initially water added at a high rate is dropped to a certain lower level as the process of anaerobic digestion proceeds. High water contents are likely to affect the process performance by dissolving readily degradable organic matter. It has been reported that the highest methane production rates occur at 60-80% of humidity. However, bioreactors under the 70% moisture regime produced a stronger leachate and consequently a higher methane production rate. Experiment has proved that 83 ml methane per gram dry matter were produced at the 70% moisture level, while 71 ml methane per gram dry matter were produced with the 80% moisture (Khalid et al., 2011).

2.4.4. Retention Time

It is the theoretical time that the influent liquid phase stays in the digester, while the solids retention time (SRT) is generally the ratio between solids maintained in the digester and solids wasted in the effluent. The required retention time for completion of the AD reactions varies with differing technologies, process temperature, and waste composition (Zamudio Canas, 2010). The conversion of organic matter to gas is more closely related to SRT rather than HRT. The retention time for wastes treated in mesophilic digester ranges from 10 to 40 days. If the retention time is too short, the bacteria in the digester are washed out faster than they can reproduce, so that fermentation practically comes to a standstill. Although a short retention time is desired for reducing the digester volume, a balance must be made to achieve the desired operational conditions, for example, maximizing either methane production or organic matter removal (Zamudio Canas, 2010). Digesters operating in the thermophilic range require lower retention times. For instance, a high solids reactor operating in the thermophilic range has been reported to require a retention time of 14 days. The degradability of food waste was approximately 20 – 30 % higher than that of bio-waste. This has been attributed to the higher concentration of digestible fat in food waste. To achieve higher biogas amount or conversion efficiency of organics with food waste a relatively long digestion time of around 6 days has been reported; as compared to about 3 days with bio-waste (Nayono, 2010).

2.4.5 Particle Size

To avoid blockage of the inlet pipe and increase ease of degradation reducing the particle size of the feedstock is important. As a general rule, substrate particle size with a diameter of maximum 5 cm are recommended although the ideal size also depends on the diameter of the inlet pipe. Shredding of the feedstock into small particles increases the total surface area of the material thus increasing the area that can be degraded by microorganisms (Schnürer and Jarvis, 2010). Many microorganisms, especially those that are active in the initial hydrolytic step, prefer to attach to the surface area of the material that they are degrading.

2.4.6. Pretreatment

Feed stocks sometimes require pretreatment to increase the methane yield in the anaerobic digestion process. Pretreatment breaks down the complex organic structure into simpler molecules which are then more susceptible to microbial degradation (Asgari et al., 2011).

2.4.7. Organic Loading Rate (OLR)

Gas production rate is highly dependent on loading rate. Methane yield is found to increase with reduction in loading rate. As study carried out in Pennsylvania on a 100 m^3 biogas plant operating on manure, when OLR was varied from 346 kg VS/day to 1030 kg VS/day, gas yield increased from 67 to 202 m^3/day. There is an optimum feed rate for a particular size of plant, which will produce maximum gas and beyond which further increase in the quantity of substrate will not proportionately produce more gas. Studies have shown that a daily loading rate of 16 kg VS/m^3 of digester capacity produced 0.04 - 0.074 m^3 of gas/kg of dung fed. A lab-scale digester operating at different OLRs produced a maximum yield of 0.36 m^3/kg VS at an OLR of 2.91 kg VS/ m^3/day (Yadvika, 2004 cited at Alemayehu Gashaw, 2014).

2.4.8. Regular Agitation

For maximizing the production of biogas regular agitation of substrate in digester is required. The regular agitation frees the produced biogas entrapped in the substrate, mixes the fresh substrate with bacteria population, prevents scum and sediment, prevents temperature gradient inside the digester, provides the homogeneous mixture of bacteria population and prevents the formulation of voids (Mohammad S. I. et. Al., 2013).

2.4.9. C:N Ratio

The ideal carbon to nitrogen (C:N) ratio for anaerobic digestion ranges from approximately 20:1 to 30:1. Dairy manures typically contain a C:N ratio of approximately 9:1, and swine manure contains a C:N ratio of approximately 6:1. The addition of co-digestion materials with higher carbon contents than manure feed stocks can improve the C:N ratio, thereby increasing methane production. For example, the C:N of the dairy and swine manures may be enhanced by adding food processing residues such as potato waste with a C:N ratio of 28:1, or the unbalanced nutrients are regarded as an important factor limiting anaerobic crop residues, such as oat straw with a C:N ratio of 48:1(Agstar, 2012).

2.4.10. Ammonia Concentration

AD process is greatly inhibited by high ammonia concentration, which accumulates during the AD process. Ammonia is the byproduct resulting from the AD of proteins present in MSW (Nair et al., 2014). Several studies have been carried out to examine the inhibitory effects of ammonia on AD of organic matter. However; there is limited information about the inhibitory effects of ammonia on AD of Organic Fraction of Municipal Solid Waste (OFMSW) (Yenigün and Demirel, 2013).

2.4.11. Chemical Oxygen Demand (COD)/Nitrogen Ratio

COD is amount of oxygen needed for waste material in the water that can be oxidized through a chemical reaction. COD/N ratio of substrate is necessary parameter to produce biogas optimally. The COD/N range of 350/7 - 1000/7 is the optimal range for anaerobic digestion. If more or less than the range, microbial growth in the digester will be hampered. So, adjustment of COD/N of substrate was needed to be done. Proteins, amino acids and urea are nitrogen source needed by microbe to build cell structures. Biogas produced at COD/N ratios of 500/7 and 600/7 were in nearly equal amount. Whereas, biogas produced at COD/N ratio of 400/7 is less than that of 500/7, 600/7, and 700/7 (Sumardiono et al., 2013).

2.4.12 Co-Digestion

It has been observed that co-digestion of mixtures stabilizes the feed to the bioreactor, thereby improving the C/N ratio and decreasing the concentration of nitrogen. The use of a co-substrate with a low nitrogen and lipid content waste increases the production of biogas due to complementary characteristics of both types of waste, thus reducing problems associated with the accumulation of intermediate volatile compounds and high ammonia concentrations (Khalid et al., 2011).

2.4.13 Energy Production Potential

Adequate quantities of biodegradable wastes (or feedstoks) of appropriate quality are said to be available for energy (or electricity) generating biogas plants in many countries . Small and medium-size biogas plants could provide a considerable contribution to national energy (or electricity) generation in such countries. However, in comparison to industrialized countries, only very few small and medium sized biogas plants are used for electricity generation in Africa, Latin America and even Asia.

Literatures indicate that the small size AD can accommodate approximate waste up to 7,500 tons with approximate energy production ranging from 25-250 kW(e); Medium size AD can accommodate approximate waste ranging from 7,500-30,000 tons with approximate energy production ranging from 250kW-1MW(e); Large size AD can accommodate approximate waste 30,000 or more tons with approximate energy production of more than 1MW(e) (GMI, 2016).

The average calorific value of biogas is about 21-23.5 MJ/m³, meaning that 1 m³ of biogas corresponds to 0.5-0.6 l diesel fuel or an energy content of about 6 kWh. However, due to conversion losses, 1m³ of biogas can be converted only to around 1.7 kWh(e).

Bigger biogas plants are generally more cost-efficient than smaller ones. However, electricity generation from biogas is a technology appropriate even for relatively small applications in the range of 10-100 kW (Mini-grid webinar series, 2019).

2.5 Solid waste generated in Adama

Solid waste in Adama is generated from households, commercial/business centers, institutions, industries, construction and demolition, health facilities and the Municipality itself. The dominant type of solid waste is Biodegradable while Non-Bio-Degradable waste also contribute substantially (WWSP, 2016).

The compositions of the solid waste generated from different sources in Adama are:

i) Biodegradable solid waste including food and food left over, leather, cardboard, chat (kha't) leftover, dust/ash (home sweepings), paper, textile, trimming (waste from park and greenery) and wood, yard waste (compound sweepings and animal manure).

ii) Non-bio-degradable waste including rubber, concrete and related, glass, industrial process waste (scrap materials, off-specification products, etc.), metals/ steels and plastics;

iii) Hazardous and/or special waste including hazardous (waste containing toxic substance or pathogens) and special waste (electronic & related waste).

iv) Street sweeping (a mix of various garbage both biodegradable and non-degradable).

The result of the household survey shows that home sweepings, paper, ash/dust, food left over and plastics (bags/bottles) are the most common types of household solid waste in Adama city. This is consistent with the detailed study conducted by Addis Ababa University in 2007, which reveals that food leftover, home sweepings (ash and dust) and yard account for 86% of the weight and 75% of the volume of solid waste generated by households.

A large portion of Adama solid waste is therefore expected to be biodegradable. This is in agreement with the assessment done by Addis Raeye MSE engaged in waste collection in the city. After careful separation of the solid waste contained in 4 dumpsters, more than 50% of the waste is fresh organic matter. The previous studies conducted in various towns/cities of Ethiopia showed that the average rate of solid waste generated from households per capita per day ranges from 0.23 to 2.03 kg (WWSP, 2016).

2.5.1 Quantity of solid waste generated in Adama

The quantity of solid waste generated from different sources was estimated based on a number of assumptions, literature and data obtained from various organizations (derived from Adama Trade Office, Culture and Tourism Office, Health Office, Education Office and Civil Service Office).

The total volume of solid waste generated in Adama is estimated to be 88,000 tons per year which is equivalent to 288,000 m^3 per annum taking into consideration that the density of solid waste generated is ranging from 300 to 400 kg/m3 (Rajesh B. K. et. Al., 2013). When properly sorted from other waste and treated, organics are converted into compost and reuse for greenery or farming.

The lion's share of solid waste in Adama comes from Households (49%), followed by hotels, restaurants, cafes, and bars (16%), commercial establishments such as market places, shops, garages, etc. (13%), industrial and agricultural solid waste (9%) and construction and demolition waste (6%). The remaining categories represent less than 10% of the waste generated. Assuming that half of the total solid waste generated is made of organic materials, this fraction would represent about 144,000 m^3/year (WWSP, 2016).

2.6 Waste collection and transportation

The social waste collection service is unsatisfactory, and scenes of scattered waste are common in most part of the cities such as Addis Ababa, Adama etc. (UNDP, 2004 cited at WWSP, 2016). According to the existing policy of Ethiopia, solid wastes are collected by the government employees, private companies based on contractual agreements and Micro and Small Enterprise. However, the principle, stating that the waste producers are subject to put their wastes into different containers based on specific type of wastes, is not practiced in the city (Hayal et al., 2014). There are two sub-stages of waste collection: primary and secondary collection.

i) Primary collection: It is done by micro and small enterprises having formal agreement to collect from households and dump them in designated containers. There are a large number of micro and small enterprises organized in different cities of Ethiopia to pre-collect waste from household.

The collection is currently handled in different types of collection systems namely the door-to-door, curbside, set out, the block (container) collection systems and the street sweeping.

The door-to-door collection system is applied for households and is carried out by MSEs by walking the short distances from house to house. Each house owner put wastes in baskets, sacks, plastic bags or other suitable materials at the door side so that the collectors pick using the pushcarts to a common temporary storage for the trucks to pick up them to the disposal site. Some of the storage areas could be street sides and pedestrian walkways. However, the regularity and frequencies of collection are not always maintained due to the less number of laborers with their low payment (Hayal et al., 2014).

Curbside collection is the most common practical method where different sized containers are kept near the street corners and street crossings so that householders deposit their wastes on them using baskets, bags, sacks, or other suitable materials. As per experience in Addis Ababa payment for the collectors is volume based rate (30 birr/m^3). Service charges are collected with water consumption rate. Residential houses pay 20%, commercial houses 42.5% of the total water consumed.

Although large proportion is collected by the MSEs, private companies and employees also participate. However the contribution of private companies is still low as compared to the government share. Due to shortage of containers collected wastes are improperly stored on open spaces and roadsides (Hayal et. al., 2014).

ii) Secondary Collection: It is a system of transporting solid wastes from containers to final dumping site, undertaken by the municipality which represents the highest level in transportation system. The role of the private sector in this system is limited (WWSP, 2016).

This study attempted to explore the size of biodegradable municipal wastes in Adama city and find a suitable way to use the organic wastes identified for biogas production by co-digestion of wastes. It plays a vital role in creating good awareness of using biodegradable solid wastes and human excrement for biogas production and soil conditioner especially in Ethiopia.

2.7 Design of Biogas Digester

Designing a properly sized digester to maximize biogas production per unit of reactor volume is important in maintaining low capital construction costs. The digester should be sized to achieve desired performance goals, and must be large enough to avoid "washout." Anaerobic digestion depends on the biological activity of slowly reproducing methanogenic bacteria. The bacteria must be given sufficient time to reproduce so that they can: 1) replace cells lost with the effluent sludge, and 2) adjust their population size to follow fluctuations in organic loading. If the rate of bacteria lost from the digester with the effluent slurry exceeds the growth rate, the bacterial population in the digester will decline or be "washed out" of the system. Washout is avoided by maintaining a sufficient residence time for solids, and thus bacterial cells, within the digester.

Design goals could be the maximizing of gas production with minimal capital investment, achieving pollution control and reduction of pathogens, or simply the production of a reasonable amount of gas with a minimum of operational attention. Criteria must be established prior to design, since not all goals can necessarily be achieved with a single design. Assuming that adequate performance data are available for the feedstock under anticipated operating conditions, the designer can optimize the digester size and other features such as degree of heating and mixing to meet the desired criteria and avoid washout.

2.8 Digester types

There are three basic design types of digesters that commonly used in many countries. These are plug flow digesters, fixed roof digester and floating roof digester (Karthik and etal 2012).

2.8.1 Plug flow digesters

This is a type of anaerobic digester that uses a long, narrow horizontal tank in which a material (manure) is added at a constant rate and that force other material to move through the tank and be digested (Refer Figure 2). Typically, a plug flow digester vessel is five times longer than it is wide, is insulated and heated, and is made or reinforced concrete, steel or fiberglass (Ishmael, 2014).

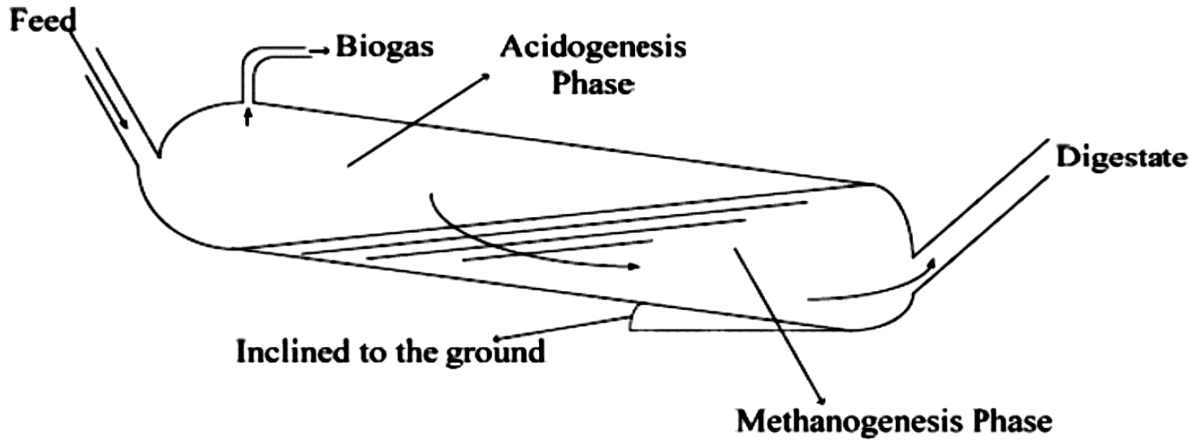

Figure 2: Schematic representation of a plug flow digester (Karthik and et. al. 2012)

The term "**plug flow**" derives from the fact that the manure in principle flows through the digester vessel as a "plug," gradually being pushed toward the outlet as new material is added. In fact, the situation is more complicated and some parts of the manure travel faster than others on their way through the vessel, or may even settle or float and remain in the digester (Ishmael, 2014). The first documented use of this type of design was in South Africa in 1957 (Ishmael, 2014). The main advantage of the plug-flow design is that it is simple and economical to install and operate. However, it is not as efficient or as consistent as the completely mixed design. Plug-flow units are limited to applications with low amounts of sand, dirt, or grit, because these substances will tend to stratify and settle out inside the digester, requiring significant effort to clean out (Ishmael, 2014). Complete mix units are more expensive to install and operate than plug flow units, because they require both the capital equipment and the energy for mixing (Ishmael, 2014).

2.8.2 Fixed dome digesters

The fixed dome digesters (Figure 3) also called "Chinese" or "hydraulic" digesters are the most common model developed and used mainly in China for biogas production. (Karthik and etal 2012). Fixed dome Chinese model biogas plant (also called drumless digester) was built in China as early as 1936 cited in (Ishmael, 2014). Fixed dome digesters are usually built underground (Santerre and et.al.,1982 cited in Karthik et.al. 2012). The dome is fixed and hence the name given to this type of plant is fixed dome type of biogas plant. The function of the modified fixed dome digester plant is similar to the floating holder type biogas plant as shown in

Figure 3, the only difference is the fixed top part of the digester. The used slurry expands and overflows into the overflow tank. Disadvantages of fixed dome digesters are that special sealants are required, high technical skills are required for construction, and gas pressures fluctuate, which causes complication of gas use. The difference between Figure 3 and 4 is that, in Figure 3 the upper part of the digester is fixed, i.e., it does not experience any movement on the upper side when the gas starts to fill up the available empty space as compared to the floating tank type digester.

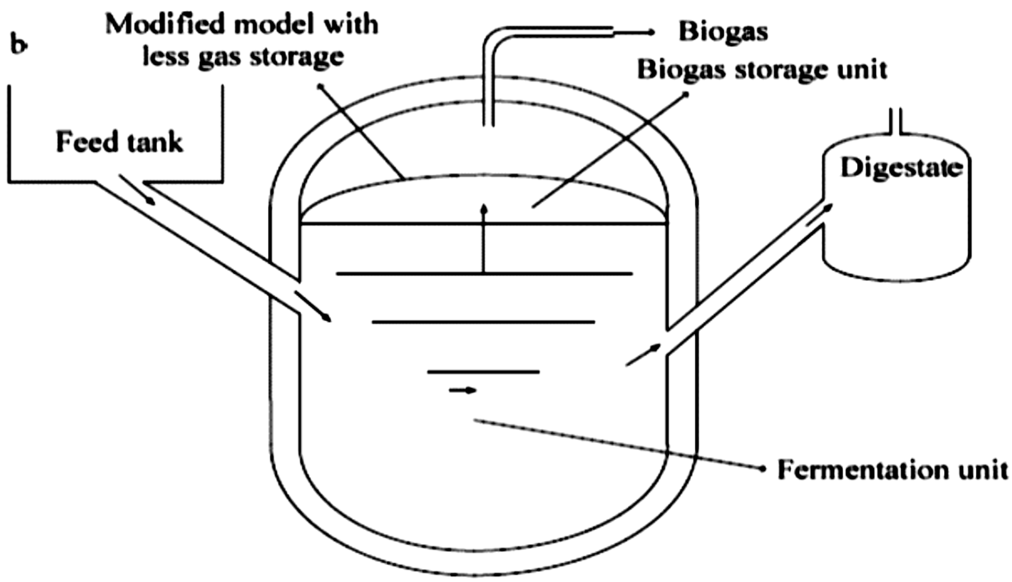

Figure 3: Schematic representation of a fixed dome digester (Karthik and etal 2012)

2.8.3 Floating drum digesters

Floating drum type biogas design was developed by Jashu Bhai J Patel in 1956 and the Patel's design was approved by the Khadi and Village Industries Commission (KVIC) of India in 1962. (Karthik and etal 2012, Ishmael, 2014).

The design is divided into two parts. One side has the inlet, from where slurry is fed to the tank as shown in Figure 4. The tank has a cylindrical dome made of stainless steel that floats on the slurry and collects the gas generated. Hence the name given to this type of plant is floating gas holder type of biogas plant (Ishmael, 2014).

The slurry is made to ferment for about 50 days. More gas is made by the bacterial fermentation, leading to the pressure inside the gas collecting dome to increase. The gas can be taken out through an outlet pipe. The decomposed matter expands and overflows into the next small holding tank.

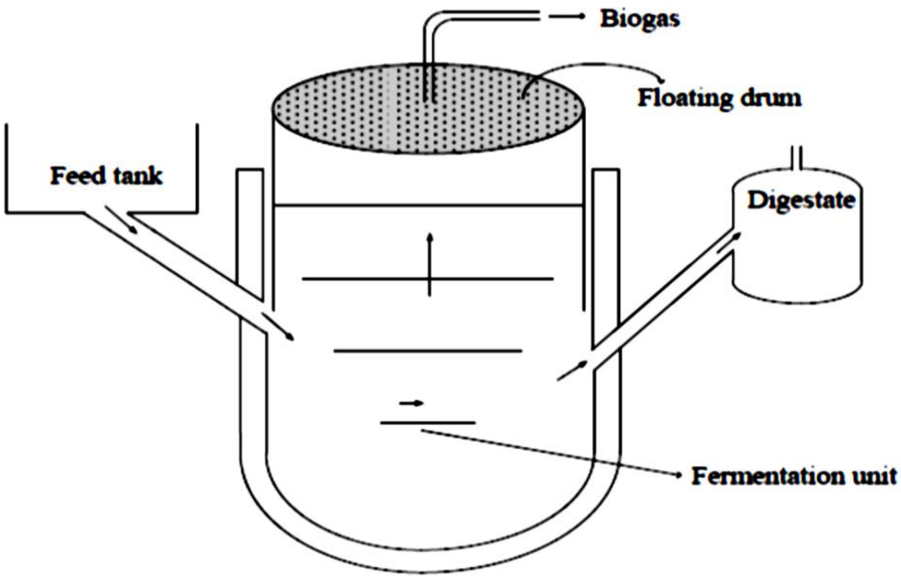

Figure 4: Schematic representation of a floating drum digester (Karthik and et. al. 2012)

The shortcomings of these digesters discussed above relative to this research is that the pressure cannot be manipulated or maintained to a specific value for a certain period of time in order to observe the effect it has on the composition of the gas and on the activity of the bacteria. The digester design for this particular research will take into account the accommodation of pressure manipulation.

CHAPTER 3
MATERIALS AND METHODS

3.1 Description of the study area

Adama town is located in the rift valley of Ethiopia, which makes it a seismically active area. It is located at about 100km southeast of Addis Ababa on the high way to Harar. It is located at 8.54°N, 39.27°E, at an elevation of 1712 meters, 99 km southeast of Addis Ababa. Adama town has a total area of 31,183 hectars (311.83 km^2)†. Adama town lies in sub humid tropical zone with an average annual temperature of 21°C. The town has a projected population size of 391,597 in 2009 (C.S.A., 2009). The newly prepared administration map is attached at the appendix.

† Source Adama city land management and development

3.2 Materials

Identifying the biodegradable materials (i.e. the main source of municipal biodegradable wastes in Adama city) is the first step for the study. Thus, four major waste categories have been identified. These are: (i) Domestic animal wastes (ii) Food wastes (iii) House hold and other wastes and (iv) Fruit and vegetable wastes. These are waste categories which are considered to be basic sources of wastes useful for the study. The list for each and the measuring devices are given as under.

Waste categories and measuring devices

i) Animal waste sources
1) Dairy farming
2) Oxen/cow fattening
3) Poultry
4) Pig breeding

ii) Food waste sources
1) Big Hotels
2) Medium Hotels
3) Small Hotels
4) Big industries (biscuit)
5) Universities
6) Boarding schools
7) Medical colleges
8) Prisons

iii) House hold and others
1) Household
2) Street
3) Juice houses
4) Fecal sludge

iv) a. Fruit wastes
1) Bananas
2) Avocados
3) Mangos
4) Oranges
5) Papayas
6) Pineapples
7) Watermelons
8) Grapes
9) Apples
10) Strawberries
11) Lemons

iv) b. Vegetable wastes
1) Beetroots
2) Cabbages
3) Carrots
4) Cucumbers
5) Eggplant
6) Local Cabbages
7) Garlics
8) Gingers
9) Green beans
10) Lettuces
11) Onions
12) Peppers
13) Potatoes
14) Pumpkins
15) Kostas
16) Sweet potatoes
17)Tomatoes
18) Zucchinis

Measuring devices
1) Analog balance
2) Mechanical balance
3) Plastic bags of different sizes

3.3 Data collection Methods

For this study two types of data have been kept in mind i.e. primary and secondary data. For the primary data collection check lists have been prepared for each data; The data obtained have been recorded for pre-set collection periods. Secondary data has been collected from different literatures, previous research works such as journals, periodicals, articles etc. The data collected as per the requirement of check list for each item are indicated in Tables 1 to 12.

3.3.1 Sample size

The sample size has been calculated based on the sample required by estimating a proportion with an approximate 95% confidence. The expression used for this is given below.

$$n = 4pq/d^2 \qquad (\dots 3.1)$$

Where n = sample size,

p = proportion of the population having the characteristic,

q = 1-p and

d = the degree of precision (error).

More accurately

$$n = (1.96)^2 pq/d^2 \qquad (\dots 3.2)$$

The proportion of the population (p) may be known from prior research or other sources; If it is unknown p = 0.5 can be used which assumes maximum heterogeneity (i.e. a 50/50 split). The degree of precision (d) is the margin of error that is acceptable. Setting d = 0.02, for example, would give a margin of error of plus or minus 2% (Susan Rose et. Al., 2015)

3.3.2 Collection of data of domestic animal manure

Before collection of data of animal wastes it was essential to determine the population of animals in urban farming from Adama city urban agriculture office. In this regard approximated number of animals in the farming owned by licensed organization and approximated number of animals in the farming owned by non licensed organization have been identified. Table 1 indicates the quantity of selected domestic animals in the farming.

Table 1: Data of quantity of selected domestic animals in Adama (March 15, 2016/17)

S.No.	Type of business	Number of licensed individuals	Number of non-licensed individuals	Approximated number of animals in the licensed organization	Approximated number of animals in the non licensed organization	Approximated total of animals in both licensed non licensed organization
1	Dairy farming	48	1410	1580	9050	10,630
2	Oxen/cow fattening	145	1510	3280	21,579	24,859
3	Poultry	49	2751	147,000	559,950	706,950
4	Pig breeding	3	8	1050	2450	3500

Source: Adama city Urban Agricultural Office

For determining the total animal wastes taking samples from each type of animals was essential. To determine the sample size for this specific case Eqn. (3.2) is used; The following assumptions have been taken into consideration: p = 0.5, d = 12.5% (0.125);

Therefore: $n = (1.96)^2 \times 0.5 \times 0.5 / (0.125)^2 = 61.5$

Based on the above estimation the size of the sample unit has be adjusted purposively taking into consideration the availability of the domestic animals kept in well organized compound with proper control of feeding and neatness. With these conditions in mind a total of 52 sample units were taken for sample collection of the study. Thus, from Diary farming 5 sample units (i.e. 3 cows and 2 calves), from oxen fattening 2 sample units (i.e. 2 oxen), from pig farming 20 sample units (i.e. 12 big size pigs and 8 medium size pigs), from poultry farming 25 sample units (i.e. 25 chickens) have been taken. Therefore The data has been collected for one week (seven consecutive days) and the results obtained are indicated in Table 2.

Table 2: Data of animal manure (May – June, 2016/17)

No	Sources of manure	Quantity (Numbers)	Domestic animals manure (Kg/day) (Monday – Sunday)						
			Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	Cow solid manure	3	41	45	47	38	41.5	43	43.5
3	Calf solid manure	2	37.5	32	13.8	20.5	19.5	18.8	19.5
5	Oxen manure pure	2	21	19	20	21	18	22	17
6	Big pigs solid manure	12	17.7	14.8	24.8	25.3	22.1	18.8	20.8
8	Medium solid manure	8	20.8	24.3	23.8	18.3	25.8	21.6	24.3
10	Poultry solid manure	25	1.5	1.2	1.9	1	2	1.1	1.8

3.3.3 Analysis of data from animal manure

In section 3.3.2 we have noted that data of manure has been collected from different domestic animals in Adama city. The focus animals were Cows, Oxen, Pigs and chickens. The data of sample collected for one week has been indicated in Table 2. Having this data the average weight of the sample per day and the average weight per source per day have been calculated and shown in Table 3.

Table 3: Data average weight of animal manure

No	Sources of food wastes	Sample size	Average wt of wastes/day	Average wt of wastes/ source/day	Avg. of combined wastes/source/day
1	Cow solid manure	3	42.72	14.24	12.89
2	Calf solid manure	2	23.08	11.54	
3	Oxen manure pure	2	19.71	9.86	9.86
4	Big pigs solid manure	12	20.59	1.72	2.27
5	Medium pigs solid manure	8	22.66	2.83	
6	Poultry manure	25	1.50	0.06	0.06

In Table 3 it is observed that the cow and the calf manure have higher, 51.4% weight share as compared with the oxen manure which is 39.3%. The pigs' manure shows 9.1%, and poultry manure shows the least almost 0.2% of weight share. The seasonal variation of the sample waste has not been done due to time constraint. From the data obtained we can conclude that the contribution of each average weight of wastes per source per day have an impact on the biogas generation.

3.3.4 Food wastes data collection

To determine the total amount of food wastes' samples from different level hotels (i.e. Big, Medium, and small hotels, source Culture and Tourism Office) were taken. The sample size has been decided purposively. The samples were collected in two seasons; The first season was Feb. – May, 2016/2017, 8 sample units from big hotels, 10 sample unit from medium hotels and 8 sample unit from small hotels and restaurants were taken. Therefore a total of 26 sample units were considered. The second season was Nov – Feb, 2017/2018, 5 sample units from big hotels, 5 sample units from medium hotels and 7 sample units from small hotels and restaurants were taken. Therefore a total of 17 sample units were considered. Regarding big industries (i.e. Floor and biscuit) 2 sample units were considered and data of samples have been collected for one week (seven consecutive days); Specific government institutions (i.e. Adama Science and Technology University and OLMA Boarding school) have been taken into consideration purposively for food wastes. The data collected for one week (seven consecutive days) is indicated in Table 4.

Table 3: Data of food wastes of different level Hotels, Industries and Institutions

No	Sources of food wastes	Quantity	Hotels and others wastes (Kg/day) (Monday – Sunday)						
			Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Food wastes data (Feb – May, 2016/2017)									
1	Big Hotels	8	375	452	385	415	581	475	130
2	Medium Hotels	10	85	65	47	55	53	65	32
3	Small Hotel and restaurants	8	42	31	49	41	35	66	28
Food wastes data (Nov-Feb,2017/18)									
1	Big Hotel	5	158	161	146	176	183	155	167
2	Medium	5	91	103	111	118	122	118	111

	Hotel								
3	Small Hotel and Restaurant	7	127	120	145	140	150	171	165
Food wastes data from industries and institutions (Feb – May, 2016/2017)									
4	Big industries (biscuit)	2	465	455	420	495	390	346	380
5	University	1	595	735	495	670	685	565	450
6	Boarding school	1	250	300	280	230	300	200	210
Food wastes data from Adama medical college and Dipo prison(Feb – May, 2017/2018)									
7	Medical College	**1**	120	74	70	70	75	70	75
8	TVCP	**1**	293.5	310.5	237.0	243.0	224.5	293.5	310.5

Note:1. Technical and vocational Center for Prisoners (or Dipo)
2. Period of data collection from Hotels was (Feb – May, 2016/2017 and Nov - Feb, 2017/18)

3.3.5 Analysis of data of food waste from Hotels

As we have discussed in section (3.3.4) data of food waste samples have been collected from three main sources, i.e. hotels, food industries, and institutions. Sample collection has been done for one week by taking the weight of each sample using precise analog weights. Hotels have been stratified into three levels, i.e. Big, Medium and Small hotels; And samples of food wastes have been purposively selected; This has been done for two seasons as mentioned in section (3.3.4). Having the data the average weight per day and average weight per source per day of the samples have been calculated for each seasons. The summary of the average weights is given in Table in 6 and 7.

Table 5: Data of season one average weight of Hotel food wastes

No	Sources of food wastes	Sample unit size (#)	Weight of Average wastes/day (kg)	Weight of Average wastes/ source/day (kg)
1	Big Hotel	8	401.86	50.23
2	Medium Hotel	10	57.43	5.74
3	Small Hotel and Restaurant	8	41.71	5.21

Table 4: Data of season two average weight of Hotel food wastes

No	Sources of food wastes	Sample unit size (#)	Weight of Average wastes/day (kg)	Weight of Average wastes/ source/day (kg)
1	Big Hotel	5	163.71	32.74
2	Medium Hotel	5	110.57	22.11
3	Small Hotel and Restaurant	7	145.43	20.78

Note: Season I - (Feb. – May, 2016/2017) and Season II – (Nov. – Feb., 2017/18)

From Table 5 and 6 it is clear that the sample average of waste per source per day of season two is more than that of season one; In season one 82.1% of the share is taken by big hotels, 9.4% medium hotels and 8.5% small hotels. In second season the share of big hotels is reduced to 43%; This due to unrest in the country ending with less flow of meetings, guests and wedding ceremonies. It is expected that this will be changed with normal condition. From this we can conclude that even though there are seasonal variations the contribution of the size of wastes per source per day has great role for biogas generation.

3.3.6 Analysis of data of food waste from Institutions

The samples are collected from institutions such as Food processing industries (i.e. Brothers biscut factory , Family floor factory etc.), Adama Science and Technology University (ASTU), OLMA Boarding school, Adama Medical college and Technical and vocational Center for Prisoners (or Dipo) as noted and indicated in section (3.3.4). The average weight per day and average weight per source per day of the samples have been calculated and shown in Table 7 as under.

Table 5: Data of average weight of food wastes from industry and institutions

No	**Sources of food wastes**	**Sample size**	**Average wt wastes/day**	**Average wt wastes/ source/day**
1	Biscuit Industry	2	421.57	210.79
2	Adama Science and Technology university	1	599.29	599.29
3	Boarding School	1	252.86	252.86
4	Adama Hospital Medical College	1	79.14	79.14
5	TVCP	1	273.21	273.21

Note: TVCP stands for Technical and vocational Center for Prisoners (or Dipo)

In table 7 is observed that the average weight of the samples per source per day is highest in case of ASTU, 42% share, and least is of medical college 6% share. The seasonal effect has not been checked here because of time constraint. We can conclude from the data above that the contribution of the average wastes per source per day will be remarkable for the biogas production.

3.3.7 Collection of data from Households and others

Households in Adama were taken as source of wastes in the town. Households of seven Kebeles (or Ganda, i.e. Gooroo (Kebele 01), Dh/Araaraa (Kebele 04), Dagagga (Kebele 05), Odaa (Kebele 08), Irreechaa (Kebele 09), Gadaa (kebele 12), and Hangaatuu (Kebele14) were recommended by Adama Municipal beautification office. Here three levels of living standard have been identified on experience and judgment base of data collectors.

For determining the household wastes taking samples from each levels of living standard was essential. To determine the sample size for this specific case Eqn. (3.2) is used; The following assumptions have been taken into consideration: p = 0.5, d = 9.5% (0.095), data collectors have better information about sample units and are closer to the data to be collected;

Therefore: $n = (1.96)^2 \times 0.5 \times 0.5 / (0.095)^2 = 106.4$

Based on the above estimation the size of the sample unit has been adjusted purposively taking into consideration the convenience, control, sorting and measurement of the waste to be collected from each level. With these conditions in mind a total of 105 sample units were taken for sample collection of the study. Thus, from each kebele (or District) 15 households (5 Higher, 5 Medium, and 5 lower standard of living) were identified. The result of collection is indicated in table 8.

Selected streets in Adama have been taken as a sample unit for source of wastes; Here wastes focused on are street sweepings. For data collection purposive sampling method was employed. To determine the street sweeping wastes three Kebeles (or Districts) i.e. Kebele 04, 05, and 08 were identified. For the data collection two levels were set within one kilometer (1000 meter) length of road; 500 m for high concentration street waste and the remaining 500 m for medium concentration of street waste were considered. The data was collected on a sample cross section area of 12 x 1000 m^2 (or 12,000 m^2) assuming the standard width of one direction road (street) is 12 m. The result of data collection is indicated in table 8.

Fecal sludge is also one of the main concern of source of wastes. The data regarding this was obtained from the 2017/2018 third quarter 3 months report of concerned office of Adama Municipality. It has been reported that about 29,520 m^3 of fecal sludge has been collected in three months the third quarter. Data of each of above sources were collected for one week (i.e. seven consecutive days). The data obtained are indicated in Table 8 as under.

Table 6 : Data of weight of wastes of Households & others

No	Sources of food wastes	Samp. size	Households and other wastes (Kg/day) (Monday – Sunday)						
			Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	Household (number)	105	210	195	225	200	220	225	240
2	Street sweeping (m^2)	12000	64.17	64.17	64.17	64.17	64.17	64.17	64.17
3	Juice House (number)	3	37	32.5	34	30.5	33	30.5	31
4	Fecal sludge (m^3/day)	410	591671	591671	591671	591671	591671	591671	591671

Note: Fecal sludge density is 1,443.1 kg/m^3 (Charles B. Niwagaba et.al., 2014)

3.3.8 Analysis of data from Households and others

In section 3.3.7 we have noted that data of households and others are comprising sample data of households of seven kebeles, data of street sweeping of three kebeles, data of fruit wastes from juice markets and data of Adama municipal fecal sludge. Street sweeping data has been collected from a weight of wastes collected on sample area as mentioned in section 3.3.6. Having the data of total area of sweeping per day from concerned Adama municipal performance third quarter three months report the total approximate weight has been obtained. The data of Adama municipal fecal (sewage) sludge has been obtained from the third quarter three months performance of sewage sludge collection report of Adama municipality sanitation record office. The data of sample collected for one week has been indicated in Table 8. Having this data the average weight of the sample per day and the average weight per source per day have been calculated and shown in Table 9 as under.

Table 7 : Data of average weight of households & other wastes

No	Sources of wastes	Sample unit size	Average wt of wastes/day (kg)	Average wt of wastes/ source/day (kg)
1	Household(#)	105	216.43	2.06
2	Street sweeping(m^2)	12000	64.17	0.005
3	Juice house(#)	3	32.64	10.88
Toilet wastes				
4	Fecal sludge trucks(#)	15	591,671	39,444.7

From Table 9 it is observed that the average weight of wastes per source per day of sample of Adama fecal sludge has a dominating size while the average value per source per day of street sweeping has the least value. Wastes cumulated without purpose will deter the conducive environment and will be an aid to a greenhouse effect. We can conclude that how much small the waste is, it has great contribution for the biogas production. The waste from juice house has got a share of 84% when compared with other two. The toilet waste (fecal sludge) has the largest share of wastes in the town.

3.3.9 Fruits and vegetables data collection

In Adama the supply of the fruits is found to be transported from southern (such as Wolaita, Kembata, Hadiya and sidamo) and eastern (Such as Harar, Methahara etc.) parts of the country. Vegetable supplies are transported from Awash, Wonji, Meki, Batu and their surroundings (source: Suppliers); And this supplies are received by 26 distributors in Adama city (i.e. 1 distributor at Ganda Badhatu (07), 10 distributor at Ganda Odaa (08), and 15 distributors at Ganda Gurmuu (06)). For the data collection two seasons i.e. Bega (Oct-Jan,2016/17) and Belg (Feb-May, 2016/17) are selected. The data of the fruit and vegetable supply per day has been collected for one week (seven consecutive days); Refer Tables 10 – 13 for the two season results.

Table 8 : Collected data of supplies of fruits (Oct-Jan,2016/17)

No	Bio-degradeable fruits	Fruit supply to Adama town (Kg/day) (Mondy - Sunday)						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	Bananas	20,000	28,000	27,000	35,000	24,000	40,000	28,500
2	Avocados	23,000	18,000	26,000	45,000	44,000	23,000	16,500
3	Mangos	29,000	13,000	18,000	12,000	28,000	22,000	15,500
4	Oranges	8,000	13,000	14,000	12,000	18,000	32,000	13,000
5	Papayas	13,000	18,000	14,000	15,000	38,000	17,000	14,000
6	Pineapples	2,000	1,500	2,300	1,800	2,000	1000	900
7	Watermelons	8,500	4,500	6,500	3,100	10,000	3,000	0
8	Grapes	190	70	75	90	135	110	0
9	Apples	1200	1050	700	1150	750	1000	0
10	Strawberries	85	70	60	45	95	150	0
11	Lemons	1,800	1,500	17,000	2,000	16,000	6,000	600

Table 9: Collected data of supplies fruits (Feb-May, 2016/17)

No	Bio-degradeable fruits	Fruit supply to Adama town (Kg/day) (Mondy - Sunday)						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	Bananas	5,000	25,000	25,000	30,000	20,000	37,000	7,500
2	Avocados	20,000	16,000	24,000	42,000	40,000	20,000	5,000
3	Mangos	25,000	10,000	15,000	10,000	25,000	20,000	2,500
4	Oranges	5,000	10,000	10,000	10,000	0.0	30,000	0.0
5	Papayas	10,000	15,000	12,000	0.0	35,000	5,000	3,000
6	Pineapples	1,050	0.0	1,800	0.0	1,200	0.0	0.0
7	Watermelons	7,500	0.0	5,000	0.0	10,000	0.0	0.0
8	Grapes	110	0.0	35	60	115	0.0	0.0
9	Apples	800	950	0.0	850	0.0	750	0.0
10	Strawberries	50	0.0	50	35	0.0	120	0.0
11	Lemons	1,000	950	15,000	1,500	14,300	5,000	200

Table 10: Collected data of supplies of vegetables (Oct-Jan,2016/17)

No	Bio-degradeable vegetables	Vegetables supply to Adama town (Kg/day) (Mondy - Sunday)						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	Beetroots	45,000	30,000	34,000	24,000	15,000	25,500	6,500
2	Cabbages	28,000	34,000	25,000	20,000	40,000	15,000	8000
3	Carrots	28,000	30,000	14,000	8,000	18,000	9,000	3,500
4	Cucumbers	500	700	1000	500	6,500	1000	0
5	Eggplant	3,500	1030	5,000	3000	6,000	1000	0
6	Local Cabbages	5,000	3,000	2,500	9,500	8,000	2,800	0

7	Garlics	5,000	3,000	8,000	1000	2,000	7,000	0
8	Gingers	4,000	2,000	5,000	4000	2,500	4,000	0
9	Green beans	2,500	1,500	2,500	700	1,350	1050	0
10	Lettuces	8,500	1,200	1,400	3,000	1,100	700	0
11	Onions	28,000	24,000	95,500	130,000	90,000	75,000	18,000
12	Peppers	6,000	1,500	800	1100	2000	800	0
13	Potatoes	85,000	65,000	55,000	35,000	81,000	28,000	7,000
14	Pumpkins	1,500	180	165	800	500	700	0
15	Kostas	1,500	800	780	950	800	700	300
16	Sweet potatoes	2,000	1,800	9,500	700	800	9,500	0
17	Tomatoes	34,000	40,000	25,000	15,500	12,000	7,000	2000
18	Zucchinis	600	200	900	180	1,500	600	0

Table 11: Collected data of supplies of vegetables (Feb-May, 2016/17)

No	Bio-degradeable vegetables	Vegetables supply to Adama town (Kg/day) (Mondy - Sunday)						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	Beetroots	42,500	25,000	30,000	20,000	12,500	22,500	5,000
2	Cabbages	25,000	30,000	20,000	15,000	37,000	12,500	0.0
3	Carrots	25,000	25,000	10,000	5,000	15,000	7,500	2,500
4	Cucumbers	400	0.0	800	0.0	5,000	0.0	0.0
5	Eggplant	2,000	0.0	3,500	0.0	4,000	0.0	0.0
6	Local Cabbages	4,000	2,000	2,000	8,000	6,000	1,600	0.0
7	Garlics	4,000	2,000	6,000	0.0	1,000	5,000	0.0
8	Gingers	3,000	1,000	4,000	0.0	1,500	3,000	0.0
9	Green beans	1,000	500	1,200	400	950	700	0.0
10	Lettuces	7,000	840	950	2,000	700	400	0.0
11	Onions	25,000	20,000	87,500	100,000	84,000	72,000	15,000
12	Peppers	5,000	1,000	500	700	1,200	400	0.0
13	Potatoes	75,000	60,000	50,000	30,000	75,000	25,000	5,000
14	Pumpkins	1,000	120	130	500	0.0	400	0.0
15	Kostas	1,000	500	360	800	400	300	100
16	Sweet potatoes	1,000	1,200	8,000	0.0	500	7,500	0.0
17	Tomatoes	30,000	37,500	20,000	12,500	10,000	5,000	0.0
18	Zucchinis	500	0.0	700	0.0	1,200	0.0	0.0

From this data the average supply per day has been determined; Having this it was essential to determine the size of the wastes for each of daily supply. It has been observed that there are wastes from the supply before market, i.e. damage on the fruits and vegetables, rotten fruits, special leaves used to cover the fruits for safety on transporting. On measuring it has been found that some percent of the supply is a waste; For example 15% of the average supply of banana has been found to be a waste before market. After removal of all these wastes the remaining will be supplied to the customers; The customers are subjected to some wastes such as leaves and stems supporting the fruits, damage during transporting, damage due to bad weather, damage due to bad storage and delayed sell. On measuring has been found that some percent of the remaining direct supply to customers is a waste. For example 20% of the average direct supply of banana to customers has been found to be a waste after market. Thus, each item of fruits and vegetables are subjected to wastes of some percent before market and after market. On this basis the data of the average weight of fruit and vegetable wastes before and after market have been generated as shown in Appendix II: 6, 7, 8 and 9.

3.3.10 Analysis of data of fruits and vegetables

In Tables 10, 11, 12 and 13 are given data of the weight of supplies received by distributors in the city for 7 consecutive days (one week) in two seasons; And the amount of wastes as per the percentage of the supplies before market and after market for each fruits and vegetables are given Appendix II: Tables 6 - 9. The summary of the average waste per day per season and total of average wastes per day are calculated and given in Table 14 as under.

Table 12: Seasonal Average weights of Fruit and vegetable wastes

S.No	Biomass averages	Season I wastes (kg/day)	Season II wastes (kg/day)	Total average/day (kg/day)
1	Average fruit wastes per day	36,675.32	25,392.01	30,761.67
2	Average vegetable wastes per day	68,270.41	54,330.13	61,300.27

Note: Season I: (Oct.-Jan., 2016/17) and Season II: (Feb. - May, 2016/17)

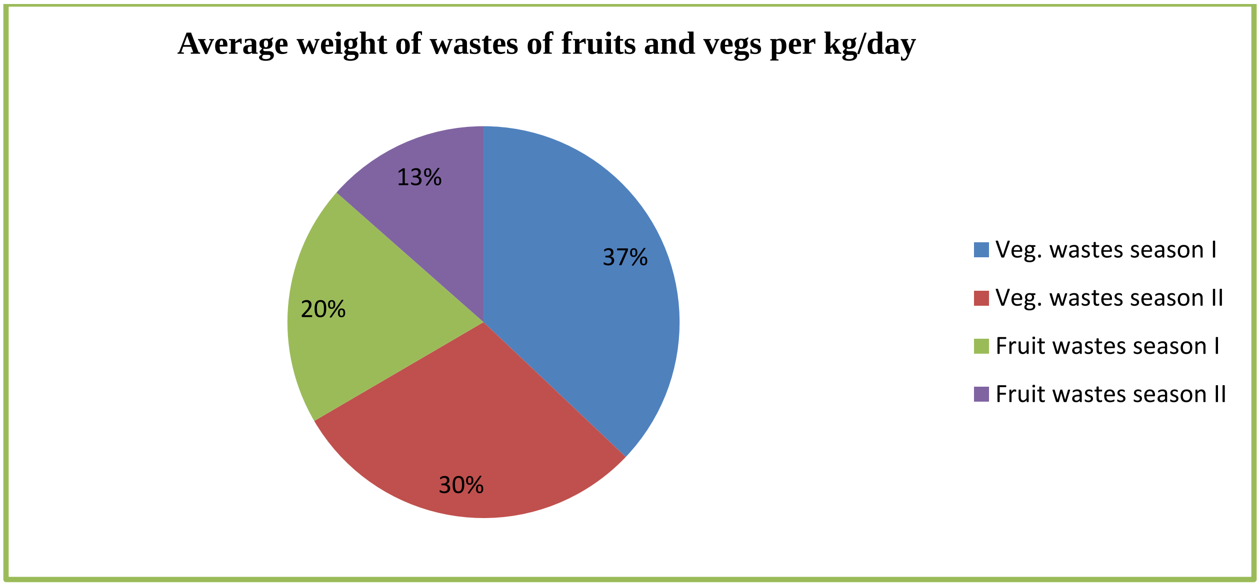

Figure 5: Average weight of fruit and veg. wastes in seasons I & II

As we observe there are seasonal weight variation. In season (I) the weight is higher than that of season (II) the reason is that it is a time for more fruits and vegetables to be harvested; It is a usual experience for so many years (source; supplier). As a result of this more supplies is availed in the market see Tabs 10 - 13; Because of different reasons in the season (II) the supply of fruits and vegetables is reduced. This results in reduction by 7% of fruit wastes and vegetable wastes per day respectively as is seen in pie chart.

From this we can conclude that for the sustainable biogas production the fruit and vegetable wastes should be mixed with other biodegradable wastes in proper proportion. As it is seen in Tab.14 the total average weight of the vegetable waste, 67%, is double of the total average weight of the fruit wastes, 33%. From this we can conclude that Average wastes of both items are reliable throughout the seasons though is dominated by vegetable wastes.

3.3.11. Selection of bio- digester type/model

In the literature part, it has been explained that there are three basic design types of bio-digesters commonly used. These are plug flow digesters, fixed roof digester and floating roof digester types. To select reasonable bio digester type/ model among the three, multiple criteria decision analysis (MCDA) technique was employed based on weighted assessment approach. Factors considered includes construction cost, ease of construction, feasibility in large scale, maintenance cost, Temperature regulation, constant pressure, easy for maintenance, reliability, and local availability of the technology. Weight factors and the computation of the results are shown in Table 15 and figure 6. According to the weighted sum of each factor, fixed roof bio-digester type is selected.

Table 15: Multiple criteria decision analysis for bio-digester type selection

S.N	**Factors**	**Weight %**	**Plug flow digesters**	**Fixed roof digester**	**Floating roof digester**
			Score %	**Score %**	**Score %**
1	Construction cost	25	17.5	16.5	19.5
2	Ease of Construction	13	7	8	10
3	Large scale feasibility	12	6	10	7
4	Maintenance cost	10	4	8	5
5	Easy for maintenance	15	10	5	8
6	Temperature regulation	5	1	5	2.5
7	Constant pressure delivery	5	4	1	3
8	Reliability	5	3	1	2
9	Local Availability	10	2	7	2
	Total score	100	54.5	61.5	59

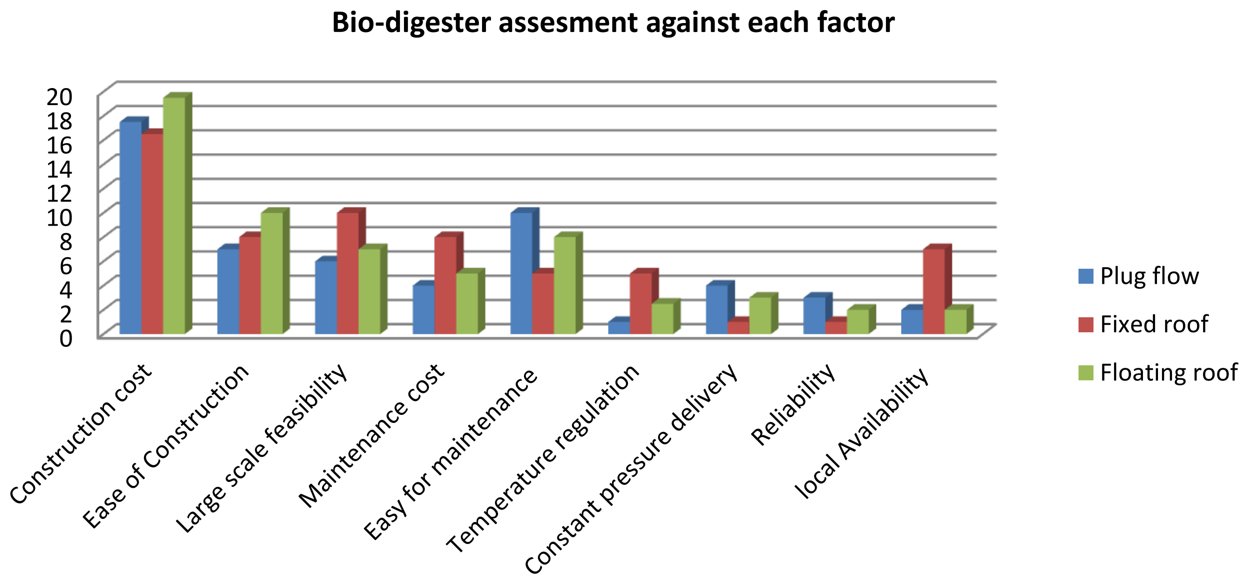

Figure. 6: Bio-digester type selection based on different factors

3.3.12. Design of bio-digester

The purpose of Bio-digester design was to demonstrate the required geometry and dimensions that satisfy the amount of bio-degradable organic waste generated from Adama city. To determine the geometry and dimensions of the digester, it involves the use of suitable prescribed model and equations. Anaerobic digestion is a multistage microbial process, whose production rate and efficiency mainly depend on substrate temperature, Hydraulic Retention Time (HRT), pH level, substrate solid content and so on (G. Kocar, 2007).

Table 16 shows temperature ranges at which AD process can take place and relation between the temperature and the HRT (Teodorita A.S et al 2008). Furthermore, a neutral pH is favorable for biogas production, since most of the methanogens grow at the pH range of 6.7–7.5. (Karthik and et.al., 2012). Recently, most digesters are designed to operate in the mesophilic temperature regime due to its advantages of lower energy requirements and higher stability compared with thermophilic treatment (G. Kocar, 2007). Temperature regime selected by (G. Zhang, 2016) also falls in the same category.

Table 16: Thermal stage and typical retention times

Thermal stage	Process temperatures	Minimum retention time
Psychrophilic	< 25^{o}C	70 to 80 days
Mesophilic	30 to 42 ^{o}C	30 to 40 days
Thermophilic	43 to 55 ^{o}C	15 to 20 days

Substrate solid content or total solid contained in a certain amount of materials is usually used as the material unit to indicate the biogas- producing rate of the materials. According to Karthik and etal, the concentration of total solids in the digester is reported to vary between 7% and 9%, (Karthik and etal 2012). Another literature shows the concentration of total solids can vary from 2 to 15% which is referred as low solids anaerobic digestion to 15–40% for high solids anaerobic digestion (Marianna G, 2016), and a recent study conducted by Ejiroghene et al (Ejiroghene, 2017) revealed that bio-digesters should be run at 10.16% total solids.

For the purpose of this research a mesophilic ($25^oC – 45^oC$) temperature range with HRT value of 30 days is considered for the bio-digester design. Based on the variable ranges indicated in different literatures, the concentration of total solids in the digester is taken as 11%, a value closer to the higher range.

The major components of the bio-gas plant consists of digester tank, an inlet for feeding the waste, a gas holder tank, an outlet for the digested slurry, a gas delivery system for taking out and utilizing the produced gas (IJEAB, 2017). Biogas digester design needs consideration of the following cross-sectional areas.

a) Volume of gas collecting and storage chamber = V_1

b) Volume of fermentation chamber = V_3

c) Volume of sludge layer = V_2

Total volume of digester $V_D = V_1 + V_2 + V_3$

Geometrical expression of cylindrical shaped bio-digester is shown in figure 5.

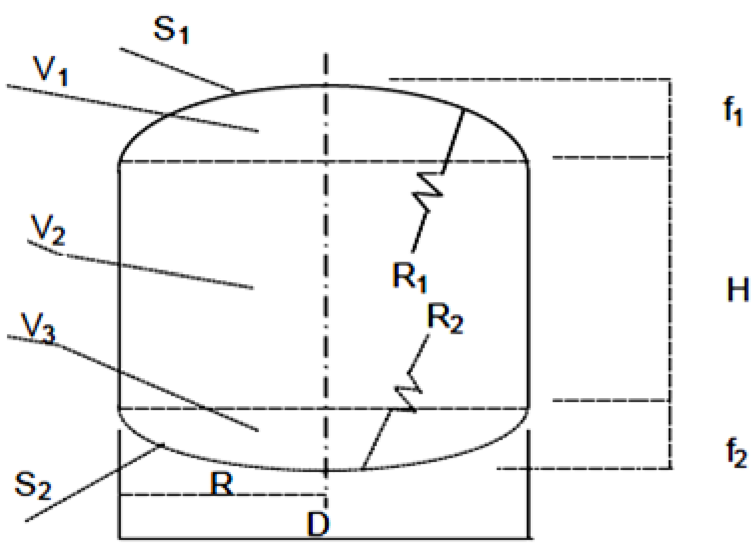

Figure 7: Geometrical dimension of cylindrical shaped bio digester

3.3.13 Design based on waste quantification and characterization

Based on waste quantity and characterization obtained from data collection, the following variables can be obtained. Digester volume is correlated to the volume of substrate fed per time unit and hydraulic retention time (Anthony N. M., 2016).

$$V_R = Q.HRT - (3.3)$$

Where, V_R: Reactor volume (in m³)

Q: Volume of substrate fed per time unit (m³/d)

HRT: is hydraulic retention time (in days)

Volume of gas holder is taken as half digester volume (Vg)

$$V_g = V_R/2 - (3.4)$$

For a digester with only top dome, total bio-digester volume can be given as a summation of digester volume and gas holder volume:

$$V_D = V_R + V_g - (3.5)$$

Where, V_D = Total bio-digester volume

Assuming the Bio-digester is cylindrical, Reactor volume (V_R) can be expressed as;

$$V_R = \frac{\pi D^2 H}{4} - (3.6)$$

Where, V_R = Reactor volume,
D = diameter of the tank and
H = height of the reactor.

Commonly height of the digester is assumed to be equal to diameter of digester. Therefore, equation 4 can be simplified as:

$$V_R = \frac{\pi D^3}{4} - (3.5)$$

From equation 5 Diameter of the tank can be formulated as;

$$D = \sqrt[3]{\frac{4V_R}{\pi}} - (3.6)$$

Taking the gas holder/digester radial clearance to be 'X' m (value decided by expertise), gives a diameter (d) of the gas holder as;

$$d = D - 2x = \left(\sqrt[3]{\frac{4V_R}{\pi}}\right) - 2x \text{------------------}(3.7)$$

For a given gas holder volume (Vg), the height (f) of the gas holder can be given as:

$$f = \frac{4V_g}{\pi d^2} = \frac{4V_g}{\pi} * \left(\left(\sqrt[3]{\frac{4V_R}{\pi}}\right) - 2x\right)^{-2} \text{----------------}(3.8)$$

Design based on digester's volume and surface area

The design of the biogas plant is the process of determining the correct dimensions and geometry of the biodigester parameters required to satisfy a given loading rate conditions. This involves the use of suitable model to determine geometric equations and the following equations are employed (Anthony N. M., 2016).

Diameter of the digester cylinder is;

$$d = \left(\sqrt[3]{d_{cap}}\right)^{1.173} \text{------------------------}(3.9)$$

Volume of the digester top dome;

$$V_1 = \frac{(3r^2 + {f_1}^2) * \pi f_1}{6} \text{----------------------}(3.10)$$

Where: V_1 = volume of the digester top dome, f_1 = height of dome and r = radius of the digester.

Volume of the digester cylinder;

$$V_2 = \pi r^2 h \text{-------------------------}(3.11)$$

Where: V_2 = volume of the digester cylinder, h = height of digester and r = radius of the digester.

Volume of the digester bottom dome;

$$V_3 = \frac{(3r^2 + {f_2}^2) * \pi f_2}{6} \text{----------------------}(3.12)$$

Where: V_3 = volume of the digester bottom dome, f_2 = height of dome and r = radius of the digester.

Surface area of digester top dome;

$$S_1 = 2\pi R_1 f_1 \text{------------------------}(3.13)$$

Where: S_1 = surface area of the digester top dome, f_1 = height of dome and R_1 = radius of the digester.

Surface area of the digester main cylinder body;

$$S_2 = \pi dh ------------------------(3.14)$$

Where: S_2 = surface area of the digester cylinder body, h = height of digester and d = diameter of the digester.

Surface area of the digester bottom dome;

$$S_3 = 2\pi R_2 f_2 ---------------------- (3.15)$$

Where: S_3 = surface area of the digester bottom dome, f = height of dome, p = radius of the digester.

For the determination of safety in operation, the mixture act on two surface areas, that of the bottom sphere and that of the cylinder hence that designed area will be;

$$S_a = \pi d(0.5d + h) -------------------- (3.16)$$

Pressure can then be determined as;

$$P = \frac{F}{\pi d(0.5d + h)} -------------------- (3.17)$$

For safety of plant without failure, the pressure or stress developed must be less than the bearing capacity multiplied by the strength of the concrete and divided by a factor of safety;

$$P < \frac{b_{cap} * f_c}{n} -------------------- (3.18)$$

Where: n = safety factor 10%, b_{cap} = bearing capacity, f_c = strength of concrete.
From equation 17 substituting for P, it can be expressed as;

$$\frac{F}{\pi d(0.5d + h)} < \frac{b_{cap} * f_c}{n} -------------- (3.19)$$

Table 17: Characteristic of wastes reported in literatures

S.N	Type of waste	TS(%, by w)	Vs(%,by w)	Vs/TS(%)	PH	Source
1	Food waste	18.1-45.35	17.1-26.35	85.30-94.96	4.2-6.5	Zhang L,2011,zhang c,2013,zhang RH,2007, Li rp,2010, Anthony N, 2018
2	Cattle slurry and manure	3.9-20.5		80		Teodorita A. S 2008, Vladislovas K.2018 Dairyone, 2019

3	Pig slurry, and manure	3-8		70-80		Teodorita A. S2008, Vladislovas K.2018
4	Poultry slurry and manure	7-30		80		Teodorita A. S2008, Vladislovas K.2018
5	Fruit waste	7.5-23		75-82.78		Teodorita A. S2008 Anthony N, 2018, Carla Asquer1,2013
6	Vegetable waste	3-13.75		87.65		Anthony N, 2018, Carla Asquer1, 2013
7	Mixed solid waste	27.33		80.69		Anthony N, 2018
8	Garden waste	29.6 -70		72.26-90		Teodorita Al Seadi, 2008, Anthony N, 2018

For the estimation of TS of wastes in the research, as an average values reported in Table 17 above are considered.

Table 18: Waste quantity and total volume of digester

S.N	Type of Biomass	Waste/day (in kg)	TS value (% wt.)	TS (in kg)	Total influent required Q (kg/day)	working Volume (V_R) m^3	Gas volume	Digester volume
1	Cow manure	137,020.70	12	16,442.48	149,477.13	4,484.31	2,242.16	6,726.47
2	Beef (Ox) manure	245,109.74	12	29,413.17	267,392.44	8,021.77	4,010.89	12,032.66
3	Solid pig manure	7,945.00	5.5	436.98	3,972.50	119.18	59.59	178.76
4	Solid poultry manure	42,417.00	18.5	7,847.15	71,337.68	2,140.13	1,070.07	3,210.20
5	Hotel waste	6,834.14	27.33	1,867.77	16,979.38	509.38	254.69	764.07
6	Biscuit Industry Waste	4,637.38	31.7	1,470.05	13,364.09	400.92	200.46	601.38
7	Institue & Prison	1,204.5	27.33	329.19	2992.64	89.78	44.89	134.67
8	Fruit waste	31,305.67	15.25	4,774.11	43,401.04	1,302.03	651.02	1,953.05
9	Vegetable waste	61,300.27	8.4	5,149.22	46,811.12	1,404.33	702.17	2,106.50
10	Household waste	165,879.44	27.33	45,334.85	412,135.01	12,364.05	6,182.03	18,546.08
11	Street Waste	28,613.4	50	14,306.70	130,059.09	3,901.77	1,950.89	5,852.66
12	Toilet Waste	591,671.00	2.2	13,016.76	118,334.20	3,550.00	1,775.00	5,325.01
	Total	**1,323,938.24**		**140,388.43**	**1,276,256.32**	**38,287.65**	**19,143.86**	**57,431.51**

In Table 18 based on daily waste quantities, the values of Total influent Q (kg/day), working Volume m^3 (Reactor volume), gas volume and the Total Volume m^3 (V_R+V_g) have been calculated. As we see the volume of bio-digester is found to be **57,431.51** m^3 and this value represents bio-digester volume with only top dome. Total volume of bio-digester with inclusion of top dome and bottom dome is shown in the table here under.

Table 19: Digester design calculated based on waste quantity

Digester type	**Q (m^3/day)**	**HRT (days)**	**V_R (m^3)**	**D (m)**	**H (m)**	**d (m)0**	**f (m)**	**V_g m^3**	**V_D m^3**
FDD	1276.26	30.00	38,287.65	36.53	36.53	36.49	18.31	19,143.86	57,431.51

Table 20: Digester design calculated based on the volume and surface area from quantification.

Digester type	**D (m)**	**r (m)**	**H(m)**	**V_1 (m^3)**	**V_2 (m)**	**V_3 (m^3)**	**f_1 (m)**	**f_2 (m)**	**R_1(m)**	**R_2(m)**	**S_1(m^2)**	**S_2(m^2)**	**S_3 (m^2)**	**total volume (m3)**
FDD	36.53	18.27	36.53	12,814.44	38,287.65	12,814.44	18.31	18.31	18.27	18.27	2,060.7	4,111.59	2,060.7	63,916.53

Where: FDD is fixed dome Digester

From Table 20, the total volume of Boi-digester is **63,916.53 m^3**. This volume includes volume of the top dome, cylindrical part and bottom dome. The construction and operation of a biogas plant is a combination of economical and technical considerations. In practice, the choice of system design (digester size and type) or of applicable retention time is always based on a compromise between getting the highest possible biogas yield and having justifiable plant economy. (Teodorita A.S et al, 2008). The calculated bio-digester size seems very huge and unrealistic to implement. Therefore, considering four bio-digester, the design can be revised as follow:

Table 21: Digester design modified for quarter waste quantity

Digester type	Q (m^3/day)	HRT (days)	V_R (m^3)	D (m)	H (m)	d (m)	f (m)	V_g m^3	V_D m^3
FDD	309.9	30.00	9571.9	23.00	23.00	22.96	11.56	4785.97	14,357.88

Table 22: Design calculated based on the quarter of volume and surface area from quantification.

Digester type	D (m)	R (m)	H (m)	V_1 (m^3)	V_2 (m^3)	V_3 (m^3)	f_1 (m)	f_2 (m)	R_1(m)	R_2(m)	S_1(m^2)	S_2(m^2)	S3 (m^2)	total volume (m^3)
FDD	23.00	11.50	23.00	3,210.3	9,571.9	3,210.3	11.56	11.56	11.50	11.50	835.3	1661.9	835.3	15,992.5

3.3.14 Materials for Construction

Material from which digester constructed plays an important role during the design phase (Ishmael, 2014). Digester construction materials are dependent on the geological, local condition and available materials for construction. Materials for construction of household digesters depend on geological, hydrological, local conditions, and locally available materials (Shian,1979; cited in Karthik R, 2012). With technological advances, different materials with improved properties and lower costs have been introduced to the market in recent years. In India, underground biogas household digesters are very popular. Stone or bricks are used as the material for construction of these kinds of digesters. Different construction materials with their advantages and disadvantages are summarized in Table 23, (Karthik Rajendran, et.al., 2012).

Table 23: List of different materials used for construction of digesters

Material	Modifications	Advantages	Disadvantages
Poly vinyl chloride (PVC) Polyethylene (PE)	Red mud PVC (mixed with aluminum) PE with UV filter	Less weight Easily portable PE is much cheaper compared to PVC	Short life span of plastics
Neoprene and rubber	Reinforced with nylon	Weather resistance elastic	Expensive Low pressure Less life span
Bricks and concrete	Pre fired earthen rings, lime concrete, slag concrete, fired clay, bricks, reinforced concrete, Ferro cement (crack proof)	Everlasting, less maintenance costs	Gas could escape through concrete pores when pressure increases. Built underground. Difficult to clean. Occupies more space.
Bamboo and wood supports	Usually a support material, Reinforced with flax	Locally available material	Can break easily
Steel drum		Produce gas at a constant flow Leak proof	Corrosion Heavy weight of gas holder

For the purpose of this research the Chinese fixed dome digester model type using Bricks and concrete is chosen. Considerations for selection of this model include, volume of waste generated, Technological level of the country, complexity, and investment cost required.

3.3.15 Cost Analysis of Biogas Plant

Cost analysis was based upon the current market value for the construction and installation works of $16m^3$ volume biogas plant. The costs include all the expenses for excavation, earthwork, concrete work, mechanical work, installation and trainings.

Table 24: Cost breakdown for construction of biogas plant

SN	Description	Unit	Qty	Rate	Total Cost ETB
I	**Excavation and Earthwork**				
1	Clear the site to remove the top soil to a depth of 20cm	m^3	2500.00	8.00	20,000.00
2	Bulk excavation over the site to reduce level up to a depth not exceeding 20m as directed by the supervisor	m^3	15500.00	40.00	620,000.00
3	Back fill around trench foundation, footing and under hard core with selected soil from outside well compacted sprinkled with water, rolled and compressed in layer not exceeding 20cm	m^3	6500.70	40.00	260,028.00
4	Cart away the excess excavated material to a convenient place recommended by the supervisor	m^3	10500.30	85.00	892,525.50
	Subtotal I				**1,792,553.50**
II	**Concrete Work**				
5	5 cm lean concrete in C-5 with minimum cement content of 150Kg./m3, under the pad of the plant	m^2	550.10	85.00	46,758.50
	Reinforced concrete in C-25 with minimum cement content of 360kg/m^3 filled and vibrated into formwork and vibrated around reinforcement bar. Formwork and reinforcement bars and measured separately				
6	In plant side wall	m^3	350.50	3500.00	1,226,750.00
7	Toping	m^3	250.20	1950.00	487,890.00
8	Water proof to control dampness	m^2	850.60	350.00	297,710.00
9	Brick masonary to protect the water proof	m^2	850.30	400.00	340,120.00
10	Installing perforated pipe	ml	50.60	80.00	4,048.00
	Reinforcement steel bar according to the structural drawing. Price shall include cutting, bending and placing in position				
11	Dia.14 deformed bar	kg	4500.00	50.00	225,000.00
12	Dia.16 deformed bar	kg	8500.70	50.00	425,035.00
13	Dia.20 deformed bar	kg	8500.00	50.00	425,000.00
14	Dia.24 deformed bar	kg	35500.00	50.00	1,775,000.00
	Subtotal II				**5,253,311.50**
III	**Mechanical Work**				
15	Chopping and mixing device (within the intake tank)	Pc	1	550,000	550,000.00
16	Main gas pipe Ø1/2", 60cm length – galvanized pipe	Pc	1	1,100	1,100.00
17	Main gas valve (ball valve) Ø1/2" – high quality valve	Pc	1	550	550.00
18	Nipple, Ø1/2" – high quality nipple (for connecting main gas pipe and main gas valve + reduction elbow)	Pc	1	550	550.00
19	Male-female socket Ø1/2" – high quality socket (for connecting main gas valve and gas pipeline)	Pc	1	550	550.00
20	90^o elbow – high quality reduction elbow	Pc	2	550	1,100.00
21	T-socket Ø1/2" for water trap (aluminum thread inside)	Pc	1	550	550.00

22	Glue for pipeline connection	Kg	3	300	900.00
23	Water drain	Pc	1	550	550.00
24	Gas tap – high quality tap	Pc	1	1,650	1,650.00
25	Gas rubber hose pipe Ø1/2" – high quality hose	m	2	300	600.00
26	Pressure gauge (manometer) – high quality gauge	Pc	1	3,100	3,100.00
27	Teflon tape	Pc	5	20	100.00
	Subtotal III				**561,300.00**
IV	**Additional Expenses**				
28	Supervisor (mechanical and construction)	No.	3	10000*12	360,000.00
29	Guard	No.	3	1000*24	72,000.00
30	Storage	No.	1	80,000	80,000.00
	Subtotal IV				**512,000.00**
	Total				**8,119,165.00**
	Vat (15%)				**1,217,874.75**
	Grand Total				**9,337,039.75**

Note: Assume 20cm thickness of the wall of Bio-digester with steel reinforcement mesh.

Generally, necessary manpower and equipment should be facilitated for an efficient and effective production of biogas energy. Firstly the wastes should be segregated as biodegradable and non-biodegradable within different bags as green for biodegradable and red for non-biodegradable. Secondly the biodegradable waste should be collected in to the trucks from all of the containers and transported to the site of biogas plant. Thirdly the biodegradable waste should be dumped in to the intake tank for the purpose of feeding in to the plant that is properly constructed from steel reinforcement mesh concrete work with 20cm wall thickness (Refer Fig. 8).

Figure 8: Steel reinforcement mesh concrete work of Bio-digester with 20cm wall thickness

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In previous chapters the list of identified materials which are the source of biodegradable wastes have been introduced. The methods of handling the data collection were also discussed. Applying the stratified and purposive sampling method as per the nature of wastes and conveniences of collection of data the average weight of wastes per source per day has been generated. In previous section we have seen that total solid contained in a certain amount of materials is usually used as the material unit to indicate the biogas-producing rate of the wastes. Further the biogas potential of each kilogram of the wastes should be determined. Literatures introduce that from one kilogram of waste a range of volume (m^3) of yield of biogas is possible to be generated as indicated in Table 25.

4.2 Biogas potentials of different wastes

The following table introduces the yield of biogas (m^3/kg) of different types of wastes.

Table 25: Biogas potentials of various wastes in literatures

S.N	Type of wastes	Yield of biogas, m^3/kg	Sources
1	Cow manure	0.25- 0.6 m^3/kg_{vs}	1,3,7
2	Beef (Ox) manure	0.25- 0.86 m^3/kg_{dm}	1,8,4
3	Solid pig manure	270- 450 m^3/t_{vs} (0.27- 0.45 m^3/kg_{vs})	2,3,7
4	Solid poultry manure	250 – 800 m^3/t_{vs} (0.25- 0.8 m^3/kg_{vs})	3,5,6
5	Hotel food waste	0.5 - 0.6 m^3/kg_{vs}	4,6,8
6	Biscuit Industry Waste	500- 700 m3/t_{vs} (0.5- 0.7 m^3/kg_{vs})	4,7
7	Institute & Prison food	0.5 - 0.6 m^3/kg_{vs}	7,8,9
8	Household waste	0.25 - 0.5 m^3/kg_{vs}	1,7,9
9	Street sweepings	150- 700 m^3/t_{vs} (0.15- 0.7 m^3/kg_{vs})	3,4,7
10	Fecal sludge	0.2- 0.75 m^3/kg_{vs}	4,6,7
11	Fruit waste	0.5- 0.7 m^3/kg_{vs}	4,5,7
12	Vegetable waste	0.15- 0.7 m^3/kg_{vs}	3,4,5

Note: 1(H. Carrère et. al.,2010); 2(Hiya Dhar et.al., 2017); 3(Jouni H., 2014); 4(Karthik R.et. al., 2012); 5(Leta Deressa et. Al., 201); 6(R. Kigozi et.al.,2014); 7(Teodorita A. S.,2008); 8(Vladislovas K. et. Al.,2019); 9(Yvonne V. et. Al.,2014);

Table 26: Animal manure biogas potentials

No	Biomass	Number of domestic animals	Average waste/Inst./ day (kg/d)	Total average/day (kg/day)	Total solid waste (kg)	Biogas yield (m^3/kg)	Total yield of biogas (m^3/kg)	
							Min	Max
1	Solid cow manure	10,630	12.89	137,020.70	16,442.48	0.25- 0.6	4110.62	9865.49
2	Beef (Ox) manure	24,859	9.86	245,109.74	29,413.17	0.25-0.86	7353.29	25295.3
3	Solid pig manure	3,500	2.27	7,945.00	436.98	0.27-0.45	117.98	196.64
4	Solid poultry manure	706,950	0.06	42,417.00	7847.15	0.25- 0.8	1961.79	6277.72
				Total	**54,139.78**		**13,543.68**	**41,635.18**

In Table 26 is shown resulted total average weight of animal manure from different domestic animal farms in Adama city. As observed from the table the solid cow and beef manure weights are much higher than the remaining. This resulted due to the higher number of animals and higher average manure droppings per head per day. When compared with the previous sections results this is much higher. Using this output as a feedstock to bio-digesters will enhance the sustainability of biogas production. Literatures reflect that one kilogram of animal manure can generate a range from 0.25- 0.6 m^3 of biogas. As we see from the table a total yield of biogas ranging from 13,543.68- 41,635.18 m^3 per day can be generated which is of much significance to energy needs.

4.3 Biogas potentials of food wastes in Hotels

In Table 27 and 28 are indicated the resulted total average weight of food wastes per day for different level of Hotels in two seasons of the year. Literatures have revealed that food wastes one kilogram can generate a biogas yield which ranges from 0.5 – 0.6 m^3. Looking closely to the results obtained the second season result is nearly three times more than that of the first season. This is resulted because of different reasons among which less meetings, less wedding ceremonies, current economic constraints, unrests etc.; Therefore from this ground we can say that the variations may not remain the same in normal conditions. In conclusion using the food wastes as a feed stock to a bio-digester can uphold a continuous biogas generation in Adama city.

Table 27: Hotel food wastes total average (Season I)

No	Biomass	Number of institutions & industries	Average waste/Inst./day (kg/day)	Total average/day (kg/day)
1	Big Hotel	11	50.23	552.53
2	Medium Hotel	25	5.74	143.50
3	Small Hotel and Restaurant	464	5.21	2,417.44

Table 28: Hotel food wastes total average (Season II)

No	Biomass	Number of institutions & industries	Average waste/Inst./day (kg/day)	Total average/day (kg/day)
1	Big Hotel	11	32.74	360.14
2	Medium Hotel	25	22.11	552.75
3	Small Hotel and Restaurant	464	20.78	9641.92

Note: Season I - (Feb. – May, 2016/2017) and Season II – (Nov-Feb,2017/18)

Table 29: Hotel food wastes biogas potentials

No	Biomass	Season I wastes (kg/day)	Season II wastes (kg/day)	Total seasonal average/day (kg/day)	Total solid waste (kg)	Biogas yield m^3/kg	Total yield of biogas (m^3/kg)	
							Min	Max
1	Hotel food wastes	3113.47	10554.81	6834.14	1867.77	0.5 - 0.6	**933.89**	**1,120.66**

4.4 Biogas potentials of food wastes in industries and institutions

In Table 30 is indicated resulted total average weight of food wastes in industries and institutions. Use of this as a feed stock to bio-digester can uphold the consistency of biogas generation. As mentioned in previous section (4.3) the same range 0.5- 0.6 m^3 biogas yield can be generated from a kilogram of food waste. This result can harmonize the overall output of biogas generation throughout the year.

Table 30: Food wastes from industry and institutions biogas potential

No	Biomass	Number of institutions & industries	Average waste/Inst./ day (kg/day)	Total average/day (kg/day)	Total solid waste (kg)	Biogas yield (m^3/kg)	Total yield of biogas (m^3/kg)	
							Min	Max
1	Biscuit Industry	22	210.79	4,637.38	1,470.05	0.5 -0.6	735.03	882.03
2	Institute & prison	1	1204.5	1204.5	329.19	0.5 -0.6	164.59	197.51
				Total	**1,799.24**		**899.62**	**1079.54**

4.5 Biogas potentials of households and others

In Table 31 is shown the result of total average of weight of household, street sweeping, and fecal sludge per day in Adama city. It is clearly seen that the weights of household wastes and fecal sludge are much higher than the other two. Using this amount of waste generated as a feed stock to bio- digesters enhances the reliability of biogas generation in Adama city. Literatures indicate that the wastes indicated in the table have different biogas potentials from one kilogram of average waste. Thus, one kilogram of household waste can generate a range of 0.5 – 0.6 m^3 biogas; street sweepings can generate a range of 0.5- 0.7 m^3; and fecal sludge can generate a range of 0.2- 0.75 m^3 biogas. The total result ranging from 32,424.1- 46,978.17 m^3 shows that the total yield of biogas is very much high when compared with the results in the previous section.

Table 31: Households & other wastes biogas potentials

No	Biomass	Number of insts & Indus.	Average waste/Inst./day (kg/day)	Total average/day (kg/day)	Total solid waste (kg)	Biogas yield (m^3/kg)	Total yield of biogas (m^3/kg)	
							Min	Max
1	Household	80,524	2.06	165,879.44	45334.85	0.5 - 0.6	22667.4	27200.9
2	Street sweeping (m^2)	5,350,800	0.005	28,613.4	14306.7	0.5- 0.7	7153.35	10014.7
4	Fecal sludge	15	39,444.7	591671	13016.76	0.2- 0.75	2603.35	9762.57
				Total	**72658.31**		**32,424.1**	**46,978.17**

Note: Fecal sludge is transported by 15 trucks of specific volume (m^3)

4.6 Biogas potentials of fruit and vegetable wastes

In Table 32 is indicated that fruit and vegetable wastes have a biogas yield within a range of (0.25-0.5) and (0.15-0.7) m^3/kg respectively. In Table 32 a total seasonal average waste result in kilogram per day for fruit waste and vegetable waste are given. As it is seen from the table a total of 31,305.67 kg of seasonal average waste of fruit per day has resulted; From this amount of total seasonal average per day of fruit waste can be generated 1193.53- 2387.06 m^3 biogas; As it is seen from the table a total of 61,300.27 kg of seasonal average waste of vegetables per day has resulted; From this amount of total seasonal average per day of vegetable waste can be generated 772.38- 3604.46 m^3 of biogas.

Table 32: Fruit and vegetable wastes biogas potentials

No	Biomass	Season I wastes (kg/day)	Season II wastes (kg/day)	Total seasonal average/day (kg/day)	Total solid waste (kg)	Biogas yield m^3/kg	Total yield of biogas (m^3/kg)	
							Minimum	Maximum
1	Average market fruit wastes per day	36,675.33	25,936.01	31,305.67	4,774.11	0.25 - 0.5	1193.53	2387.06
3	Average market vegetable wastes per day	68,270.41	54,330.13	61,300.27	5,149.22	0.15- 0.7	772.38	3604.46
				Total	**9,923.33**		**1,965.91**	**5,991.52**

In general from both sources of waste we can have a total of biogas yield ranging from 1,965.91- 5,991.52 m^3 of biogas per day.

From this we can conclude that using the fruit and vegetable wastes accumulated in Adama city as feed stock to a bio-digester can enable the city to have a reliable source of biogas energy throughout the year.

4. 7 Summary of biogas potential of wastes

Table 33: Biogas potential of wastes summary

S.N	Type of waste	Waste/day (in kg)	TS value (% by wt.)	TS (in kg)	Biogas yield m^3/kg	Total yield of biogas (m^3)	
						Minimum	Maximum
1	Cow manure	137,020.70	12	16,442.48	0.25- 0.6	4,110.62	9,865.49
2	Beef (Ox) manure	245,109.74	12	29,413.17	0.25-0.86	7,353.29	25,295.33
3	Solid pig manure	7,945.00	5.5	436.98	0.27-0.45	117.98	196.64
4	Solid poultry manure	42,417.00	18.5	7,847.15	0.25- 0.8	1,961.79	6,277.72
5	Hotel waste	6,834.14	27.33	1,867.77	0.5 - 0.6	933.89	1,120.66
6	Biscuit Industry Waste	4,637.38	31.7	1,470.05	0.5 -0.6	735.03	882.03
7	Institute & Prison	1,204.50	27.33	329.19	0.5 -0.6	164.59	197.51
8	Household waste	165,879.44	27.33	45,334.85	0.5 - 0.6	22,667.43	27,200.91
9	Street Waste	28,613.40	50	14,306.7	0.5- 0.7	7,153.35	10,014.69
10	Fecal sludge	591671.00	2.2	13,016.76	0.2- 0.75	2,603.35	9,762.57
11	Fruit waste	31,305.67	15.25	4,774.11	0.25 - 0.5	1,193.53	2,387.06
12	Vegetable waste	61,300.27	8.4	5,149.22	0.15- 0.7	772.38	3,604.46
	Total	**1,323,938.24**		**140,388.43**		**49,767.23**	**96,805.07**

In this summary the minimum and maximum biogas yield (Refer Fig. 9) from all types of wastes under the study are clearly indicated. From Table 33 and line diagram beef manure and household wastes have shown the maximum biogas yield while others have also remarkable potential. As we see from the table above Adama city generates 1,323,938.24 kg of wastes per day (or 1,323.938 metric tons per day) which has a yield of biogas ranging from 49,767.23-96,805.07 m^3 per day; From this we can conclude that Adama city can get reliable biogas yield from biodegradable wastes through the year.

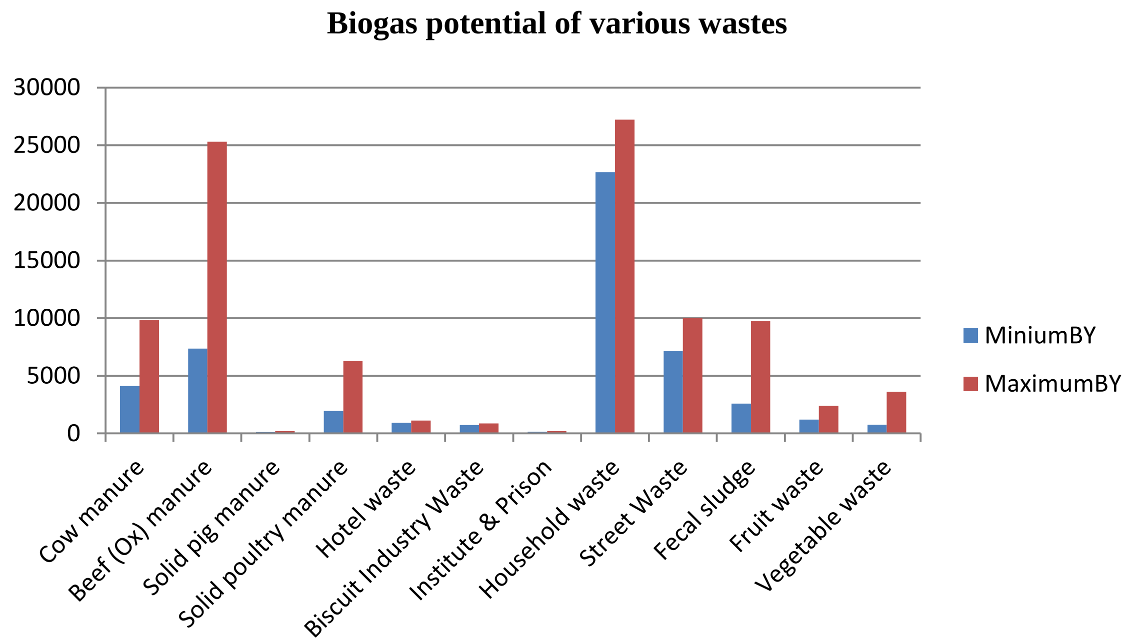

Figure 9: Biogas yield of various wastes (m^3/kg)

4.8 Biogas plant location

4.8.1 Biogas Plant Site Selection

The selection of a feasible construction site for the implementation of biogas plant is very important. The characteristics of the plant site itself strongly influence the technical and economic feasibility of the project of biogas plant. As a result, the site for biogas plant construction should be selected with upmost care along the following criteria.

The plant must be (1) close to the source of feed material (biodegradable waste) and also (2) close and access to transportation. (3) Quality of water must be accessible, but the plant (4) should not be built close to water source, as there is a risk of pollution. The plant (5) should not be built close to trees, as tree roots could grow into the plant and break the walls. The area to construct plant should have (6) even surface and the site should be in (7) slightly higher elevation than the surrounding. For effective functioning of bio digesters, right temperature (25 – 45°C) has to be maintained inside the digester at (8) sunny place. The (9) edge of plant should be at least 2 meter away from the foundation of house or any structure. There should be (10) enough space for compost treatment. The (11) soil should have enough bearing capacity to avoid the possibility of sinking of the plant. And also (12) enough free space to properly undertake installation, operation and maintenance activities.

Table 35: Rating the criteria for biogas plant site selection

S.N	Criteria	Rating with the weight of 10			
		Malka Adama	**Boku Shanan**	**Dhaka Adi**	**Dabe Soloke**
1	Close to the source of biodegradable waste	8	8	7	7
2	Close and access to transportation	8	8	8	8
3	Clean water must be accessible	7	7	7	7
4	Not close to drinkable water source	9	9	9	9
5	Not close to trees at the surrounding	9	9	9	9
6	Even surface for construction	8	8	8	8
7	Higher elevation than the surrounding	10	8	9	7
8	Sunny place to maintain the right temperature	9	9	9	8
9	Far away from the foundation of any structure	10	10	10	10
10	Enough space for compost treatment	9	9	9	9
11	The soil should have enough bearing capacity	8	8	8	8
12	Enough free space to properly undertake installation, operation and maintenance	8	8	8	8
	Total	**103**	**101**	**101**	**98**

Based upon the above criteria (Refer Tab. 34), the researchers in collaboration with Adama City Administration Office recommended four sites used for the implementation of biogas plant namely Malka Adama, Boku Shanan, Dhaka Adi and Dabe Soloke. The rating shows that these sites have higher elevation than the surroundings, enough free space for the plant and compost treatment, even surfaces for construction of the plant, and sunny places for the effective bio-reaction. As a result, an even surface and free space at Malka Adama was recommended for the construction of the first plant, since the current dump site for the solid wastes is around the same recommended area. The remaining three plants are suggested to be constructed phase by phase at Boku Shanan, Dhaka Adi and Dabe Soloke respectively based on the success experience of the first plant at Malka Adama.

4.8.2 Biodegradable Waste Collection Mechanism

The collection of fresh biodegradable waste is one of the major problems of biogas plant. To enhance biodegradable waste collection for the designed bio-digester, different methods can be employed. Currently in different cities of Ethiopia mixed wastes of both biodegradable and non-biodegradable are collected through primary collection method from the sources of the waste to designated containers, secondary collection method from the containers to transfer stations and finally transported from transfer stations to the dump site by using carts, dumpsters and trucks respectively. Based upon the investigation made in Adama city in collaboration with Adama city Administration Office, some drawbacks on the current waste collection methods were identified. These are: (1) Zero waste segregation practice at the sources, (2) insufficient quantity of the two wheeler carts, dumpsters and trucks for the collection and transportation of the wastes, and (3) lack of awareness creation for the society and waste collectors on the segregation of biodegradable and non-biodegradable wastes. In addition, the collected wastes were dumped and remain for longer period of time at the dumpsters and transfer stations before transporting to the final dump site.

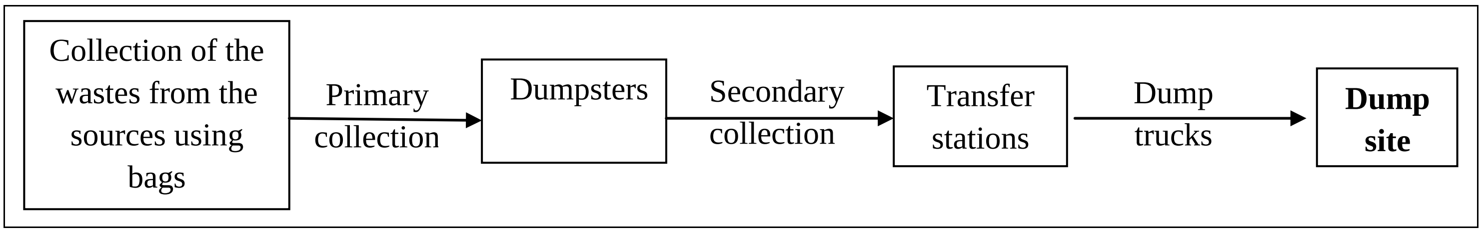

Figure 10: Existing solid waste collection method flow diagram

Therefore, it is observed that the current waste collection methods should be analyzed in terms of sound engineering approach based upon the pre-specified collection methods. The major methods include: segregation, collection and transportation of the wastes to the dump site (Refer Fig. 10). Thus, 1) the wastes should be segregated and stored separately as biodegradable and non-biodegradable wastes within different color bags at the sources of the wastes. The bags may be categorized as green for biodegradable waste and red for non-biodegradable waste by sticking the lists of the wastes on the side of the bags for the understanding purpose; 2) the biodegradable waste will be collected from the individual sources and moved to the designated containers by using carts; 3) the biodegradable wastes will be transported using dump trucks and dumped directly into the intake storage tank to be crushed for ease of feeding to the digester.

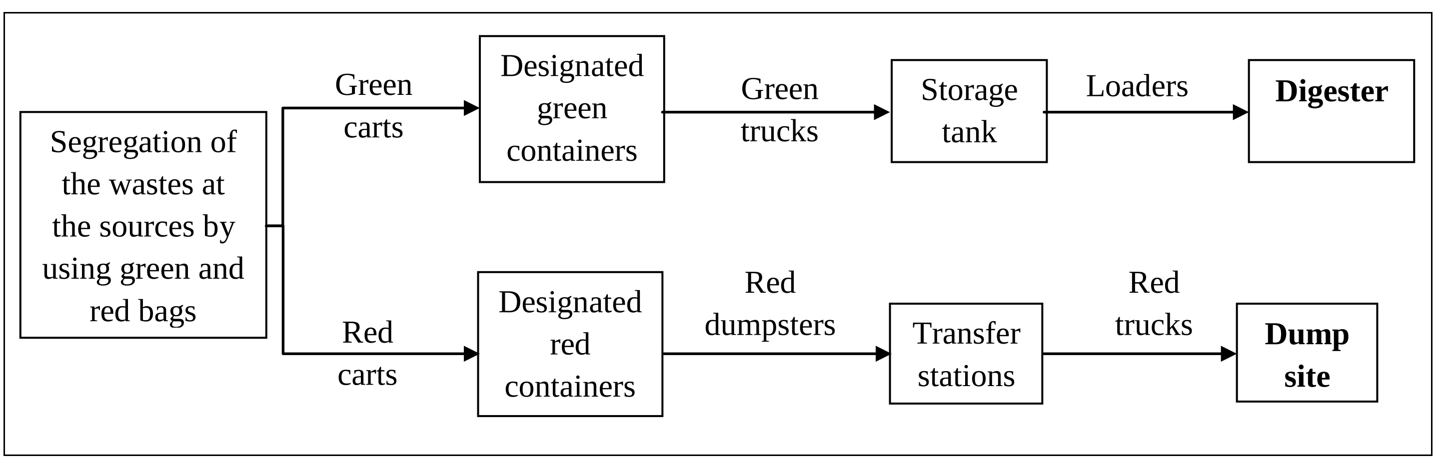

Figure 11: Newly proposed solid waste collection method flow diagram

The green colored bags, containers and trucks are used for the collection and transportation of biodegradable waste (Refer Fig. 11). And, the red colored bags, containers, dumpsters and trucks are used to collect and transport non-biodegradable waste as usual. In order to minimize the time taken to reach biogas plant site, the secondary collection method will not be needed for biodegradable waste. This helps to generate higher amount of biogas, since fresh wastes have higher potential of biogas generation.

i) Waste Segregation

Waste segregation at the source usually allows for reducing collection, transportation and treatment complexity. It also reduces the volume of waste disposed at the dump site. It contributes to the optimization of the cost and resource recovery (e.g. composting of organic waste). But, waste segregation at the source is not a common practice in Adama city. All the wastes are thrown together in plastic bags and any other devices. Even at the market place where large amount of organic wastes are generated, the wastes are not properly sorted as biodegradable and non-biodegradable.

For this study to have efficient bio-digestion, waste segregation at the source is of paramount importance. Thus, all the wastes: household wastes, street sweepings, commercial wastes, food wastes and animal wastes need careful segregation at their sources. Segregated wastes should be collected in plastic bags of required size with different colors and stickers (or marks) for the identification of biodegradable waste from non-biodegradable waste (Refer Fig.12).

Figure 12: Color coding for biodegradable and non-biodegradable wastes' bags

ii) Collection

Segregated wastes are further treated by collection means which is done by micro and small enterprises (MSEs) having formal agreement to collect from Adama households, city active centers (i.e. markets and hotels) and dump them within the designated containers. The current collection methods had two phases: the primary and secondary collection methods. The primary collection method is the collection of wastes from the sources to the designated containers by using carts. Two wheeler carts are used by MSEs and private service providers for collection of the wastes. And, the secondary collection method is the collection of the wastes from the containers to the transfer stations by the use of two wheeler carts and skip loaders. According to Adama Assessment Report (AAR, 2016) Adama Municipality has registered 32 dumpsters with 8 m^3 capacity each. Ministry of Urban Development and Housing has set a standard that 8 m^3 equivalent dumpster should be available per 6,000 people. The AAR has indicated that for Adama City 54 dumpsters are needed. This shows that Adama does not meet the required demand. Thus, as a current status additional 22 dumpsters are required for meeting the standard. The frequency of collection varies from place to place and by category of clients. According to the MSEs' operators, the waste is collected once in a week for households living in regular type of houses, twice a week for shops, three times a week for households living in condominium house and daily for hotels and restaurants. Adama city is equipped with 10 solid waste transfer stations, but these stations are poorly constructed. The stations are used as temporary storage for secondary collection. As per Ministry of Urban Development and Housing, one transfer station per 20,000 people is the set standard. Thus, Adama city needs at least 16 transfer stations for the collection of solid wastes. Accordingly, as a current status additional 6 solid waste transfer stations are required to meet the standard.

For biogas generation, the biodegradable wastes should be collected at the storage tanks placed around biogas plant site which is colored green and then directly be fed to digester. The wastes under the study which are meant for generation of biogas should be collected in a more organized and responsible manner to meet the continuous feeding of the bio-digester.

iii) Transportation

Different kinds of transport means are used by SMEs, private service providers and Municipality to transport the solid wastes to the existing dump site that is found around Oromia Police College. As reported in previous study (AAR, 2016) as well as current study based on questionnaire by the researchers and the real experience observed in different Kebeles (or districts) it is found that the solid waste from dumpsters and transfer stations are not timely collected and transported to the solid waste dumping site as a result of which the solid waste remains for several days in the dumpster and transfer stations with disgusting odors, etc. From this the issue of waste collection and transportation which is dominated by more delays and inconsistencies is of paramount importance to be solved by Adama city Municipality.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Summary

This study is entitled 'Determination of biogas generation from the biodegradable municipal wastes and design of bio-digester'. To meet the objective of the study various strategies have been designed. These are: identifying the major sources of wastes, brain storming of commercial active center, Identifying the organizations which are sources of data, Identifying data needed from organizations, Preparing check lists for data gathering for identified major wastes. There are four major sources of wastes identified, i.e. (i) Domestic animal wastes (ii) Food wastes (iii) House hold and other wastes and (iv) Fruit and vegetable wastes. The collection of essential data have been performed with the use of Stratified and purposive sampling method for each identified wastes.

For seasonally varying wastes such as hotel food wastes, fruits and vegetables two Ethiopian seasons have been considered i.e. Bega and Belg. Using Precise analog measuring device and plastic bags with tags for sample set data of the sample weight of have been generated for one week (or 7 consecutive days). Average weight of wastes/day (kg) of the sample size have been determined; Further the Average weight of wastes/ source/day (kg) have been calculated. From this total average weight of wastes (kg/day) of each sources of wastes have been determined.

Having this data important parameters such as Total solid (TS kg), Total influent required (Q kg/day) and working Volume (Vgs+Vf, m^3) have been determined (Refer Tab.); Using the values determined above the total volume of bio-digester has been determined which enables determination of the diameter of the digester. Further on the base of design economic analysis i.e. Cost Breakdown for the Construction and installation of digester have been done.

Biogas plant location selection criteria have been identified, waste collection and transport means have been suggested.

5.2. Conclusion

In this study had been tried to explore the size of biodegradable wastes which are important for energy generation. From the results obtained the following conclusions are drawn;

- The identified major sources of municipal biodegradable wastes in Adama city are found to be reliable biogas potentials;
- Adama city generates 1,323,938.24 kg of wastes per day (or 1,323.938 metric tons per day) with the expected mean standard error ranging from 10-20%;
- The study has clearly shown that a total solid (TS) of 140,388.43 kg has been obtained which important for anaerobic digestion and biogas generation;
- The waste produced per day is found to generate a biogas yield ranging from 49,767.23 – 96,805.07 m^3/kg per day; Thus, this generates an energy ranging from 84.6-164.6 MWh electricity according to literatures referred.
- From the result it is clearly seen that Household wastes and Beef (Ox) manure have shown high level of biogas yield which is 27,200.91 m^3 and 25,295.33 m^3 respectively; Street wastes (Street sweepings), Cow manure, Fecal sludge and poultry manure have shown medium level of biogas yield per day;
- Multiple criteria decision analysis technique has shown that among the three types i.e. plug flow, fixed roof, and floating roof digester the fixed roof (dome) has got higher weighted sum of the factors set and is selected as a digester to be implemented for this study.
- From the result is seen that the size of the digester is found to be 57,431.51 m^3 as per the waste quantity and 63,916.53 m^3 as per the quantification of volume and surface area; It is obvious that the larger size is the base for digester design.
- The above digester design size is so high that led the researchers to divide it into four sizes for ease of implementation; Thus a digester with a volume of 15,992.5 m^3 having a diameter of 23 m is a favorable size as a quarter of the whole size.
- The multiple criteria decision technique and questionnaire feedback from Adama city sanitation and beautification office has shown Malka Adama, Boku Shanan, Daka Adi, and Dabe Soloke have got the ranking order as better sites respectively for digester construction.

- The cost analysis for construction of biogas digester has shown that a total of about 9,337,039.75 Birr is required for materials and labor cost of quarter of the bio-digester to be constructed.
- The study has revealed that there are: (1) Zero waste segregation practice at the sources, (2) insufficient quantity of the two wheeler carts, dumpsters and trucks for the collection and transportation of the wastes, and (3) lack of awareness creation for the society and waste collectors on the segregation of biodegradable and non-biodegradable wastes. (4) Wastes not timely collected and transported to the solid waste dumping site as a result of which the solid waste remains for several days in the dumpster and transfer stations with disgusting odors, etc.
- The questionnaire response from the respondents of Adama city Sanitation and Greenary officials and previous report on the city sanitation (AAR,2016) has proved that Adama municipality from the standard 54 dumpsters 32 are available and still in need of additional 22 dumpsters and from the standard 20 transfer station 10 are available though is reported 4 are in progress still 10 additional transfer sites are needed to manage the wastes generated in the city successfully.

5.3 Scope for future research and Recommendation

- In this study wastes thrown by the side of roads and streets, wood wastes, abattoirs wastes, wastes of grass and leaves (such as chat) etc. are not considered; Continuation of the study on the generation of energy can be made from this point of view.
- Since this study is based on majorly on both stratified and purposive sampling method this study can be revised with better statistical methods using recent and upgraded data;
- Based on the data collected in this study further small scale experimental studies on the basis of co-digestion can be done;
- Optimization of biogas production and scrubbing of the biogas can be made so that it can be used as vehicle fuel like Compressible natural gas ;
- Adama Science and Technology University(ASTU) and Adama municipality should cooperate to change the large volume of waste generated to useful energy and fertilizer;
- Awareness creation should be conducted jointly with ASTU and Adama municipality with regards to waste segregation, collection, transportation and dumping.

- Optimization of the schemes and route of waste collection and transportation should be done based on careful data collection and analysis of the service rendered;
- Most of Adama city dumpsters are located near the residential areas that can affect of the health of people; Optimization of the location for the dumpsters and dump sites can be made;
- Adama municipality should reserve site for locating a number of digesters which can accommodate the biodegradable wastes in the city;

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APPENDICES

Appendix I: Check list for survey of wastes before data collection

Table 1: Animal manures (Data from municipality or related office)

S.N	Type of business	Number of licensed individuals	Number of non-licensed individuals	Approximated number of cow/ox/chicken/pig in the licensed organization	Approximated number of cow/ox/chicken/pig in the non licensed organization	Approximated number of cow/ox/ chicken/pig in both licensed and non-licensed organization	Remark
1	Dairy farming						
2	Oxen/Cow fattening						
3	Poultry						
4	Pig breeding						
5	Camel fattening						

Table 2: Toilet waste disposal (data from municipality)

S.N	Source of human waste	Average Weekly disposal of toilet waste (m^3)
1	Hotel	
2	House hold	
3	Hospital	
4	Sector office	
5	Others	
Total		

Table 3: Fruit wastes

S.N	List of degradable Items	Approx. weight per week (Kg)
	Fruit	
1	Apples	
2	Avocados	
3	banana	
4	Black berries	
5		

Table 4: Vegetable wastes

S.N	List of degradable Items	Approx. weight per week (Kg)
	Fruit	
1	Cabages	
2	Tomato	
3	Potato	
4	Onion	
5		
6		

Table 5: Food wastes

S.N	List of degradable Items	Approx. weight per week (Kg)
	Foods leftover	
1	Hotels	
2	Industries	
3	Universities	
4	Boarding schools	

Appendix II: Data of fruits and vegetables wastes

Table 6: Average data of wastes collected from supplies of fruits (Oct-Jan,2016/17)

No	Average supply/day (kg)	Supply waste before market (%)	Average waste/day before market (kg)	Remained supply for market (kg)	Supply waste after market (%)	Average wastes/day after market (kg)	Sub-total wastes/day (kg)
	1	2	3 = 1 x 2	4 = 1 - 3	5	6 = 5 x 4	7 = 3 + 6
1	28,928.57	18	5,207.14	23,721.43	22	5,218.71	10,425.86
2	27,928.57	15	4,189.29	23,739.29	20	4,747.86	8,937.14
3	19,642.86	15	2,946.43	16,696.43	22	3,673.21	6,619.64
4	15,714.29	5	785.71	14,928.57	6	895.71	1,681.43
5	18,428.57	15	2,764.29	15,664.29	25	3,916.07	6,680.36
6	1,642.86	4	65.71	1,577.14	5	78.86	144.57
7	5,085.71	3	152.57	4,933.14	5	246.66	399.23
8	95.71	2	1.91	93.80	5	4.69	6.60
9	835.71	3	25.07	810.64	5	40.53	65.60

10	72.14	2	1.44	70.70	3	2.12	3.56
11	6,414.29	6	384.86	6,029.43	22	1,326.47	1,711.33
						Grand total (kg/day)	**36,675.32**

Table 7: **Average data of wastes collected from supplies of fruits** (Feb-May, 2016/17)

No	Average supply/day (kg)	Supply waste before market (%)	Average waste/day before market (kg)	Remained supply for market (kg)	Supply waste after market (%)	Average of wastes/day (kg)	Total wastes/day (kg)
	1	2	3 = 1 x 2	4 = 1 - 3	5	6 = 5 x 4	7 = 3 + 6
1	21,357.14	15	3,203.57	18,153.57	20	3,630.71	6,834.29
2	23,857.14	12	2,862.86	20,994.29	20	4,198.86	7,061.71
3	15,357.14	15	2,303.57	13,053.57	20	2,610.71	4,914.29
4	9,285.71	5	464.29	8,821.43	4	352.86	817.14
5	11,428.57	10	1,142.86	10,285.71	25	2,571.43	3,714.29
6	578.57	2	11.57	567.00	3	17.01	28.58
7	3,214.29	2	64.29	3,150.00	3	94.50	158.79
8	45.71	2	0.91	44.80	3	1.34	2.26
9	478.57	3	14.36	464.21	5	23.21	37.57
10	36.43	2	0.73	35.70	3	1.07	1.80
11	5,421.43	2	108.43	5,313.00	22	1,168.86	1,277.29
						Grand total (kg/day)	**24,848.00**

Table 8: Average data of wastes collected from supplies of vegetables (Oct-Jan,2016/17)

No	Average supply/day (kg)	Supply waste before market (%)	Average waste/day before market (kg)	Remained supply for market (kg)	Supply waste after market (%)	Average of wastes/day (kg)	Total wastes/day (kg)
	1	2	3 = 1 x 2	4 = 1 - 3	5	6 = 5 x 4	7 = 3 + 6
1	25,714.29	20	5,142.86	20,571.43	15	3,085.71	8,228.57
2	24,285.71	18	4,371.43	19,914.29	30	5,974.29	10,345.71

3	15,785.71	15	2,367.86	13,417.86	20	2,683.57	5,051.43
4	1,457.14	2	29.14	1,428.00	3	42.84	71.98
5	2,790.00	3	83.70	2,706.30	5	135.32	219.02
6	4,400.00	14	616.00	3,784.00	12	454.08	1,070.08
7	3,714.29	2	74.29	3,640.00	2	72.80	147.09
8	3,071.43	2	61.43	3,010.00	3	90.30	151.73
9	1,371.43	5	68.57	1,302.86	8	104.23	172.80
10	2,271.43	13	295.29	1,976.14	10	197.61	492.90
11	65,785.71	13	8,552.14	57,233.57	12	6,868.03	15,420.17
12	1,742.86	14	244.00	1,498.86	12	179.86	423.86
13	50,857.14	20	10,171.43	40,685.71	25	10,171.43	20,342.86
14	549.29	2	10.99	538.30	2	10.77	21.75
15	832.86	14	116.60	716.26	10	71.63	188.23
16	3,471.43	14	486.00	2,985.43	6	179.13	665.13
17	19,357.14	14	2,710.00	16,647.14	15	2,497.07	5,207.07
18	568.57	4	22.74	545.83	5	27.29	50.03
Grand total (kg/day)							**68,270.41**

Table 9: Average data of wastes collected from supplies of vegetables (Feb-May, 2016/17)

No	Average supply/day (kg)	Supply waste before market (%)	Average waste/day before market (kg)	Remained supply for market (kg)	Supply waste after market (%)	Average of wastes/day (kg)	Total wastes/day (kg)
	1	2	3 = 1 x 2	4 = 1 - 3	5	6 = 5 x 4	7 = 3 + 6
1	22,500.00	20	4,500.00	18,000.00	10	1,800.00	6,300.00
2	19,928.57	10	1,992.86	17,935.71	30	5,380.71	7,373.57
3	12,857.14	10	1,285.71	11,571.43	20	2,314.29	3,600.00
4	885.71	2	17.71	868.00	3	26.04	43.75

5	1,357.14	1	13.57	1,343.57	3	40.31	53.88
6	3,371.43	14	472.00	2,899.43	12	347.93	819.93
7	2,571.43	2	51.43	2,520.00	2	50.40	101.83
8	1,785.71	2	35.71	1,750.00	3	52.50	88.21
9	678.57	5	33.93	644.64	6	38.68	72.61
10	1,698.57	13	220.81	1,477.76	10	147.78	368.59
11	57,642.86	14	8,185.29	49,457.57	12	5,934.91	14,120.19
12	1,257.14	14	176.00	1,081.14	12	129.74	305.74
13	45,714.29	14	6,400.00	39,314.29	25	9,828.57	16,228.57
14	307.14	2	6.14	301.00	2	6.02	12.16
15	494.29	14	69.20	425.09	10	42.51	111.71
16	2,600.00	14	364.00	2,236.00	3	67.08	431.08
17	16,428.57	14	2,300.00	14,128.57	14	1,978.00	4,278.00
18	342.86	2	6.86	336.00	4	13.44	20.30
						Grand total (kg/day)	**54,330.13**

Appendix III: Descriptive statistics of various wastes

Table 10: Descriptive Statistics for domestic animal wastes

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Cow manure	7	29.30	39.30	32.9143	1.56790	4.14826	17.208
Oxen manure	7	17.00	22.00	19.7143	.68014	1.79947	3.238
Pig manure	7	19.30	24.30	21.6714	.76896	2.03446	4.139
Polutry manure	7	1.00	2.00	1.5000	.15430	.40825	.167
Valid N (listwise)	7						

Table 11: Descriptive Statistics hotel food wastes

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
BigHW	7	148.50	382.00	282.7857	26.81592	70.94825	5033.655
MediumHW	7	71.50	91.50	84.0000	2.54484	6.73300	45.333
SmallHW	7	7.50	118.50	74.8286	14.26646	37.74549	1424.722
Valid N (listwise)	7						

Table 12: Descriptive Statistics for Industries and Institutions food wastes

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Big Indu.	7	346.00	495.00	421.5714	20.02006	52.96809	2805.619
University	7	450.00	735.00	599.2857	39.37652	104.18048	10853.571
BoardingS	7	200.00	300.00	252.8571	15.69263	41.51879	1723.810
MedicalC	7	70.00	120.00	79.1429	6.86755	18.16983	330.143
TVCP	7	224.50	310.50	273.2143	13.97355	36.97055	1366.821
Valid N (listwise)	7						

Table 13: Descriptive Statistics for household and other wastes

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
House hold	7	195.00	240.00	216.4286	5.94762	15.73592	247.619
Street swp	7	64.20	64.20	64.2000	.00000	.00000	.000
JuiceH	7	30.50	37.00	32.6429	.88448	2.34013	5.476
FecalS	7	591671.00	591671.00	591671.00	.00000	.00000	.000
Valid N (listwise)	7						

Appendix IV: Questionnaire

A study to determine the amount of biogas generation from Adama municipal biodegradable wastes is on its finalizing stage; we are in need of important data which will assist us to finalize the study with your kind co-operation from your concerned office.

The following questionnaire is Aimed to get information regarding waste segregation, waste collection, waste transportation and disposal (of adama municipality biodegradable wastes.

The study is carried out to complete research project from group of Adama Science and Technology University (ASTU) faculty members.

Introductory information:

1) Name of Sector/office:____

2) Position:____

3) Gender:___________________________

4) Work experience:____

For the given inquires make tick(√) mark in the box given and write your additional information in the space provided.

1) Is there any segregation of wastes as degradeable and non-degradeable at the sources (households, hotels etc.) in Adama city?

Yes, ☐ No , ☐

2) If your answer is ‘No’ for question 1 what is planned for the future. Write the response below;

____

____

3) If your answer is ‘Yes’ for question 1 what is the practice. Write the response below;

____

____

4) There are waste collections methods (both from the sources and transfer stations) observed throughout Adama city Ganadas (or Districts); Do you think they are adequate enough?

Yes, ☐ No, ☐

5) If your answer for question ‘4’ is ‘yes’ how do you evaluate it? Write the response below;

____

____

6) If your answer for question ‘4’ is ‘No’ what is your reason? Write the response below;

____

____

7) Do you think the numbers of dumpsters in Adama are sufficient to accommodate the city waste?

Yes, ☐ No, ☐

8) If your answer for question ‘7’ is ‘yes’ do you think it is to the standard? Write theresponse below;

____

____

9) If your answer for question ‘7’ is ‘No’ what is the reason? Write the response below;

____

____

10) Do you think the number of transfer stations in Adama are sufficient to accommodate the city waste?

Yes, ☐ No, ☐

11) If your answer for question ‘10’ is ‘yes’ do you think it is to the standard? Write your response below;

____

____

12) If your answer for question ‘10’ is ‘No’ what is the reason? Write the response below;

____

____

13) Do you think the number of dump trucks in Adama are sufficient to transport the city waste to the dump site?

Yes, ☐ No, ☐

14) If your answer for question ‘13’ is ‘yes’ do you think it is adequate for the work? Write the response below;

____

____

15) If your answer for question ‘13’ is ‘No’ what is the reason? Write the response below;

____

____

16) Do you think the number of dump sites in Adama are sufficient to accommodate the city wastes?

Yes, ☐ No, ☐

17) If your answer for question ‘16’ is ‘yes’ do you think it is adequate adequate? Write your response below;

18) If your answer for question '16' is 'No' what is your recommendation? Write your response below;

19) If Bio-digester should be built for biogas generation in Adama city are there any appropriate locations or sites.

Yes, ☐ No, ☐

20) If your answer for question '19' is 'yes' Which sites do you recommend? And where are they located? If your answer is 'No' what is the reason? Write the response below;

21) Please refer the attached requirements to recommend (or select) a site or location for building bio-gas reactor (plant).

Thank you for cooperation

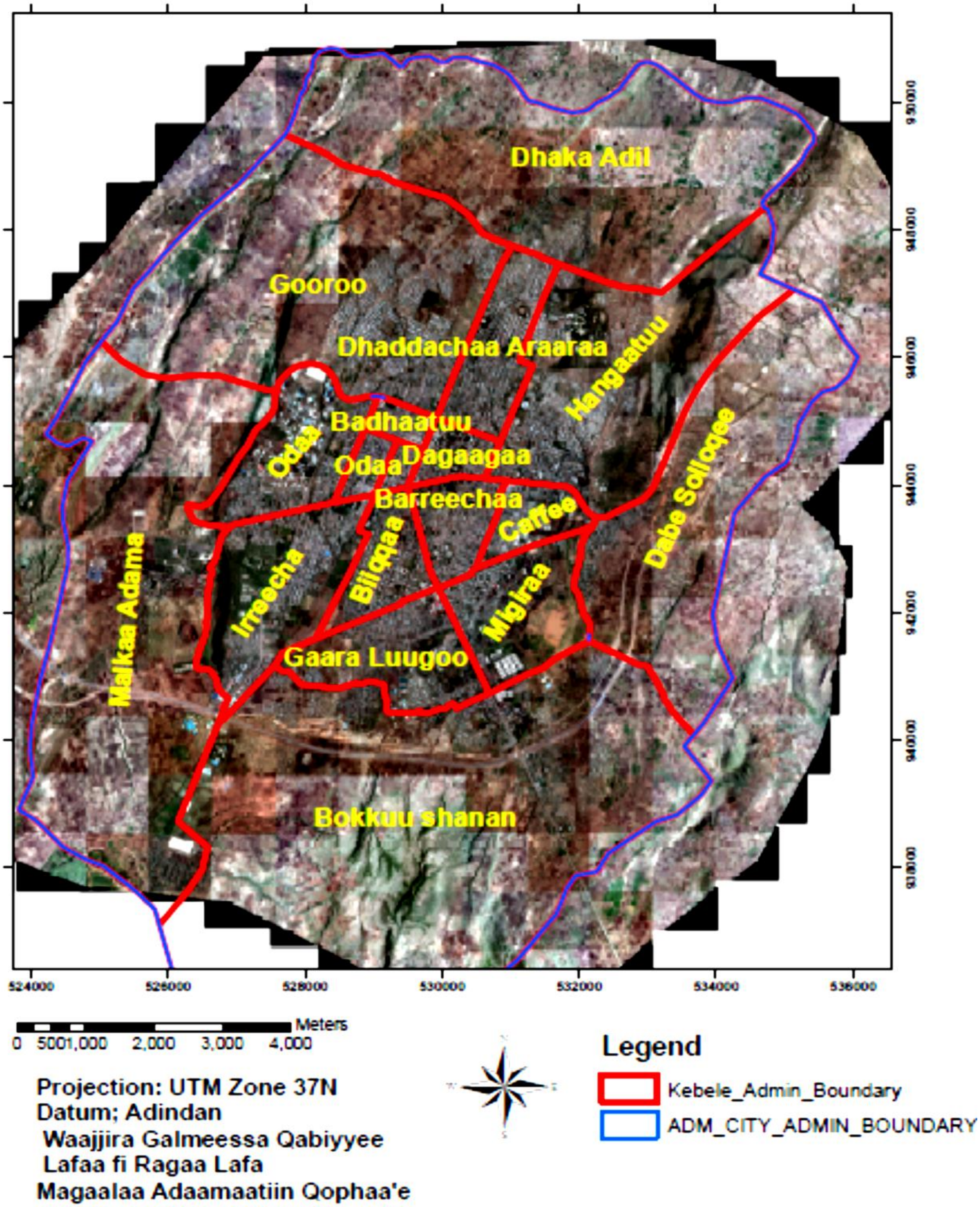
Appendix V: Budget utilized for the research work

Table 34: Total cost expended for the research

S.No	Activities	Cost expended
1	Data gathering from different energy sectors at Bishoftu, AA, Hawasa, Bahir Dar, and Haramaya, by the four researchers, active for 30 days perdiem;	23,800.00
2	Transportation costs (For 15 days)	30,000.00
3	Data collectors (45 persons)	62,454.00
4	Sample collection facilitators (10 persons)	20,000.00
5	Communication cost (Mobile card for 5 researchers)	3,000.00
6	Printing and compilation cost	3,000.00
7	Photo copy papers (5 packs)	750.00
8	Note pads	1,050.00
9	RW CD (25 pieces)	750.00
10	Flash disc (5 pieces 16 GB)	1000.00
	Total cost	**145,804.00**

It is clearly seen from the table 34 that the total cost is expended is 145,804 Birr; The fund proposed is 204,250 Birr. Thus it can be concluded that approximately 71.4% of the fund is utilized for the research work.

Appendix VI: Adama administration map



Appendix VII : Various waste pictures