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Investigation of biogas production potential from fruit and vegetable wastes generated from a wholesale market of Addis Ababa by Co-digestion process and upgrading methane content using commercial Biochar Adsorption

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BAHIR DAR INSTITUTE OF TECHNOLOGY

SCHOOL OF RESEARCH AND GRADUATE STUDIES

FACULTY OF CHEMICAL AND FOOD ENGINEERING

M.Sc. Thesis on

Investigation of biogas production potential from fruit and vegetable wastes generated from a wholesale market of Addis Ababa by Co-digestion process and upgrading methane content using commercial Biochar Adsorption

By: Biruk Zeleke

Bahir Dar, Ethiopia

July 2022

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Investigation of biogas production potential from fruit and vegetable wastes generated from a wholesale market of Addis Ababa by Co-digestion process and upgrading methane content using commercial Biochar Adsorption

By
BIRUK ZELEKE BOGALE

A thesis submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Chemical Engineering (**Environmental Engineering) in the Faculty of Chemical and Food Engineering.**

Advisor: Temesgen Atnafu (Ph.D.)

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Bahir Dar, Ethiopia

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Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

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As members of the board of examiners, we examined this thesis entitled "**Investigation of biogas production potential from fruit and vegetable wastes generated from a wholesale market of Addis Ababa by Co-digestion process and upgrading methane content using commercial Biochar Adsorption**" by **Biruk Zeleke.** We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science in "Environmental Engineering".

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DECLARATION

This is to certify that the thesis entitled **“Investigation of biogas production potential from fruit and vegetable wastes generated from a wholesale market of Addis Ababa by Co-digestion process and upgrading methane content using commercial Biochar Adsorption”,** submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering under Faculty of Chemical and Food Engineering**,** Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during this investigation have been duly acknowledged.

Biruk Zeleke	______________	**July 2022**
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ABSTRACT

Energy is one of the limiting parameters for the economic growth of one nation. Energy could be generated from various sources and biogas can be one among to be mentioned. Biogas production is a key technology in the development of sustainable energy supply systems that aims to cover the energy demand using renewable sources, other solid waste management options and to mitigate greenhouse gas emissions. In this work, biogas was generated from the fruit and vegetable wastes by using an anaerobic co-digester. Various process parameters were characterized in terms of pH, total solids, volatile solids, moisture content, ash content, total nitrogen, and C: N ratio. The wastes were digested for 30 days and the water displacement method and biogas analyzer measured biogas generation and methane composition of the product, respectively. The effects of the C/N ratio, pH, temperature, and sonication time on the biogas generation and methane composition were examined. Biogas generation was observed to increase with an increase in C/N ratio, pH, temperature, and sonication time in all cases. Moreover, methane yield was increased from 0.17 to 0.32, 0.21 to 0.32, 0.19 to 0.33, and 0.15 to 0.39 L CH_4/gVS with an increase of C/N ratio from 20 to 30, pH from 6 to 8, temperature from 25 to 35 ^{o}C, and sonication time from 0 to 60 min., respectively. Passing the generated biogas through activated carbon, NaOH, and KOH solution, and silica gel was observed to increase the methane composition of the product.

Keywords: Biogas; Methane yield; silica gel; C/N ratio; Co-digestion

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ABBREVIATIONS AND ACRONYMS

AD	Anaerobic Digestion
APHA	American Public Health Association
C: N	Carbon to nitrogen
FVW	Fruit-Vegetable Waste
GVS	gram volatile solids
HRT	Hydraulic Retention Time
LCFA	Long-chain Fatty Acid
N	Normality
TS	Total solid
v/v	Volume by volume
VFA	Volatile fatty acid
VS	Volatile solid
WDC	Weight of dry crucible in gram
WDS	Weight of a dry sample at 103°C
WVS	Weight of volatile solids
WWS	Weight of wet sample in gram

1. INTRODUCTION

1.1.Background of the Study

The standard of living and national development of any nation depends on the amount and quality of energy supply. It is well known that the primary energy source for many nations belongs to fossil fuels (Otun T F et al. 2015). Assuming the current energy usage trend, reports indicated that oil will run out within 40-70 years, and natural gas will be finished within 50 years (Otun T F et al. 2015). The intensive use of fossil fuels results in the current global environmental problems namely global warming, acid rain, sea-level rise, ice melting, flooding, drought, etc. (Divya, Gopinath, and Merlin Christy 2015). To reduce the fossil fuels energy dependency, Ethiopia has been investing incredibly in developing its hydroelectric power generating capacity from water sources like Gelgel Gibe I and II dam, Great renaissance dam, Koysha, and Finch dams. Another energy sector given attention in Ethiopia is the development of decentralized off-grid renewable and sustainable energy source like biogas (Deressa et al. 2015; Dhingra 2021). According to the present report by (Hailu and Kumsa 2020), Ethiopia has 1-3 million households potential to be exploited from the biogas energy sector and to date only less than 1% exploited. Biogas can be produced from locally available digestible substrates. Namely sewage sludge, thickened waste activated sludge, food wastes, animal manure, and municipal solid wastes are some of the potential substrates for biogas generation (Pavi et al. 2017). Several studies have shown that biogas systems are among the most viable options for the production of clean, cost-efficient, and environmentally sound energy with multiple benefits to user households (Wassie and Adaramola 2020). One of the most renewable efficient energy sources is the biogas produced from Fruit & Vegetable Wastes. Biogas production has multiple benefits; energy production, waste minimization, from landfilling reduction and the reduction of pollution levels, bio-fertilizer from digestate, pure chemicals, and the creation of green jobs. The global generation of municipal solid waste (MSW) has grown annually, along with urbanization and consumption standards.

MSW produced in the cities and urban areas comprises a high fraction of putrescible organic wastes that can easily be degraded and causes serious environmental hazards and health risks (Dhanalakshmi Sridevi, Rema, and Srinivasan 2015). A considerable amount of municipal solid waste residue is generated from different cities in Ethiopia and Addis Ababa is not exceptional.

The main components of municipal solid waste are plastic bottles, glasses, metals, bones, food wastes, leaves, stones, and fruit and vegetable wastes. Fruits and vegetable wastes (FVW) are a very important class of solid waste because they are produced in considerable amounts in supermarkets and wholesale markets (Pavi et al. 2017).

Municipal solid wastes are composed of different refuse generated from households and different institutions such as schools, hospitals, hotels, markets, etc. Fruit and vegetable wastes (FVWs) represent a specific waste produced largely by the wholesale markets and constitute a source of nuisance in municipal landfills because of their high biodegradability. FVWs have very high moisture contents, biochemical processes, such as anaerobic digestion, are the most suitable conversion technologies to treat FVWs.

FVW are mainly generated within the entire process chain due to problems in storage, damages during transport, contamination along the process, or in separation stages that create by-products not intended for human consumption (feathers, skins, fruit peels) (Morales-Polo, Cledera-Castro, and Soria 2019). Separate digestion of fruit wastes and vegetable wastes was observed to face problems due to the large production of free fatty acids which result in the decrease of the pH in the digester (Alemu G. 2016). This decrease in pH was observed to decrease the quality and quantity of the biogas produced from the biodegradable fruit wastes and vegetable wastes. The best solution and the current research direction in biogas development is the co-digestion of different wastes (Fonoll et al. 2015). On the other hand, the biogas produced using anaerobic digesters, especially using fruit and vegetable wastes lacks the quality to be used directly (Alemu G. 2016). As a result, it needs upgrading using different available technologies. Among the reported technologies for upgrading the methane concentration in the biogas, the use of commercial biochar adsorption was selected due to its ease of operation and abundant availability. Inspired by these reported works, this study was developed to generate biogas from the co-digestion of fruit vegetable wastes using anaerobic digestion technology.

1.2.Statement of the Study Problem

There are wide municipal solid waste management problems in Ethiopia and this problem is more severe in the cities such as Addis Ababa. According to the existing management practices of MSW in the city of Addis Ababa, it is estimated that the solid waste generated rate is about 0.45 kg per capita per day, the average estimated density is 330 kg/m3, and a total of approximately 6019 m3 solid waste is generated in the city this one is approximately 1990 tons municipal waste generated. According to a representative of Cambridge Industries, Kosh power plant processed 1,400 tons of the city's waste per day at full capacity. And generate 185-gigawatt hours of electricity annually which is connected to the national grid. Still, there is a gap between power plant processed wastes and the daily generated wastes.

Currently, about 2 to 3 trucks of fruit and vegetable wastes are generated daily from the Addis Ababa fruit and vegetable wholesale market site (Alemu G. 2016). These considerable amounts require large landfills or dumping sites. It means approximately 50 Ton to 75 Ton of FVWsThese wastes are currently underutilized and have wide-ranging environmental and societal impacts (Sri Suhartini et al. 2021). Decreasing the aesthetical value of the city, being the source of flies and rodents, closing up of sewerages channels and bad odor are some of the environmental and societal impacts belonging to the fruit and vegetable wastes.

On the other hand, the absence of converting the fruit and vegetable wastes to biogas by anaerobic digestion technology results in the lack of alternative energy sources for specifically low-income residents of Addis Ababa. This highly increases the grid energy dependency of society. Not only this but also the lack of green energy from biogas results in the absenteeism of large or small scale urban agricultural activities using the nutrient-rich digestate by-product from this technology. Due to this, the city missed the job created and economic support gained from the anaerobic digestion process and its byproducts, which can be used as fertilizer to improve soil fertility, soil structure, and crop yield. Moreover, due to the unavailability of cheap, clean, and green energy, there are considerable numbers of households that use charcoal and fire woods for cooking, are mainly exposed to indoor air pollution, and encourage deforestation. Moreover, the installed digester lack attached simple and easily available auxiliary upgrading units like adsorption column to increase the methane concentration in the biogas. Increasing the methane in the biogas increase the heating value of the energy generated which helps to cook quickly during its application. It can, therefore, be summarized that lack of fruit and vegetable wastes valorization resulted in the absence of cheap and sustainable energy, complicated environmental problems, and socio-economic problems (Masebinu et al. 2018).

1.3. The objective of the Study

1.3.1. General Objective

The main objective of this research is to determine the potential of biogas production from fruit and vegetable waste generated from the wholesale market of Addis Ababa by co-digestion process and upgrading methane content using commercial biochar adsorption.

1.3.2. Specific objective

- Characterize the physical-chemical /proximate composition of fruit and vegetable wastes as a substrate
- Study the effects of mixing C/N ratio, initial pH, temperature, and Sonication on biogas yield and methane content.
- Upgrading the methane content of the biogas using commercial biochar adsorption.

1.4.Significance of the study

This study result significantly helps eliminate the environmental, socio-economic problems emanated from the lack of fruit and vegetable wastes. It also helps to show the potential of the fruit and vegetable wastes in the sustainable and renewable energy generation section. Using fruit and vegetable waste for biogas production has a great contribution to environmental pollution mitigation and wise solid waste management. This study result can be used as the starting point for the researchers working in this area.

2. LITERATURE REVIEW

2.1. Anaerobic digestion

Anaerobic digestion is a series of biological processes that use a diverse population of bacteria to break down organic materials into biogas which primarily contain combustible gas methane and solid-liquid by-products which are considered as digested mainly in the absence of free oxygen (Morales-Polo, Cledera-Castro, and Soria 2019). The primary substrate for anaerobic digestion is organic wastes. The organic materials are composed of organic compounds resulting from the remains or decomposition of previously living organisms such as plants and animals and their waste products. Sources of organic material for anaerobic digestion include dairy manure, food processing waste, plant residues, and other organic wastes such as municipal wastewater, food waste, fats, oils, grease, and fruit and vegetable wastes (Debruyn and Hilborn 2007). The end product of anaerobic digestion biogas is composed of methane (CH_4) typically about 60-70% v/v, carbon dioxide (CO_2) 30-40% v/v, and small amounts of H_2S and other trace gases. Biogas can be combusted to generate electricity and heat or processed into renewable natural gas and transportation fuels. Separated digested solids can be composted and directly applied to croplands, or converted into other products such as potting soil mixes. Moreover, digested liquid, which contains fewer pathogens and weed seeds and is rich in crop nutrients, can be used as agricultural fertilizer. Digestion of livestock manure also reduces emissions of greenhouse gases and odors. Anaerobic digestion is considered a reliable process owing to its economic and technical viability compared to other available approaches such as pyrolysis, incineration, gasification, and composting methods. Besides, anaerobic digestion has less impact on air quality than combustion-dependent processes and helps to minimize carbon emissions by generating energy to replace fossil fuels (Zamri et al. 2021). Generally, anaerobic digestion technology has benefits of reducing odor missions, which improves air quality; harvesting biogas (mainly the greenhouse gases CH_4 and CO_2), which reduces greenhouse gas emissions to the atmosphere; generating energy (gas, electricity, heat); improving nutrient availability to plants, reducing fertilizer costs; and help as a means to receiving carbon credit payments (Debruyn and Hilborn 2007).

2.2. Biogas

Biogas was produced as early as 3000 years ago from animal dung, human sewage, and organic waste consisting generally of household waste, agricultural waste, human and animal waste (U.S Environmental Protection Agency, 2008). Evidence points out that biogas was used for water bath heating in Assyria in the 10th century BC. Persia, on the other hand, started to use biogas in the 16^{th} century AD. Organic waste was recognized as a source of energy for the first time when Davy in 1808 recognized that methane was produced from the decomposition of cattle manure but it was not until the end of the 19^{th} century that methanogenesis was associated with microbial activity (Philip,2008). There has been considerable development in these modern times, as this idea was later exploited and many new technologies that are now used to produce and purify such gas (biogas) began to spring up (Özmen and Aslanzadeh, 2009). Biogas is a flammable gas composed mainly of a mixture of methane and carbon dioxide. Biogas-generating technology is a favorable dual-purpose technology, at present: the biogas that is generated can be used to meet energy requirements; thus, renewable energy that can be used for heating, generating electricity, and many other operations such as used in vehicles, where it can fuel an internal combustion engine. The secondary product of the process is a sludge residue (digestate) that can be directly used as a soil amendment (Sagagi et al., 2009) or as starting material for high-quality compost preparation (Nguyen, 2012). Biogas is a renewable source of energy. Biogas is a mixture of gases comprising 50 to 75% methane (CH_4), 25 to 45% carbon dioxide (CO_2), and 0 to 5% a combination of hydrogen sulfide (H_2S), N_2, H_2, and others (Florian, 2013). Besides these two gasses, biogas additionally contains minor amounts of other compounds, such as nitrogen (N2) at concentrations of 0-3 %, which could originate from air saturated in the influent, vapor water (H_2O) at concentrations of 5-10 %, or higher at thermophilic tempera- tures, derived from medium evaporation, oxygen (O_2) at concentrations of 0-1 %, which is entering the process from the influent substrate or leakages, hydrogen sulfide (H_2S) at concentrations of 0-10,000 ppm, which is produced from the reduction of sulfate contained in some waste- streams, ammonia (NH_3) originating from hydrolysis of proteinaceous materials or urine, hydrocarbons at concentrations of 0-200 mg/m^{-3} and siloxanes at concentrations of 0-41 mg m^{-3}, originating for example from effluents from cosmetic medical industries (Angelidaki et al. 2018). Apart from CH_4, all the other gasses contained in biogas are bi-products and are considered biogas pollutants. The energy content of methane described by the Lower Calorific Value (LCV) is 50.4 MJ/kg CH_4 or 36 MJ/m^3-CH_4 at the standard conditions. Therefore, it is well noted that the higher the CO_2 or N_2 content is, the lower the LCV in biogas. For biogas with methane content in the range of 60-65% the LCV is approximately 20-25 MJ/m^3-biogas (Angelidaki et al. 2018). The carbon dioxide that is released when biogas is combusted and mixed with the oxygen in the air does not contribute to the greenhouse effect as the carbon in the methane molecule originates from carbon dioxide in the air that growing plants have previously taken up by photosynthesis. As a result, the use of biogas is thus an important step in climate change mitigation. The development of biogas represents a strategically important step away from oil dependency that will contribute to a sustainable energy supply in the long term. Biogas is also produced locally meaning that it is not dependent on trade relationships. This also contributes to improved energy security (Lars, 2012).

2.3. Stages of anaerobic digestion

2.3.1. Hydrolysis

The first step in the anaerobic digestion process is hydrolysis, which occurs due to the extracellular enzymes produced by hydrolytic microorganisms such as cellulase, amylase, protease, and lipase to decompose complex organic polymers into simple and soluble monomers. During this time, proteins are broken down into amino acids, lipids into long- and short-chain fatty acids, starch into glucose, and carbohydrates into simple sugars (Debruyn and Hilborn 2007) Different specialized bacteria produce several specific enzymes such as cellulase, amylase, protease or lipase that catalyze the decomposition process.

2.3.2. Acidogenesis

At this process stage, the small molecules resulting from hydrolysis are converted by acidogenic, which can be considered as fermentative bacteria to a mixture of volatile fatty acids (VFAs) such as acetic, propionic, and butyric acids and other minor products such as hydrogen, carbon dioxide, and acetic acid. Moreover, due to fermentation acetate, hydrogen, carbon dioxide, formate, methanol, methylamines, propionate, butyrate, and others similar are produced by acidogenesis (Neshat et al. 2017). In the anaerobic digestion process, acidogenesis is usually the fastest step in the anaerobic conversion of complex organic matter in liquid-phase digestion (Atelge et al. 2020).

2.3.3. Acetogenesis

In this third stage of anaerobic digestion, acetogenic bacteria play a role to convert the volatile fatty acids to acetate, CO_2, and/or hydrogen (H_2) (Debruyn and Hilborn 2007), while the remaining is broken down to short-chain volatile fatty acids (VFA) with one to five carbon (valeric acid, butyric acid, propionic acid, acetic acid, and formic acid). A large portion of the monomers (glucose, xylose, amino acids) and long-chain fatty acids are broken down mainly to acetic acid and propanoic acid. This process is closely interlinked with methanogenesis (Alemu G. 2016).

2.3.4. Methanogenesis

As indicated above (section 2.3.3), provides substrates for methanogenesis, which is the last stage in the anaerobic process for methane production (Debruyn and Hilborn 2007). Reported works indicated that a stable anaerobic digestion process requires maintaining a balance between several microbial populations. The hydrolysis and acidogenesis steps have the most robust microbes (acid formers), which thrive in the broadest environmental range. They react quickly to increased food availability, so the fatty acid concentration could rise very quickly. The pH range is maintained under normal circumstances by the buffering action of the system provided by CO_2 in the form of bicarbonate (HCO_3^-) alkalinity. However, if the acid concentration overcomes the system's buffering capacity, the pH value could be out of the acceptable limits of the acetogenic and methanogenic bacteria (methane formers). When this happens, methane production stops, and the acid levels rise to the tolerance level of the acid formers, thus resulting in system failure (Debruyn and Hilborn 2007).

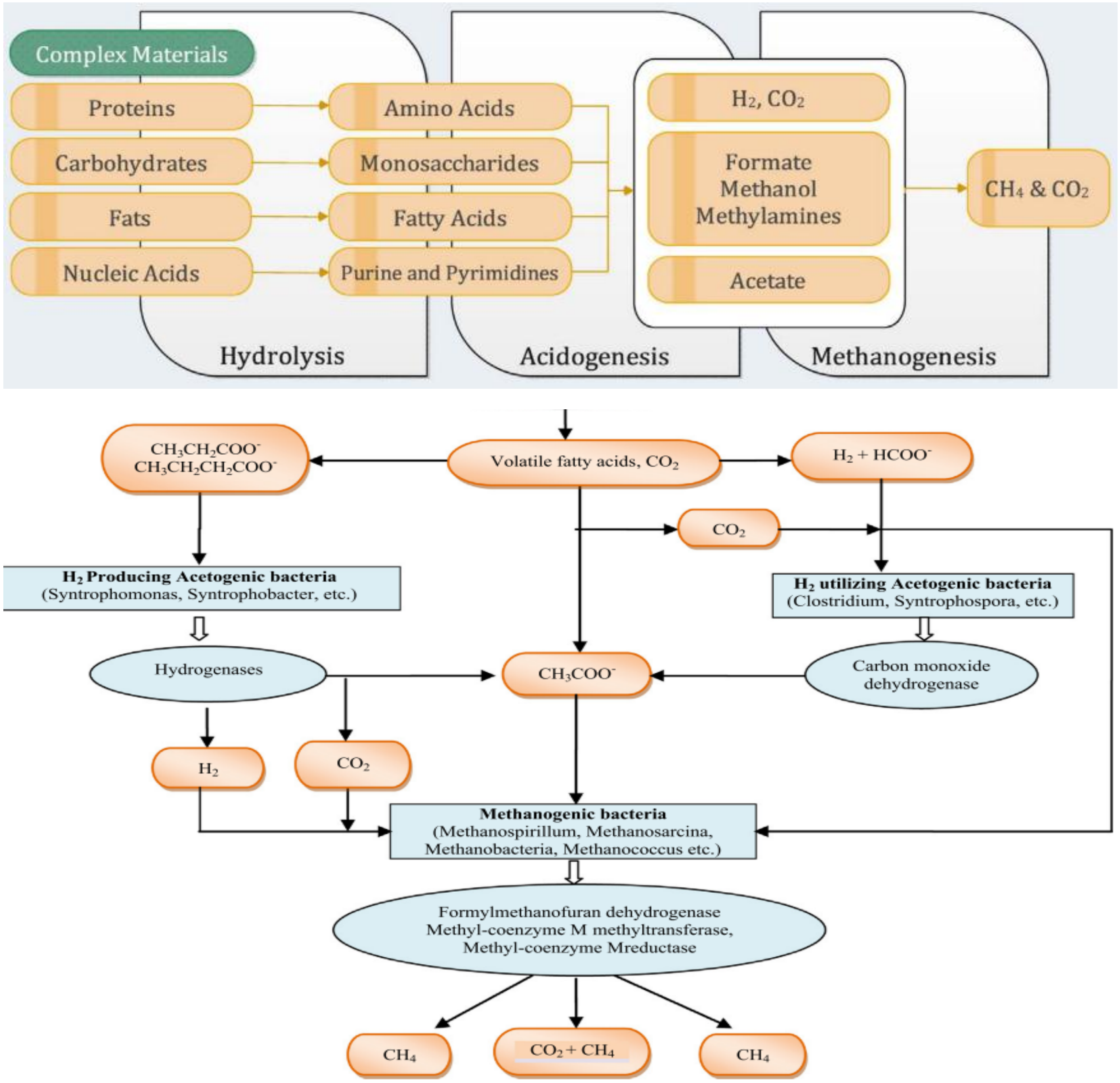


Figure 2-1 Systematic indication of the stages involved in anaerobic digestion (Divya, Gopinath, and Merlin Christy 2015; Neshat et al. 2017)

According to Alemu G. 2016, three biochemical pathways are used by methanogens to produce methane gas. These are: The first and second reaction involves acetoclastic methanogenesis and reductive methanogenesis, respectively. Acetoclastic methanogens split acetate into methane and carbon dioxide, while hydrogen-utilizing methanogens (the second reaction) are responsible for methane production using CO_2 and hydrogen as electron acceptor and donor, respectively (Neshat et al. 2017). Methanol is shown as the substrate for the methylotrophic pathway, although other methylated substrates can be converted. Sugars and sugar-containing polymers such as starch and cellulose yield one mole of acetate per mole of sugar degraded. Since acetotrophic methanogenesis is the primary pathway used, theoretical yield calculations are often made using this pathway alone (Alemu G. 2016).

Acetotrophic methanogenesis: $4CH_3COOH \rightarrow 4CO_2+4CH_4$ (1)

Hydrogenotrophic methanogenesis: $CO_2+4H_2 \rightarrow CH_4+2H_2O$ (2)

Methylotrophic methanogenesis: $4CH_3COOH+6H_2 \rightarrow 3CH_4+2H_2O$ (3)

Generally, the synthesis of methane from different precursors involves different chemical reactions responsible for the generation of biogas during anaerobic digestion can be summarized as below (Neshat et al. 2017):

$$4H_2+CO_2 \rightarrow CH_4+2H_2O \quad (4)$$

$$4HCOO^-+4H^+ \rightarrow CH_4+3CO_2+2H_2O \quad (5)$$

$$4CO+2H_2O \rightarrow CH_4+3CO_2 \quad (6)$$

$$4CH_3OH \rightarrow 3CH_4+CO_2+2H_2O \quad (7)$$

$$4(CH_3)_3N+6H_2O \rightarrow 9CH_4+3CO_2+4NH_3 \quad (8)$$

$$4CH_3COOH \rightarrow 4CO_2+4CH_4 \quad (9)$$

The microorganism responsible for hydrolysis and acidogenesis is facultative and obligate anaerobic bacteria. Moreover, all of the methanogens are also strict obligate anaerobes which require redox potentials below -300 mV for growth. They are very sensitive to oxygen and grow very well in the presence of H_2 and CO_2 (Neshat et al. 2017).

2.4. Anaerobic digester substrates

2.4.1. Fruit and Vegetable Wastes (FVW)

FVWs have been known to be a potential substrate for the production of biogas. The currently reported study indicated that pineapple waste exhibited the highest biogas production, that is, 965cm^3 followed by wastes from orange (612 cm^3), pumpkin (373 cm^3), and spinach (269 cm^3). Panda et al. 2018, demonstrated the enhancement of biogas production by the application of facultative anaerobic bacterial strains. It showed that the vegetable wastes when subjected to inoculation with Lactobacillus sp. along with methanogens showed higher production of biogas, which was much higher than the control sample. Further, it was recommended to add FVWs to the first stage of the anaerobic digester to enhance methane generation. Studies revealed that for vegetable waste, cow dung should be added in the same proportion (1:1), whereas in the case of fruit waste, the ratio should be 1:2 for optimum production (Panda et al. 2018).

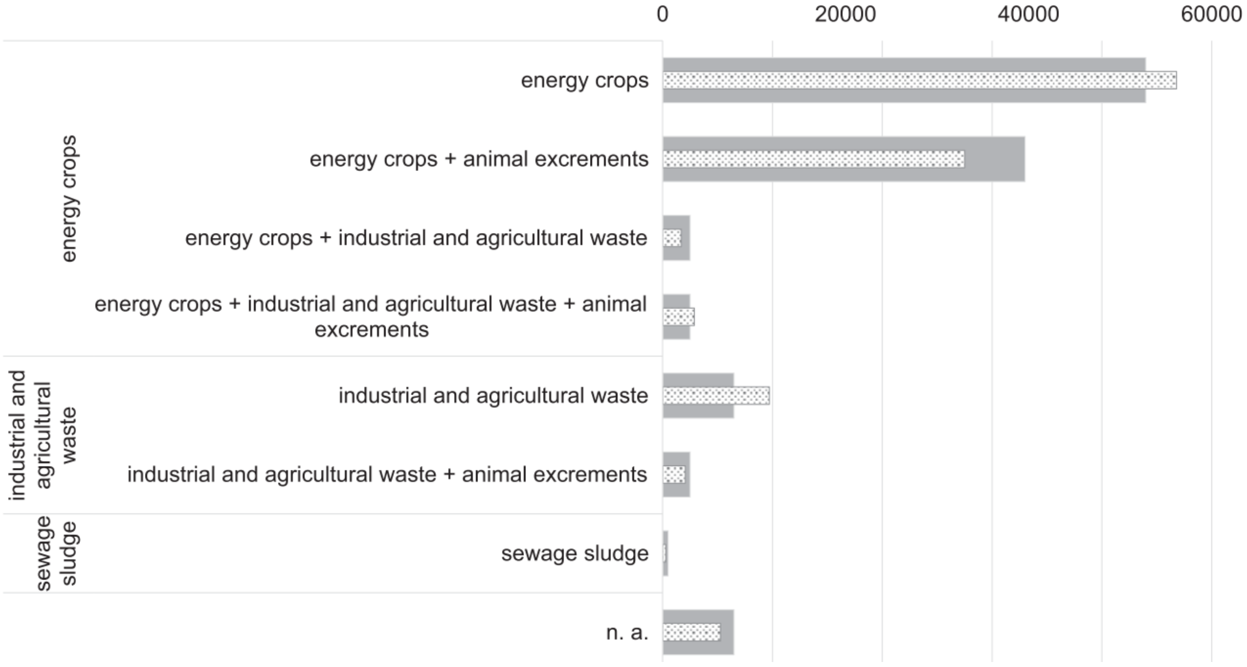


Figure 2-2: Amount of produced biogas dependent on substrate input in m^3/h. Adapted from Daniel-Gromke et al. (2018).

2.5. Co-digestion and its advantages

Anaerobic co-digestion can result in synergistic interactions via the balance of nutrients, supplementation of trace elements, dilution of toxic and inhibitory compounds, and promotion of microbial diversity (Karki et al. 2021). Previous studies have shown that a balanced C/N ratio achieved through co-digestion of different feedstocks prevents the accumulation of volatile fatty acids due to an improved buffering capacity despite a higher organic loading rate. For example, co-digestion of food waste with trace element-rich piggery wastewater can avoid volatile fatty acid accumulation, resulting in process stability and improved methane production rates (Elsayed, Diab, and Soliman 2021). Food waste is deficient in trace elements, which play an important role in activating enzymes needed for the growth of syntrophic bacterial communities and methanogens. The nutrient balance and trace element (e.g., Fe, Ni, Co) supplementation by piggery wastewater can enhance microbial diversity and enzyme activities, and support symbiotic and syntrophic associations. A reduction in inhibitory compounds, such as total ammonia nitrogen lignin derivatives was observed through the dilution effect of co-digestion in laboratory-scale experiments (Karki et al. 2021).

Most long-term studies of co-digestion of agricultural residues use animal manure as the primary feedstock because the availability of agricultural residues varies seasonally. The high nitrogen content of animal manures opposes an obstacle to providing the optimum C/N ratio required for anaerobic digestion. To address this issue, the carbon content of animal manure needs to be increased before proceeding to anaerobic digestion. Lignocellulosic materials including agricultural wastes are potential candidates to compensate for the carbon deficiency of animal manure, as they contain high carbon content but can hardly be used as the sole substrate for anaerobic digestion. The anaerobic digestion of lignocellulosic materials is restricted by their slow degradation and consequently low methane yield. The digestibility rate of lignocellulosic feedstock is governed by slow hydrolysis of cellulose which is suggested to be the rate-controlling step of the process (Nguyen et al. 2021). Although biogas production potential from lignocellulosic materials can be enhanced through the exploitation of pretreatments such as a steam explosion or enzymatic hydrolysis, however, the economic feasibility of the process might be disturbed. The co-digestion of lignocellulosic materials and animal manures are offers the best solution to balance the C/N ratio of feedstock for anaerobic digestion. The process allows the conversion of organic waste materials to bio-energy in the form of biogas, while leaving behind a nutrient-rich residue that can be used as fertilizer. Increasing the buffering capacity, dilution of potentially toxic compounds, utilizing the nutrients, bacterial diversity, and lowering the risk of ammonia inhibition are some benefits that come along co-digestion of lignocellulosic materials and animal manures (Fonoll et al. 2015). Moreover, the high water content of animal manures dilutes the concentrated organic compounds existing in lignocellulosic wastes which may oppose inhibitory effect on the process. Some anaerobic digestion processes wherein lignocellulosic residues or other carbon-rich streams were utilized as co-substrate with animal manures are discussed here (Neshat et al. 2017). Organic municipal wastes containing high content of carbon could be stabilized by nutrient supplementation from livestock manure, and food waste. Moreover, the high ammonia concentration of organic municipal wastes could be reduced by balancing the C: N ratio in the mixture through the combination with the co-substrates and also significantly improve the biogas yield and solid and liquid digestate condition (Karki et al. 2021).

Co-digestion of sewage sludge with rapidly biodegradable feedstocks with higher C/N ratio resulted in improved methane yield, provided supplemental alkalinity and trace elements, and diluted heavy metals and pathogens present in sewage sludge observed a two-fold increase in methane yield when sewage sludge was co-digested with the organic fraction of municipal solid wastes compared with mono-digestion of sewage sludge. Sewage sludge co-digestion with grease trap sludge at the ratio of 7:3 was reported to improve methane yield compared to mono-digestion. However, long-chain fatty acids accumulation and foaming are major concerns. Furthermore, co-digestion of sewage sludge with microalgae is beneficial for nutrient recovery due to the rapid growth, availability, and low lignin content of algal biomass. However, a low C/N ratio due to high protein and pH over 8.5 can inhibit methanogens due to ammonia accumulation. Hence, digester stability could be an issue when using microalgae as a co-feedstock (Karki et al. 2021). Generally, co-digestion could reduce both operating costs and chemical usage. The C/N ratio plays a pivotal role in selecting an optimal mixing ratio of feedstocks with other co-feedstocks (Karki et al. 2021).

2.6. Factors affecting anaerobic digestion

2.6.1. pH

The solution pH is one of the key parameters which should be kept in control as much as possible during anaerobic digestion. It is categories alkalinity or acidity of the digestion process. The volatile fatty acids (VFA) content in the anaerobic digester is directly linked to the magnitude of pH and indicates the development of acidogenesis. Reported works indicated that failure to control the acidogenesis stage results in poor digestion as the acidogenesis inhibited when the pH was less than 4.0 due to the suppressed activity of the microorganisms (Zamri et al. 2021). The carbon content, nitrogen, and the ratio between them (C/N ratio) can play a role in controlling the acidogenesis stage. Ammonia content and training can play acidogenesis stage pH controlling. ammonia accumulation below a 2 g/L limit has a positive role acting as a pH buffer whereas if it accumulates above the previous limit, it acts with a negative effect, causing a drastic increase in pH and process stop (Morales-Polo, Cledera-Castro, and Soria 2019). Thus the pH in the digester should be kept in a range of 6.5 to 7.5 at this stage of digestion. The methane formers are pH sensitive, and pH values outside of the range will affect their metabolic rates and slow or completely stop methane production, resulting in decreased biogas production or digester failure (Debruyn and Hilborn 2007). Moreover, a methanogenic bacterium is also directly affected by changes in pH. Ideally, the optimum pH for methanogenic stages ranges from pH 6.5 to 8.2. Like acidogens, methanogens are also susceptible to VFA formation. The accumulation of the VFA at high acidic pH inhibits the methanogenic bacteria through the dissociation of acids leading to a decoupling of the membranous proton motive force. Hence, a low pH in the digester inhibits the activity of both acidogens and methanogens (Zamri et al. 2021). Therefore, in addition to the controlling mechanism mentioned above, in cases of a very high or low pH of anaerobic digestion feedstock, neutralization is necessary before the plant is fed (Figure 2-3). The pH is chemically improved by adding the base, such as lime, to the reactor if negligible acidification happens during the anaerobic digestion process (Zamri et al. 2021).

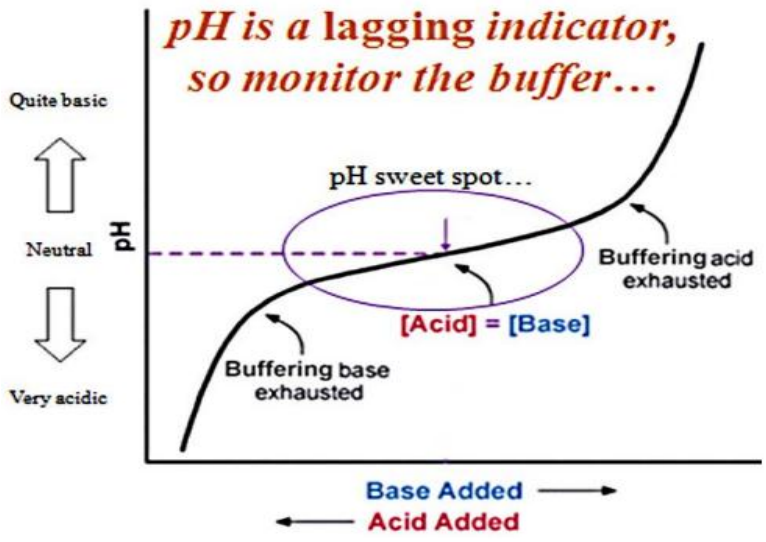
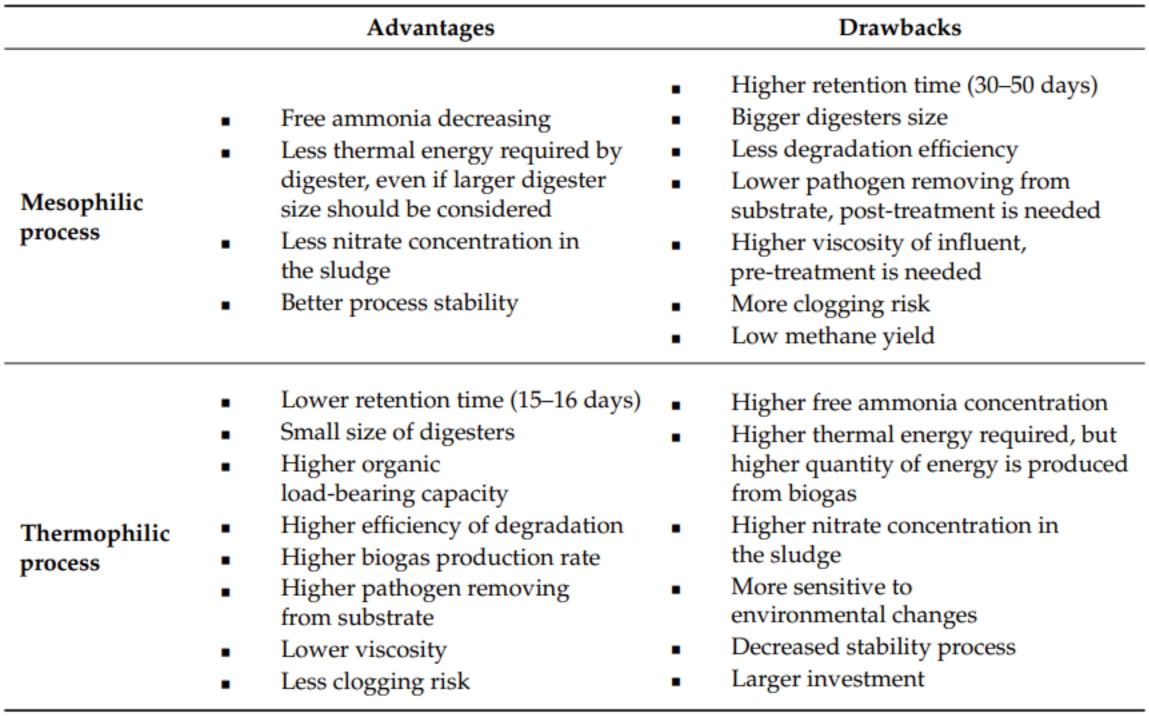


Figure 2-3 :Effect of pH adapted from Zamri et al. (2021)

2.6.2. Temperature

Anaerobic digestion can be carried out under mesophilic (about 35 ◦C), thermophilic (about 55 ◦C) or, more rarely, psychrophilic conditions (below 20 ◦C). The reaction temperature may affect the kinetics, the specific biogas production and the overall efficiency. The duration of the process, in terms of hydraulic retention time, is 15-50 days, if the process takes place in mesophilic conditions, 14-16 days, if it takes place in thermophilic conditions and 60-120 days in psychrophilic conditions. According to several experiences at the full-scale level, the mesophilic process is easier to control, for that reason it is still the most common and detail given in Table 1.

Table 2-1 :comparison of thermophilic and mesophilic processes operations



	Advantages	Drawbacks
Mesophilic process	▪ Free ammonia decreasing ▪ Less thermal energy required by digester, even if larger digester size should be considered ▪ Less nitrate concentration in the sludge ▪ Better process stability	▪ Higher retention time (30–50 days) ▪ Bigger digesters size ▪ Less degradation efficiency ▪ Lower pathogen removing from substrate, post-treatment is needed ▪ Higher viscosity of influent, pre-treatment is needed ▪ More clogging risk ▪ Low methane yield
Thermophilic process	▪ Lower retention time (15–16 days) ▪ Small size of digesters ▪ Higher organic load-bearing capacity ▪ Higher efficiency of degradation ▪ Higher biogas production rate ▪ Higher pathogen removing from substrate ▪ Lower viscosity ▪ Less clogging risk	▪ Higher free ammonia concentration ▪ Higher thermal energy required, but higher quantity of energy is produced from biogas ▪ Higher nitrate concentration in the sludge ▪ More sensitive to environmental changes ▪ Decreased stability process ▪ Larger investment

Experiences on anaerobic digestion indicated that there are two temperature ranges most suitable for optimum biogas production. The first one is mesophilic bacteria optimally function in the 32 ^{o}C to 43 ^{o}C range. The second is thermophilic bacteria are most productive in the 49 ^{o}C to 60 ^{o}C range. Thermophilic digestion kills more pathogenic bacteria, but the cost to maintain a higher operating temperature is greater. Thermophilic digesters may also be less stable. It is reported that psychrophilic which is bacterial digestion below 32 ^{o}C was not preferred for biogas generation due to the sluggishness of the digestion process. The temperature within the digester is critical, with maximum conversion occurring at approximately 35 ^{o}C in conventional mesophilic digesters (Debruyn and Hilborn 2007). Moreover, the solubility of different materials such as NH_3, CH_4, and H_2S change with temperature. High-temperature water has less solubility than low-temperature water. Therefore, it can affect the inhibitory material in the reactor (Atelge et al. 2020).

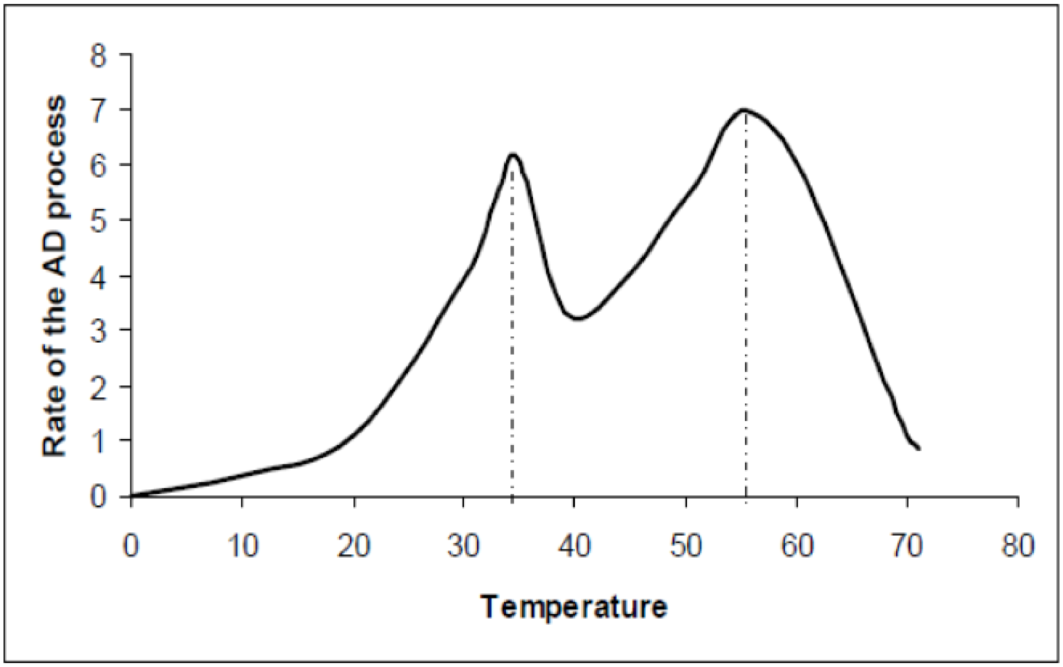


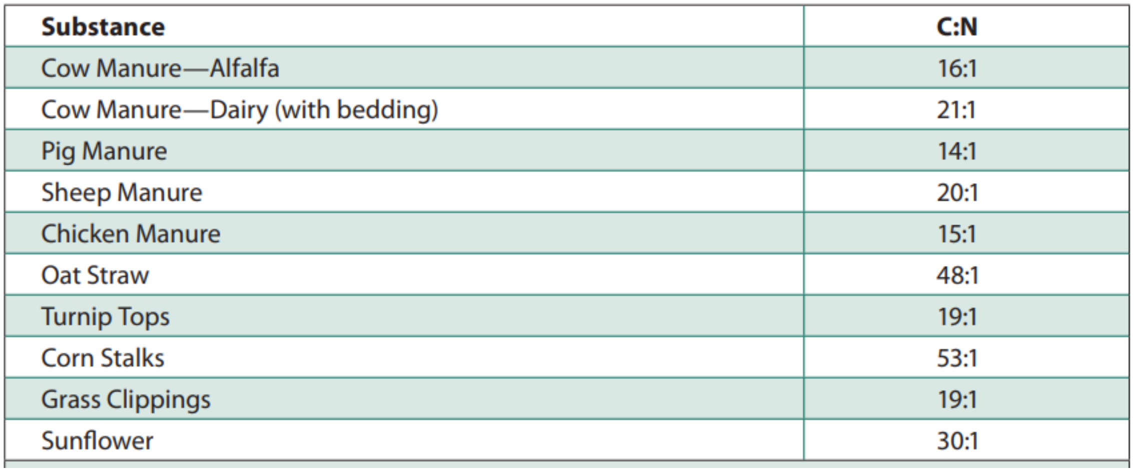
Figure 2-4 Temperature range for anaerobic digestion

2.6.3. Carbon to nitrogen ratio (C: N ratio)

This ratio indicates the amount of carbon and nitrogen available for the microorganism as the substrate which is the essential source for energy and development of new cell structure. An optimum C: N ratio which is between 20-30 is generally required for an effective anaerobic digestion process (Alemu G. 2016). Besides, both elements are used to indicate the substrate nutrient level in the anaerobic digestion process. A high C: N ratio indicated the low nitrogen sources that are needed to sustain the material supply for the digestion whereas the low C: N ratio signified the potential of NH_4 ratio could be developed through the different ratio fractions configuration. Different substrates have different C/N ratios and that is why the co-digestion recommended compensating the deficiencies (Zamri et al. 2021).

Municipal and institutional wastewater has a low C/N ratio (C/N < 8.0) which is an important indicator that it can directly affect the anaerobic treatment. The optimal C/N ratio for anaerobic degradation depends on the substrate used, but a value between 20-30 is recommended. When a substrate has low C/N ratios, it is considered to contain relatively high ammonium concentrations, inhibiting microbial growth and anaerobic digestion. Furthermore, anaerobic reactors treating wastewater rich in nitrogen tend to have high pH values. At high pH values, free ammonia dominates and this form is more inhibitory than the ammonium ion (NH_4). The C/N ratio and the pH play an important role in the anaerobic digestion process. The pH influences the chemical equilibria of NH_3, H_2S, and Volatile Fatty Acids (VFA's), which could inhibit the activity of the microorganisms. The ideal pH range for anaerobic digestion has been reported to be 6.8-7.4. Wastewater with a low C/N ratio and high pH need to be balanced to treat in anaerobic reactors. Combined treatment (anaerobic-aerobic) offers many advantages as the effluent polishing and a sludge treatment simplified because only the dewatering stage is necessary. Furthermore, the excess aerobic sludge can be used as a co-substrate to balance the C/N ratio and the pH. To define the optimal sludge recirculation to balance the pH and the C/N ratio and obtain the maximum methane production is necessary to carry out tests with different mixtures of sludge and wastewater (Zamri et al. 2021). Different feedstocks C/N ratio was indicated in Table 2.

Table 2-2**:** C/N ratio of different feedstocks



Substance	C:N
Cow Manure—Alfalfa	16:1
Cow Manure—Dairy (with bedding)	21:1
Pig Manure	14:1
Sheep Manure	20:1
Chicken Manure	15:1
Oat Straw	48:1
Turnip Tops	19:1
Corn Stalks	53:1
Grass Clippings	19:1
Sunflower	30:1

2.6.4. Organic loading rate (OLR)

The loading rate is the number of volatile solids fed daily to the digester. Experience indicates that uniform loading, daily, of feedstocks, generally works better (Debruyn and Hilborn 2007). Typically, a decrease in biogas yield indicates an excessive degradation capacity of the reactor due to high OLR. The increment of OLR will increase the inhabitant concentration (VFA concentration and soluble COD) that contributed to excessive degradation. Nevertheless, the OLR behavior relies on the characteristics of the substrates, temperature conditions, and hydraulic retention time of the anaerobic digester operation. A high organic loading rate can extend the dormancy time of the microorganism in the anaerobic digestion process (Zamri et al. 2021).

2.6.5. Hydraulic retention time (HRT)

The average time that a given volume of sludge stays in the digester, is one of the most important design parameters affecting the economics of a digester. For a given volume of sludge, a smaller digester (lower capital cost) results in a shorter HRT. This may not be long enough to reach the optimum result such as higher biogas production, lower emissions of odor and greenhouse gases, and higher destruction of chemical oxygen demand, total solids, volatile solids, pathogens, and weed seeds (Debruyn and Hilborn 2007). The period depends on the types of feedstock and digester temperature. Higher OLR in an anaerobic digester indicates lower HRT, which possibly increases the accumulation. High HRT will contribute to a high reduction of total VS mass that results in high biogas yields. In addition, the buffering capacity at high HRT provides the process protection against the shock loadings effects, toxic compounds, and biological acclimation to toxic compounds, respectively (Zamri et al. 2021).

2.6.6. Sonication

The ultrasonic technique has been well confirmed as the most powerful method when compared with bacterial, thermal, and chemical pre-treatment in the digestion of organic wastes. However, it is worth mentioning that studies have indicated that the noise from ultrasonic devices may cause negative symptoms in exposed operators (e.g., dizziness, tinnitus, excessive fatigue, nausea, ear fullness, and headache). Therefore, it has been suggested to control the ultrasonic pollution using steel or even glass casings, coupled with acoustic absorbing blankets to line the machine enclosure to reduce the noise. The effect of ultrasonic is based upon monolithic cavitation, with physical and chemical impacts in the slurry. The collapse of cavitation bubbles during the sonication modifies the chemical structure by the creation of free radicals. This physical disintegration leads to the enhancement of microbial activity, which in turn improves biogas yield. The impact of ultrasonic has widely been investigated in the anaerobic digestion of sludge and municipal wastewater; however, there are limited reports on solid wastes (Zeynali, Khojastehpour, and Ebrahimi-Nik 2017).

2.7. Methane upgrading of biogas

The estimated heating value of biogas is estimated around 5300 kcal/m^3 and this heating value is associated with the concentration of methane. The presence of CO_2 in the biogas lowers its heating value. The reported works indicated that the heating value of biogas can be improved by about 30% by reducing its CO_2 content. In addition to reducing the heating value, the presence of CO_2 in biogas increases the costs for compression and transportation and limits the economic feasibility of utilizing the biogas at the point of production. H_2S and NH_3 are toxic and extremely corrosive, damaging the combined heat and power (CHP) unit and metal parts via the emission of SO_2 from combustion. Moreover, the presence of siloxanes in biogas, even in minor concentrations, is associated with problems. It is well known that during combustion silicone oxides generate sticky residue, which is a deposit in biogas combustion engines and valves causing malfunction (Angelidaki et al. 2018). Nowadays, there are different treatments targeting removing the undesired compounds from the biogas expanding its range of applications. The first treatment is related to “biogas cleaning” and includes the removal of harmful and/or toxic compounds from the aforementioned biogas bi-products (Angelidaki et al. 2018). The second treatment is called “biogas upgrading” and aims to increase the low calorific value of the biogas, and thus, to convert it to a higher fuel standard. In case the upgraded biogas is purified to specifications similar to natural gas, the final gas product is called bio-methane (Angelidaki et al. 2018). Among the existing biogas upgrading methods scrubbing CO_2 and/or H_2S from biogas include chemical absorption using alkaline and amine solutions, water and polyethylene glycol scrubbing, pressure swing adsorption (PSA), membrane separation, cryogenic separation, use of bio-filter, etc. Cost comparison of summary of these technologies detail was given in Table 3 and their distribution was indicated in Fig. 2.5. Water scrubbing was tried to compare with the activated carbon adsorption to treat biogas and this report indicated that using activated carbon is economically preferred (Muhammad Farooq et al. 2017). H_2S can be removed by passing the biogas through beds of ferric oxide and iron. Granular activated carbon fixed bed reactor with a bed of 10 g of activated carbon was used to treat a gas mixture with 10,000 ppm H_2S (M. Farooq et al. 2018). Each of these biogas purification techniques has its strengths and weaknesses which include cost considerations, robustness, and the possibility of in-site biogas upgrading and environmental impacts (Neshat et al. 2017). Microporous activated carbon pellets prepared from pine sawdust were reported to remove CO_2 and resulted in high purity of methane above 95% (Durán, Rubiera, and Pevida 2022). Mamun et al. 2016 also used solid CaO, CaO solution, and activated carbon to CO_2 from the biogas generated from vegetable, fruit, and cafeteria wastes for 30 days and observed an increase in the concentration of methane in the biogas (Mamun et al. 2016). Similarly, activated carbon from commercial pine wood pellets showed excellent behavior as a CO_2 selective adsorbent for biogas upgrading (Vivo-Vilches et al. 2017).

The direct usage of biogas as cooking fuel is a common practice in Asian countries, such as China, India, Malaysia, etc., particularly for the small-scale decentralized AD reactor. However, the thermal efficiency of the biogas stove is slightly lower compared to the stove using natural gas or liquid petroleum gas (LPG), for which the former is normally between 55 and 57.4% while the latter can achieve 60–69%. The biogas was considered to substitute natural gas as cooking fuel in this study. As for the substitution, the gross calorific value of biogas (65%

methane) and natural gas (default in Ecoinvent database) was adopted as 26 and 39 MJ/m^3, respectively, while an average thermal efficiency of 56% and 65% was applied for biogas and natural gas, respectively (Tian et al. 2021).

Table 2-3: Cost comparison of summary of technologies for cleaning and upgrading biogas adopted from Angelidaki et al. (2018).

Parameters	Technologies				
	PSA	Water scrubbing	Physical scrubbing	Chemical absorption	Membrane separation
Consumption for raw biogas (kWh/Nm^3)	0.23-0.3	0.25-0.3	0.2-0.3	0.05-0.15	0.18-0.2
Consumption for clean biogas (kWh/Nm^3)	0.29-1.0	0.3-0.9	0.4	0.05-0.25	0.14-0.25
CH_4 losses (%)	<4	<2	2-4	<0.1	<0.6
CH_4 recovery (%)	96-98	96-98	96-98	96-99	96-98
H_2S co-removal	Possible	yes	Possible	Contaminant	Possible
N_2 and O_2 co-removal	Possible	No	No	No	Partial
Operation pressure (bar)	4-5	7-10	1.3-7.5	4-5	4-6

Iron oxide (Fe_2O_3), zero-valent iron (Feo), and iron chloride ($FeCl_2$) react with hydrogen sulfide (H_2S) to deposit colloidal sulfur. Silica gel, sodium sulfate (Na_2SO_4), and calcium oxide (CaO) reduce the water vapor (H_2O) and carbon dioxide (CO_2) from produced biogas using the cafeteria. It is possible to upgrade methane (CH_4) above 95% in biogas using chemical or physical absorption or adsorption process (Al Mamun and Torii 2017). Moreover, Mezmur and Bogale 2019 reported that activated carbon to remove H_2S, NaOH, and KOH to remove CO_2, silica gel, and charcoal to remove the moisture. The experimental result shows that these innovative technologies reduce the acidic content (H_2S) by 99% and remove the CO_2 content by 82%. As a result, the methane content increased from 56.7% to 85%. The CO_2 content decreased from 36% to 7% (Mezmur and Bogale 2019).

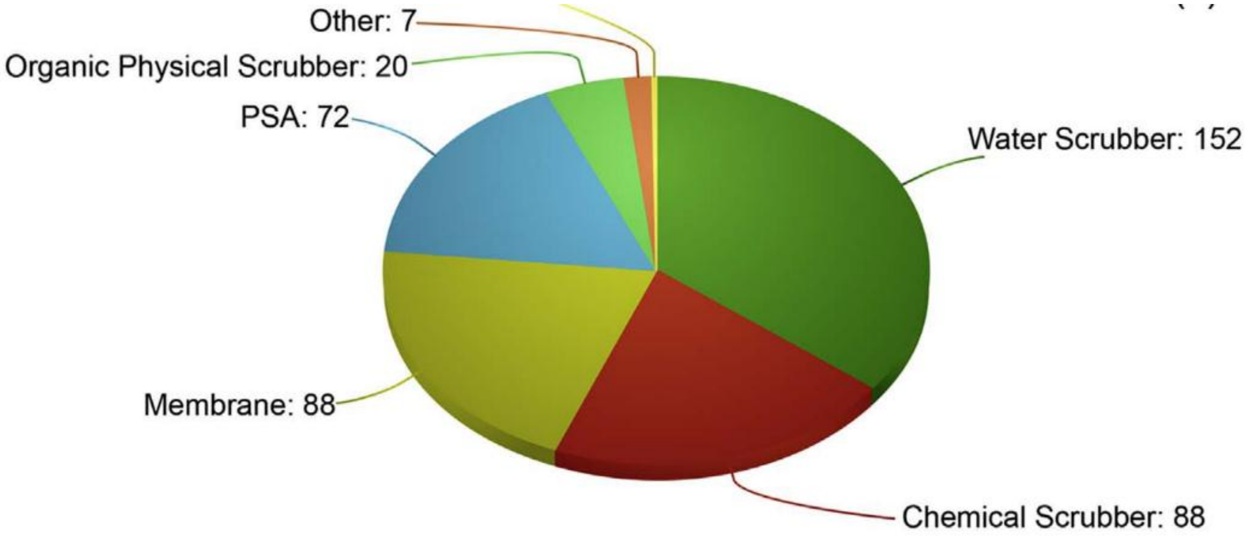


Figure 2-5: Distribution of applied commercial technologies used for the biogas upgrading adopted from Angelidaki et al. (2018).

2.8. Digestate as bio-fertilizer

To secure food supply using the digestate as a fertilizer plays a great role. Thus, food production is an urgent task faced by the different countries' governments in developing nations. The digestate after AD contains abundant nutrients, such as N, P, K, which can be used in place of inorganic fertilizer. Diluting the digestate to 40 % without heat pretreatment achieved the highest fresh and dry weight of the vegetable. Before spreading the digestate into the soil, onsite dilution with tap water needs to be done, while the spreading consumes about 22.7 MJ diesel/ton digestate (Tian et al. 2021).

2.9. Utilization of biogas

Biogas is a multifaceted fuel with a multitude of utilization options. Biogas can be utilized in without cleaning or after applying the upgrading process. Commonly, unprocessed biogas can be used directly from the digester for cooking, heating, and lighting on the site of production itself. The second means of utilization is after applying different cleaning and upgrading technologies. Therefore, being a mixture of gases, innovative and efficient approaches for the valorization of biogas for applications like power production, as a replacement of natural gas or high value-added chemicals are highly desirable. Biogas can be exploited through various pathways indicated in Fig 2.6. Raw biogas can be utilized either directly for cooking or lighting purpose. Indirect utilization of biogas includes the physical, chemical, and biological approaches in which biogas is treated to improve its quality or transformed to other utilizable forms (Kapoor et al. 2020).

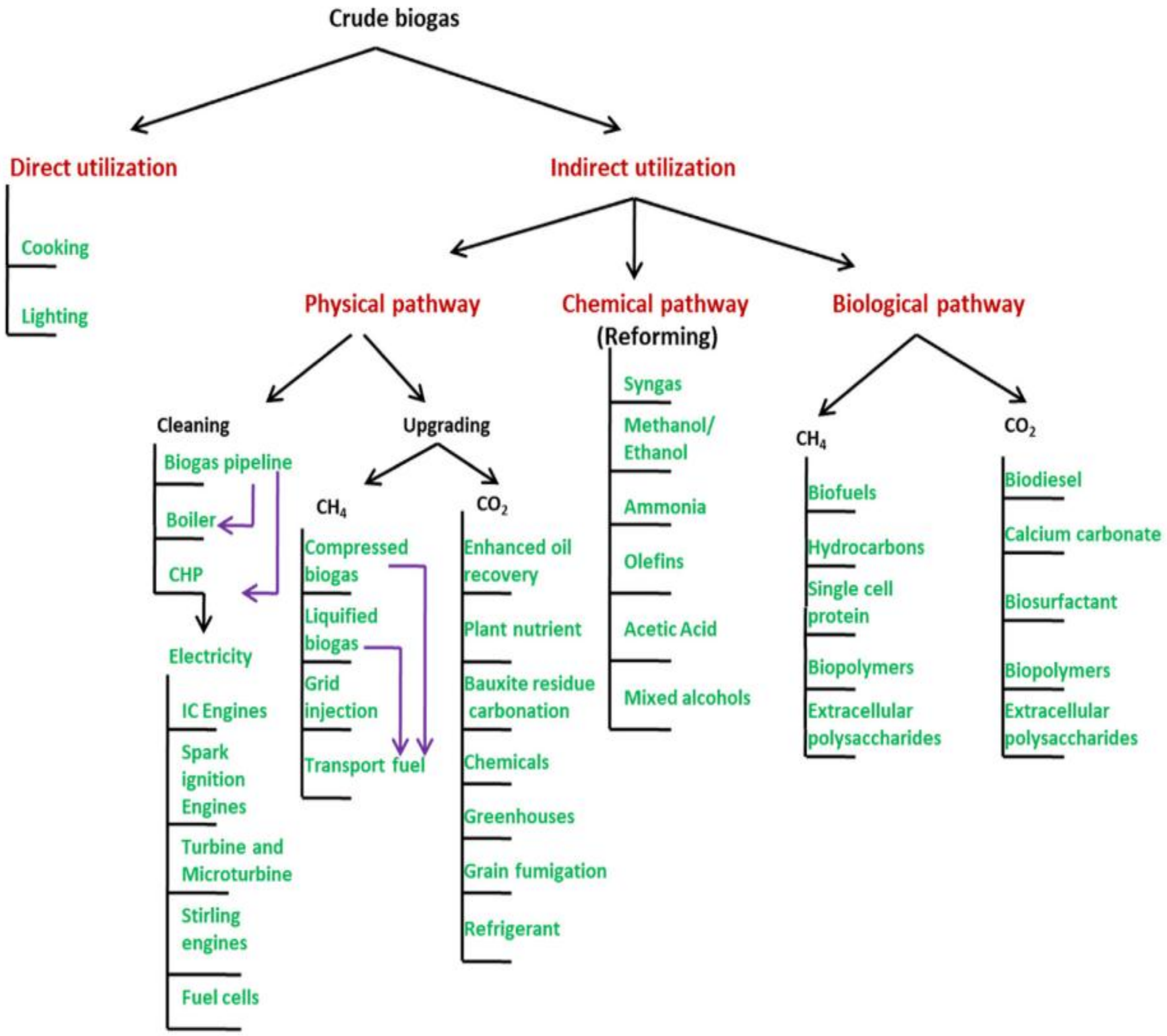


Figure 2-6 : utilization of biogas adopted from Kapoor et al. (2020)

2.10. The feasibility of biogas projects

According to the report by Tian et al. (2021), sustainable feedstock supply is an important factor for biogas projects. It is rational to determine biomass available, its energy, and economic traits. The energy efficiency ratio for biogas (bio methane) production and biomass energy cost can be used for the feasibility study of biogas units. The feasibility of biogas projects depends on a biogas (bio methane) utilization pathway. The best economic results can be obtained in the following cases:

- The substitution of petroleum vehicle fuels
- The direct selling of bio methane by a producer to the end consumer
- The selling of all by-products of both biogas and bio methane producing

Some agricultural practices or renewable energy resource utilization may be subsidized. Their economic profitability depends on existing market conditions and governmental regulations. Suitable policies, management schemes, taxation, and legislation will be a substantial push towards biogas development; which are currently subject to further study (Tian et al. 2021).

2.11. Advantages of bio gasification technology

2.11.1. Biogas is Eco-Friendly

Biogas is a renewable, as well as a clean, source of energy. Gas generated through bio digestion is Biogas is a renewable, as well as a clean, source of energy. Gas generated through bio digestion is non-polluting; it reduces greenhouse emissions (i.e. reduces the greenhouse effect). No combustion takes place in the process, meaning there is zero emission of greenhouse gasses into the atmosphere; therefore, using gas from waste as a form of energy is a great way to combat global warming. Unsurprisingly, concern for the environment is a major reason why the use of biogas has become more widespread. Biogas plants significantly curb the greenhouse effect: the plants lower methane emissions by capturing this harmful gas and using it as fuel. Biogas generation helps cut reliance on the use of fossil fuels, such as oil and coal. Another biogas advantage is that unlike other types of renewable energies, the process to create the gas is natural, not requiring energy for the generation process. In addition, the raw materials used in the production of biogas are renewable, as trees and crops will continue to grow. Manure, food scraps, and crop residue are raw materials that will always be available, which makes it a highly sustainable option.

2.11.2. Biogas Generation Reduces Soil and Water Pollution

Overflowing landfills do not only spread foul smells- but they also allow toxic liquids to drain into underground water sources. Subsequently, another advantage of biogas is that biogas generation may improve water quality. Moreover, anaerobic digestion deactivates pathogens and parasites; thus, it is also quite effective in reducing the incidence of waterborne diseases. Similarly, waste collection and management significantly improve in areas with biogas plants. This, in turn, leads to improvements in the environment, sanitation, and hygiene.

2.11.3. Biogas Generation Produces Organic Fertilizer

The by-product of the biogas generation process is enriched organic digestate, which is a perfect supplement to, or substitute for, chemical fertilizers. The fertilizer discharge from the digester can accelerate plant growth and resilience to diseases, whereas commercial fertilizers contain chemicals that have toxic effects and can cause food poisoning, among other things.

2.11.4. A Simple and Low-Cost Technology That Encourages A Circular Economy

The technology used to produce biogas is quite cheap. It is easy to set up and needs little investment when used on a small scale. Small bio digesters can be used right at home, utilizing kitchen waste and animal manure. A household system pays for itself after a while and the materials used for generation are free. The gas produced can be used directly for cooking and the generation of electricity. This is what allows the cost of biogas production to be relatively low. Farms can make use of biogas plants and waste products produced by their livestock every day. The waste products of one cow can provide enough energy to power a lightbulb for an entire day. In large plants, biogas can also be compressed to achieve the quality of natural gas and utilized to power automobiles. Building such plants requires relatively low capital investment and creates green jobs. For instance, in India, 10 million jobs were created, mostly in rural areas, in plants, and inorganic waste collection.

2.11.5. Healthy Cooking Alternative for Developing Areas

Biogas generators save women and children from the daunting task of firewood collection. As a result, more time is left for cooking and cleaning. More importantly, cooking on a gas stove, instead of over an open fire, prevents the family from being exposed to smoke in the kitchen.

This helps prevent deadly respiratory diseases. Sadly, 4.3 million people a year die prematurely from illnesses attributed to household air pollution caused by the inefficient use of solid fuels for cooking.

Home Biogas systems allow you to enjoy all the advantages of biogas production and use from home. They are easy to install, require minimal effort to use, and produce clean, renewable energy and fertilizer.

2.11.6. Environmental benefits of using biogas

When biogas is burned, it does produce CO_2, which is a greenhouse gas. However, using biogas is still environmentally beneficial. Along with CO_2, methane is one of the greenhouse gases that concern scientists most in their study of global climate change. According to the U.S. Environmental Protection Agency (EPA), although there is less methane in the environment than CO_2, methane is about 21 times more powerful at warming the atmosphere than CO_2 (by weight). Methane's chemical lifetime in the atmosphere is approximately 12 years. Burning the methane (rather than allowing it to escape into the atmosphere), using the energy and turning the emissions into CO_2 reduces the potency of the greenhouse gases being released, but more importantly, displaces fossil fuel use and prevents the release of additional CO_2. The EPA estimates that in large-scale dairy digesters, for every 10 cows from which the manure is anaerobically digested and the biogas captured and used, greenhouse gas emissions are reduced. Of course, this statistic does not address the overall lack of sustainability of large-scale confined animal feeding operations. Other sources estimate that small digesters can reduce greenhouse gas emissions by the equivalent of 5-7 metric tons of CO_2 in households that currently burn wood.

3. MATERIALS AND METHODS

3.1.Description of Study Area

This research was conducted in Addis Ababa city, Lafto Sub city (around Haile Garment) a wholesale market of fruit and vegetable as a study area, in a coordinate of 81 53' 38"N and 398 48' 6" E. (Google map, 2022).

3.2.Materials

3.2.1. Chemicals Used

The initial pH of the solution was adjusted using 0.1 M NaOH and HCl. The COD reagent, distilled water, nitrification inhibitor B (Allyl Thiourea or ATH), and 45 % KOH were used to analyze the COD, as solution medium and nitrification inhibitor during BOD_5 determination, respectively. Commercial activated carbon, a solution of NaOH and KOH, and silica gel were used to remove H_2S, CO_2, and moisture, respectively.

3.2.2. Fruit and vegetable waste and sampling

The fruit and vegetable waste used in this work was collected from the fruit and vegetable market located around Haile Garment in Addis Ababa. The sample was taken from four different piles. To collect the representative and homogeneous sample, the piles were partitioned into different parts from which samples were taken and mixed to form smaller piles from which the final representative sample was collected.

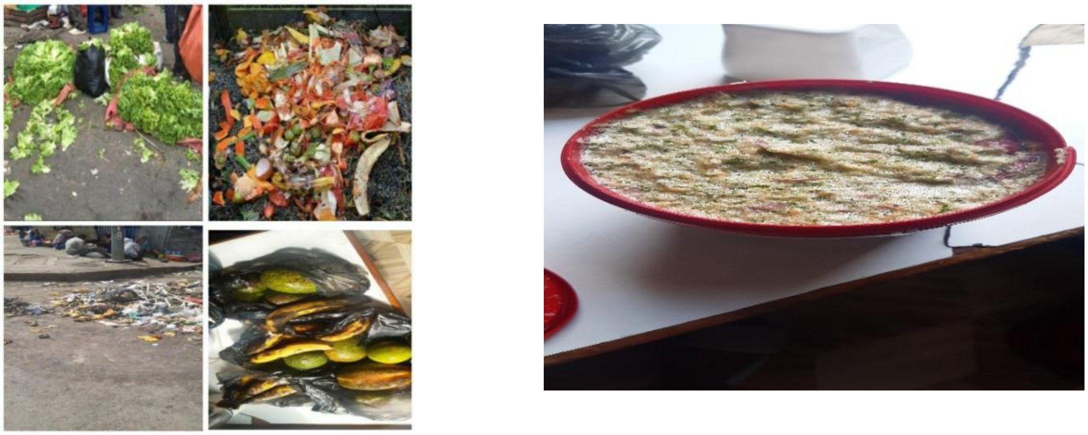


Figure 3-1 Sample collection and preparation

3.2.3. Equipment Used

Digital balance (ACZET CY224) was used to measure the masses during the experimental work. Digital oven (GP-150-CLAD-250-HYD) and furnace (Carbolite S33 6RB) were used to determine the total solids (TS) and moisture content, and ash and volatile solids (VS) content of the fruit and vegetable wastes, respectively. The Kjeldha unit (KjelFlex K-360) was also applied to determine the total nitrogen content of the fruit and vegetable wastes. The sample BOD5 and COD were determined using a digital BOD incubator (TS 606/4-i) and COD digester (HANA), respectively. The %CH_4, %CO_2, %H_2S and %O_2 content of the biogas generated from the plastic bottles which were used as anaerobic digester, was measured using a biogas analyzer (Geotech GA5000). The fruit and vegetable wastes samples were size reduced using the juicer. The initial pH of the solution was measured using a pH meter (JENWAY3505). A water bath was used to set constant temperature.

Figure3-2. Equipment used for the experiment

3.3.Method

3.3.1. Fruit and vegetable waste analysis

3.3.1.1.pH

The fruit and vegetable wastes solution was formed using deionized water for the pH measurement. The initial pH of the solution was adjusted to the required pH using 0.1M sodium chloride and hydrochloric acid. The pH electrode used in the pH measurement is a combined glass electrode. It consists of sensing half-cell and reference half-cell, together forming an electrode system. The sensing half-cell is a thin pH-sensitive semi-permeable membrane, separating two solutions, viz., the outer solution, the sample to be analyzed, and the internal solution enclosed inside the glass membrane and has a known pH value. An electrical potential is developed inside and another electrical potential is developed outside, the difference in the potential is measured and is given as the pH of the sample.

3.3.1.2.Proximate Analysis

Proximate analysis of provides the percentage of the material that burns in a gaseous state/volatile matter, solid state/fixed carbon and the percentage of inorganic material waste/ash, which is fundamental importance for biomass energy. Proximate analysis methods were used to determine the moisture content (%), ash content (%) and volatile content (%) of biomass of the mixed fruit and Vegetable wastes.

Moisture Content Determination

The moisture content of composite fruit and vegetable wastes were calculated using Equation (1);

$$MoistureContent(\%) = \frac{W0 - W}{Ws0} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where; W_0 represents the initial weight of sample and crucible together, W is the resulting dry weight of the crucible plus dry sample and W_{S0} the initial sample weight.

Ash Content Determination of Fruit Waste

The resulting sample of FVWs wastes were combusted at 550˚C for 12 hours using a chamber furnace then final dried sample were weighted, the ash content was calculated using Equation (2);

$$AshContent(\%) = \frac{Wa - Wc}{Wds0} * 100 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where; *Wa* is the resulting weight wastes plus crucible, *Wc* is the weight of composite fruit waste after combusted at 550˚C plus crucible and W_{dS0} is the initial weight of the dried sample after moisture content.

Volatile Matter Determination of Fruit Waste

The initial weight of wastes or samples were measured and placed on the crucible, then the waste were combusted at 950˚C for 7min using Furnace, and then the final weight were recorded again. The percentages of volatile matter were calculated using Equation (3);

$$\mathrm{VolatileMatter}(\%) = \frac{\mathrm{Wvo - Wv}}{\mathrm{Ws0}} * 100 - \mathrm{MostureContent}(\%) \dots\dots\dots\dots\dots\dots. (3)$$

Where; *Wv*o represents the initial weight of sample plus crucible, W_{S0} the initial sample weight and *Wv* is the resulting weight of the crucible plus and sample waste.

3.3.1.3. Total solids (TS)

Total solids are nothing but the summation of total dissolved solids and total suspended solids. Total solids of fruit and vegetable wastes were determined according to the standard methods for the examination of water and wastewater APHA 2540 B (Greenberg 1984). A clean, dry, and weighted crucible was used to place the sample in the oven preheated to 103 °C. The sample allowed drying at this temperature overnight to achieve constant mass over-drying. The dried sample was cooled in the desiccator to avoid moisture absorbance and then measured. The following equation was used to determine the sample total solids and moisture content.

$$TS(\%) = \frac{W_{DS} * 100}{W_{WS}} \qquad (10)$$

Where WDS-weight of the dried sample (mg), W_{WS}-weight of a wet sample (mg).

3.3.1.4. Volatile solids (VS)

The term total volatile solids refer to materials that are completely volatilized from water at higher temperature (550 ºC). These solids are often referred to as the organic content of the water. The term total fixed solids can be referred to materials that are not volatilized from water at higher temperatures (550 ºC). These solids are often referred to as the inorganic content of the water. The sample is evaporated in a weighed dish on a steam bath and is dried to a constant mass in an oven at 103-105 °C. The residue obtained is ignited to constant weight at 550 ^{o}C. The remaining solids represent the total fixed solids and the weight lost during the ignition represents the total volatile solids. To determine the volatile solids, the sample dried according to method APHA 2540 B (Greenberg 1984) to constant weight was ignited in a muffle furnace at a temperature of 550 ^{o}C. The muffle furnace was first heated to this temperature before inserting the sample. The sample was allowed to ignite for about 15 minutes and cooled in the desiccator for measurement. Equation 11 was used to determine the volatile solids of the sample.

$$VS(\%) = \frac{W_{VS} * 100}{W_{DS}} \qquad (11)$$

Where W_{VS}-weight of volatile solids (W_{DS}-ash) (mg) and W_{DS}-weight of dried sample.

3.3.1.5. Biological oxygen demand (BOD_5)

To determine the biological oxygen demand (BOD_5) of the fruit and vegetable waste the digital BOD incubator (TS 606/4-i) which operates at 20 ^{o}C was used. The sample pH was adjusted to the neutral, poured into the BOD bottle, five drops of Nitrification inhibitor B (Allyl Thiourea or ATH) and four drops of 45% KOH solution were added, tightly closed and finally placed into BOD incubator for five days of digestion. This BOD incubator gives a reading in mg O_2/L (Alemu G. 2016).

3.3.1.6. Chemical oxygen demand (COD)

The chemical oxygen demand (COD) test is commonly used to indirectly measure the number of organic compounds in water. Most applications of COD determine the number of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution. COD is the measurement of the amount of oxygen in water consumed for the chemical oxidation of pollutants. COD determines the quantity of oxygen required to oxidize the organic matter in a water or wastewater sample, under specific conditions of the oxidizing agent, temperature, and time. The standard reagent was used to determine COD. About 2 mL fruit and the vegetable waste sample were added to the standard reagent, shaken, tightly closed, and placed in the COD digester for about 2 hr at 148 ^{o}C, cooled, well shaken, cleaned, and measured using spectrophotometry.

3.3.1.7. Total nitrogen (N)

The total nitrogen of the sample was determined according to the Kjeldahl method. First, the sample is digested, then distilled, and finally titrated. Sampled weighted in the tecator tube, 6 mL of concentrated H_2SO_4 was added and mixed carefully, and then 3.5 mL of H_2O_2 was added systematically until violent color due to the reaction was observed. After adding 3g catalyst mixture the sample was stand for 10 minutes in the tecator rack before digestion at 370 ^{o}C for about 4 hr. The tube cooled and about 50 mL distilled water was added and shaken to avoid sulfate precipitation in the solution, then 25 mL 40% NaOH solution was added into the digested and diluted solution. Finally, the solution was titrated using 0.1 N HCl to a reddish color. To determine the total nitrogen in the solution the following equation was used (Alemu G. 2016).

$$N_2(\%) = \frac{(V*0.1*14)*100}{W} \tag{12}$$

where, V-volume of consumed HCl to end of titration (L), W-dry base weighted sample (g), the 14-molecular weight of nitrogen, and 0.1- normality of HCl solution.

3.3.1.8. C/N ratio

Assuming the total organic carbon in the sample as the COD, the C/N ratio is calculated by applying the following equation.

$$C/N = \frac{COD}{N} \tag{13}$$

The mixture was designed based on the C: N ratio value of each substrate. The amount of each substrate to be added was determined iteratively using the following equation (Alemu G. 2016):

$$C/N_{Mixture} = \frac{V_{VW} * C/N_{VW} + V_{FW} * C/N_{FW}}{V} \tag{14}$$

Where V_{VW}-volume of vegetable waste mixed (L), V_{FW}-volume of fruit waste mixed (L), C/N_{VW}- vegetable waste C/N ratio, C/N_{FW}- fruit waste C/N ratio, and V-effective volume of the digester (L).

3.3.2. Effects of C/N ratio, pH, temperature, and Sonication time

The effects of C/N ratio, pH, temperature, and sonication time were examined using one parameter at a time method of experimental study. The experimental parameters coded and actual levels were summarized in Table 4.

Table 3-1: Experimental parameter ranges for anaerobic digester biogas generation

Parameter	Code	Unit	Coded factors level	
			Minimum (-1)	Maximum (1)
Mixture C/N ratio	A	None	20	30
Initial pH	B	None	6	8
Temperature	C	^{o}C	25	35
Sonication time	D	Minute	0	60

3.3.3. Data analysis

The most common decision rule is to reject the null hypothesis if the p-value is less than or equal to 0.05 and to retain it otherwise. A p-value has meaning only if the correct null sampling distribution of the statistic has been used, i.e., if the assumptions of the test are (reasonably well) met. Confidence intervals can add a lot of important real-world information top-values and help us complement statistical significance with substantive significance. In this work duplicate experiments were conducted, p-value < 0.05, and confidence of interval of > 95 % was used to ensure the accuracy of the experimental works. SPSS software was used for this experiment and used one way ANOVA to compare the result was significant or not. Origin lab software was used to generate attractive graphs used in this thesis report.

3.3.4. Upgrading methane content of biogas

To increase the content of the methane in the generated biogas commercial activated carbon, a solution of NaOH and KOH and silica gel was used to remove H_2S, CO_2, and moisture, respectively. To achieve this generated biogas was allowed to pass through the units containing the aforementioned materials and the sample was taken before and after passing the units to analyze the amount removed. Removal of H2S: Since activated carbon has high surface area, porosity, and surface chemistry, it is suitable to adsorb H2S from biogas. During removal process the impregnated activated carbon was 10 g per liter of water and NaOH. This reaction is an adsorption process. Hydrogen Sulfide is adsorbed on the carbon surface and dissolution of H2S into the water film is resulted. Removable of CO2: The upgrading section consists of solutions of NaOH/KOH .Biogas was passed through the upgrading first flask where it reacts with NaOH of 0.1 moles. Removal of H2O: Silica gel as it has very good moisture absorbing capacity. The biogas enters the moisture eliminating column after passing the H2S and CO2 removal unit. H2O is mostly adsorbed on silica without chemical reactions.

3.4. Experimental setup

The 1000 ml plastic bottles were used as a digester and 500g of biomass was added in each digester. The plastic rubbers are tightly fitted to it to form the anaerobic condition and placed in the water bath to control digestion temperature. The plastic hoses were used to extend the flow of generated gas to upgrading units and finally to the water displacement units. The syringes were connected before and after the upgrading units for the sampling purpose and analyzed using a biogas analyzer. The amount of biogas generated was equivalent to the amount of water displaced due to the gas produced. Fig.3-3. indicates the experimental setup of this study.

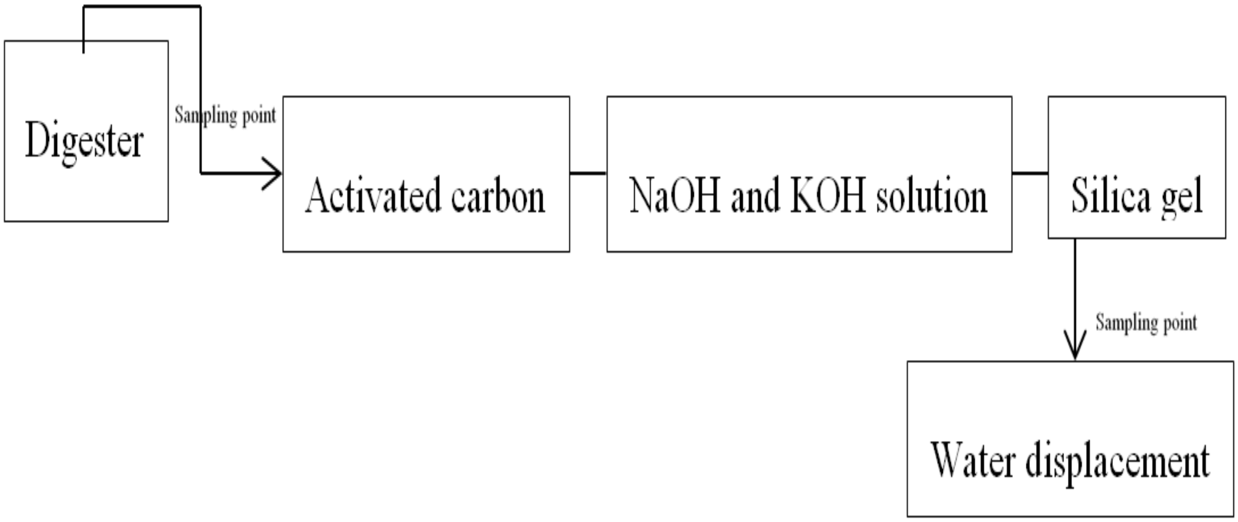


Figure 3-3: Systematic experimental flow diagram for upgrading methane content

3.5.Production yield

The amount of biogas produced and collected in an airbag was measured using the water displacement method. The amount of methane produced from the digested volatile solids of the fruit and vegetable waste during the digestion period in the digester was calculated using equation 17 (Alemu G. 2016).

$$CH_{4Yield}(L/g) = \frac{\sum CH_{4\mathrm{Pr}oduced}(L)}{VS_{fed}(g)} \tag{17}$$

where VS (g)-total solids in the digester (g) multiplied by the change in the % VS during digestion which can be given as $VS(g)=TS*(\%\ VS_{fed}-\%VS_{digestate})$.

4. RESULTS AND DISCUSSION

4.1. Characteristics of fruit and vegetable characterization of Addis Ababa Vegetables wholesale market

The fruit and vegetable wastes were characterized by following several different standard procedures listed for each parameter. As indicated in Table 4.1, both wastes have high volatile solids, which is a very important parameter indicating the waste could be used for the generation of biogas. The low pH values of these wastes indicated the need for pre-pH adjustments near to the neutral. Similarly, the low C/N ratio observed for the vegetable waste reveals that this waste has to co-digest with some other substrate, which compensates for the deviation in the C/N ratio. Similar observations to this result were reported (Caruso et al. 2019; Zeynali, Khojastehpour, and Ebrahimi-Nik 2017).

Table 4-1**:** Fruit and vegetable characterization

No.	**Characteristics**	**Mixed Fruit Waste**	**Mixed Vegetable Waste**
1	Total Solid (TS) %	13.8	11.22
2	Moisture Content (MC) %	86.2	88.78
3	Volatile Solid (as %TS)	89.4	88.6
4	Ash Content (%)	0.6	0.4
5	BOD5	8.65	9.32
6	COD(g/l)	13.2	10.82
7	pH	5.77	6.62
8	Total Nitrogen (N)	0.46	0.78
9	C: N Ratio	29	14

4.2. Effects of C/N ratio, initial pH, temperature and sonication on biogas generation and methane yield

4.2.1. Effect of C/N ratio

C/N ratio is a relevant factor in methane production. When the C/N ratio is high in the substrate, nitrogen will be consumed rapidly by methanogens to meet their protein requirements, which results in low methane production, and with a low C/N ratio, nitrogen will be present in the form of ammonia which inhibits the methanogens metabolism due to its toxicity. Necessary elements such as carbon, nitrate, and others including microelements are very important for the growth of microorganisms. Especially, it has been recognized that all living organisms need nitrogen to synthesize protein used for metabolic activities. In the absence of sufficient nitrogen, the bacteria would not be able to utilize all the carbon present and the process would be less efficient (Alemu G. 2016). An inadequate C/N ratio may inhibit the microbial activity in degrading the organic matter into biogas, which potentially reduces biogas or methane production (S. Suhartini, Hidayat, and Hadi 2021). Reported work indicated that the optimum C/N ratio for ensuring stable biodegradation was found in the optimal range of 20-30 (S. Suhartini, Hidayat, and Hadi 2021). In this work, the fruit and vegetable wastes were mixed based on the C/N ratio. The C/N ratio of 20, 25, and 30 were considered to examine the effect of C/N on the biogas generation and yield as well.

Table 4-2: Effects of C/N ratio

Day	Biogas (L)			Methane (%)		
	20	25	30	20	25	30
5	0.14	0.17	0.18	23	36.2	32.1
10	0.39	0.47	0.50	29	55.8	44.9
14	0.67	0.81	0.85	32	53.7	45.4
15	0.57	0.69	0.72	42	52.1	49.6
16	0.65	0.79	0.83	47	52.4	52.2
17	0.98	1.19	1.25	47	53.1	52.6
18	0.87	1.05	1.11	45	52	51.0
19	0.86	1.04	1.09	53	54.8	56.4
20	0.47	0.57	0.60	55	55.5	57.8
30	0.21	0.25	0.27	45	51.2	50.6

As depicted in Fig.4-1, biogas production and methane composition were observed to increase as the C/N ratio of the fruit and vegetable wastes increased from 20 to 25 while it was constant though the C/N ratio increased from 25 to 30. Methane yield was also observed to increase with the C/N ratio (Table 4-2). This increase in cumulative biogas generation and methane yield might be due to an adequate nutrient balance and the adaptation of anaerobic microorganisms to the substrate used, which ensures the easy degradation of the mixture (Beniche et al. 2021).

Table 4-3: Methane yield at different operational parameters

Parameter	Levels	Yield (L CH_4/g VS)
C/N ratio	20	0.17
	25	0.25
	30	0.32
pH	6	0.21
	7	0.25
	8	0.32
Temperature (^oC)	25	0.19
	30	0.21
	35	0.33
Sonication (min.)	Un-sonicated	0.15
	20	0.25
	40	0.29
	60	0.39

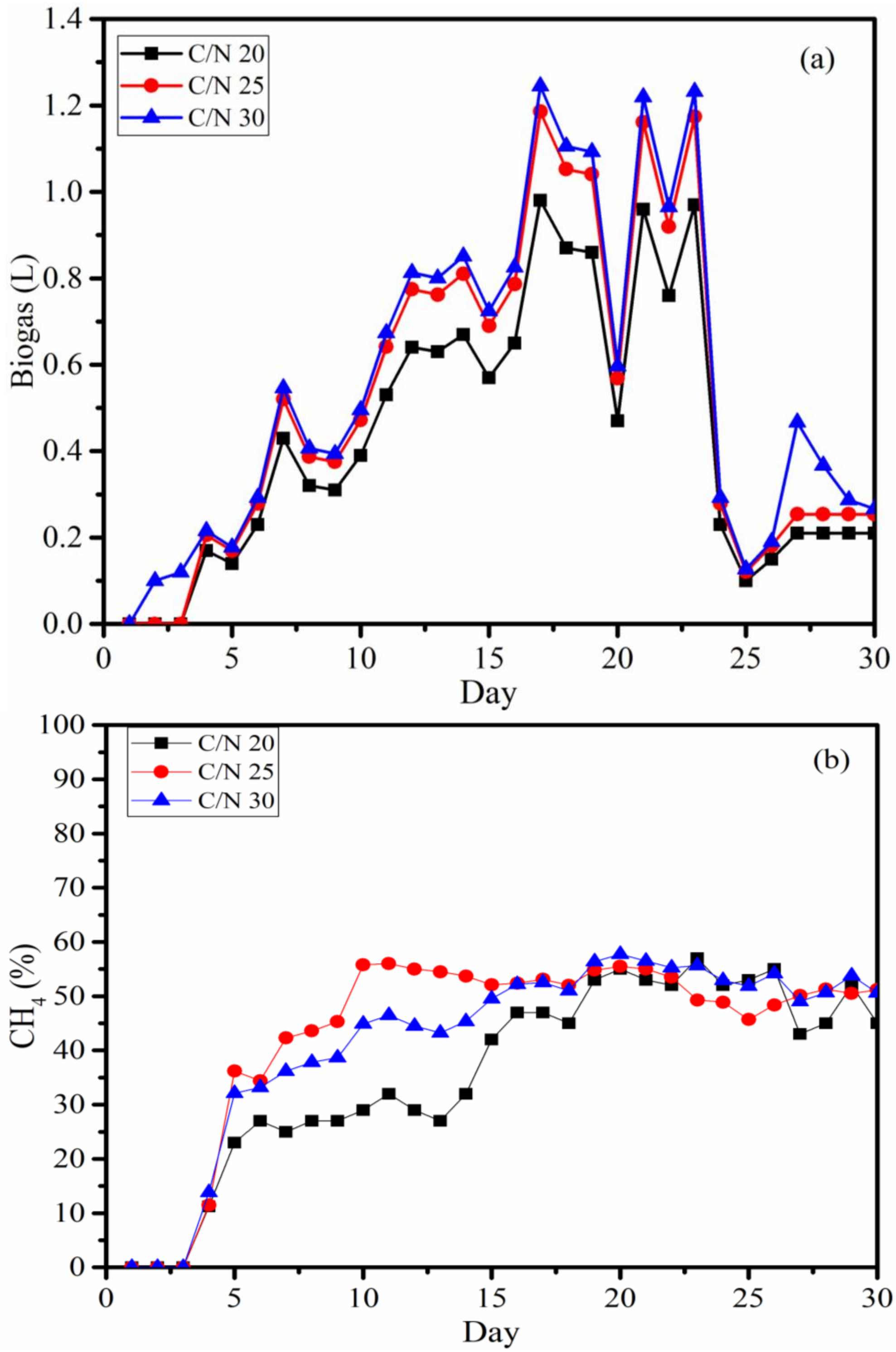


Figure 4-1: Effect of C/N ratio on biogas generation and methane yield: a-biogas generation (L); b-methane yield (L CH_4/gVS) (at room temperature, pH=7, TS=10 %)

4.2.2. Effect of pH

In this work, the initial pH of 6, 7, and 8 were examined for their effect on the biogas generation and methane yield as well. Both biogas generation rate and methane yield were observed to increase as the pH increased from 6 to 7 and no significant change was observed between pH 7 to 8 (Fig.4-2). Moreover, a relatively high yield was observed at pH 8 (Table 4-4). The low pH, high easily biodegradable material, high oil content, and low alkalinity were easily created a low pH environment in the anaerobic digester resulting in complete failure of the biogas production process (Singkhala et al. 2021). According to Gunorubon, Woyinbrakemi, and Michael, (2021), the pH value less than 5 or greater than 8 had also been reported to rapidly inhibits methanogenesis and anaerobic bacteria required a natural environment, hence, optimum biogas production was obtained at a pH range of 6-7 (Gunorubon, Woyinbrakemi, and Michael 2021). The observed pH trends in this research are in tandem with previous studies (Bhurat et al. 2021; Dinnebier et al. 2021; Gunorubon, Woyinbrakemi, and Michael 2021; Hodaei et al. 2021). In this work, pH 7 was selected as optimum to be used in the subsequent experiments.

Table 4-4: Effects of PH

Day	Biogas (L)			Methane (%)		
	8	7	6	8	7	6
5	0.28	0.26	0	28.0	34.6	39.2
10	0.58	0.56	0.28	34.0	47.4	55.4
14	1.28	0.93	0.64	37.0	47.9	54.5
15	1.06	0.86	0.73	47.0	52.1	55.8
16	0.74	0.62	0.65	52.0	54.7	57.3
17	0.74	0.81	0.76	52.0	55.1	57.8
18	0.16	0.51	0.74	50.0	53.5	56.5
19	1.32	0.90	0.76	58.0	58.9	60.6
20	0.46	0.87	0.95	60.0	60.3	61.6
30	0.53	0.30	0.23	50.0	53.1	55.9

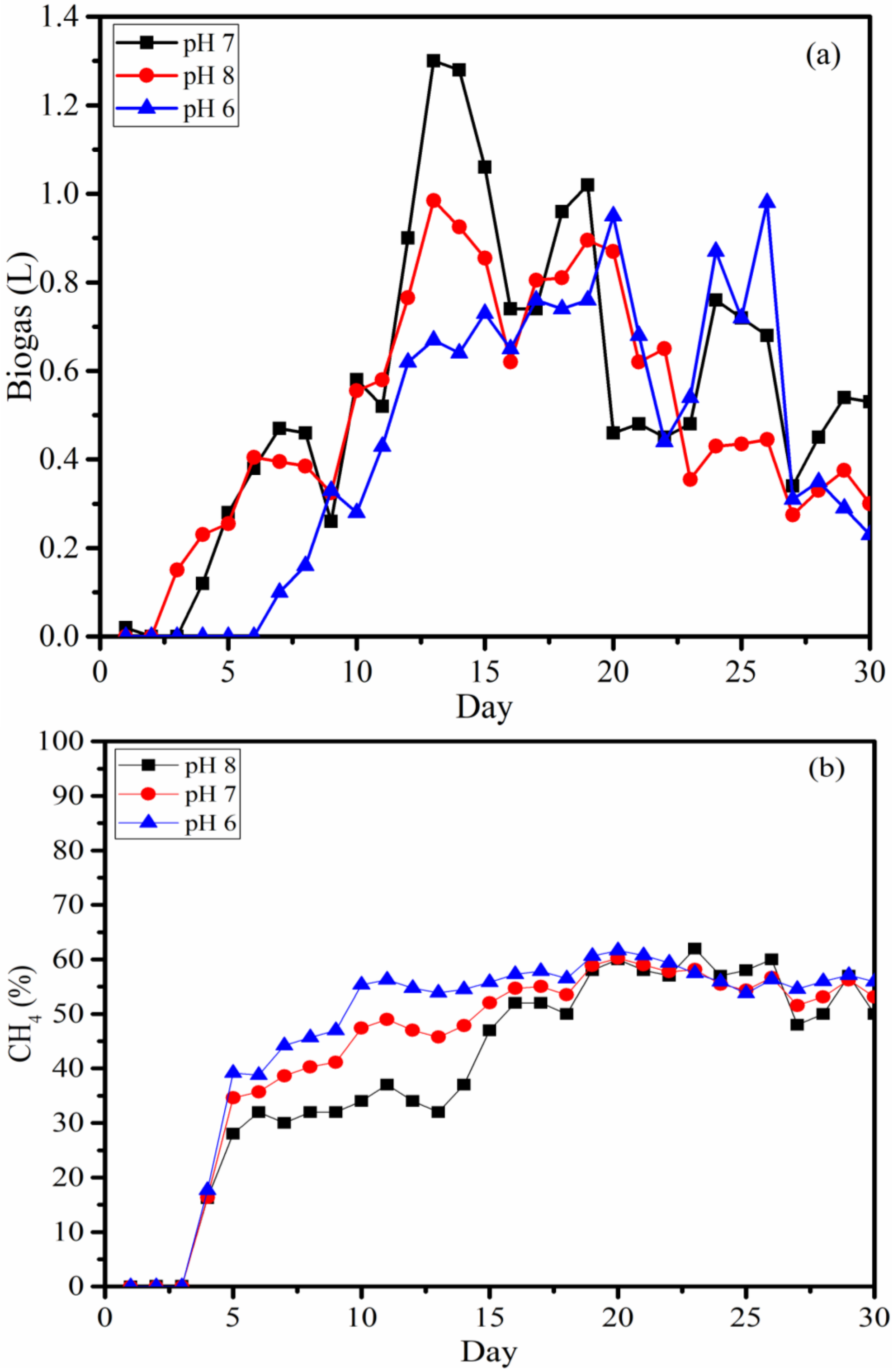


Figure 4-2: Effect of pH on biogas generation and methane yield: a-biogas generation (L); b-methane yield (L CH_4/gVS) (C/N ratio=25, at room temperature, TS=10 %)

4.2.3. Effect of temperature

As the temperature increases from 25 to 35 ^{o}C, generally, the biogas generation rate and the methane content increase (Fig.4-3). The maximum biogas was generated at days 18 to 20 for the three digestion temperatures. This indicated that at high temperatures the digestion of the fruit and vegetable wastes was increased as the high temperature is more favorable for the growth of the methanogens bacteria which play a great role in biogas generation. there are a lot of reports similar to this observation (Nouri, Asakereh, and Soleymani 2020; Rahman et al. 2021; Shao et al. 2021). Not only this but an increase in the digester temperature was also observed to increase the methane composition of the produced biogas, which in turn increase the yield of biogas production (Table 4-5) and (Carrillo-Reyes et al. 2021; Obileke et al. 2021). It is well known that biogas production increases as the temperature increases. However, as the temperature increases the running cost due to the increase of temperature increases which challenges the feasibility of biogas. the thermoplilic bacteria are more sensitive than that of mesoplilic bacteria, so higher costs are needed to control the temperature in the thermophilic range. In this work, the temperature of 30 ^{o}C was used in the subsequent experiments as optimum temperature.

Table 4-5: Effects of Temperature

Day	Biogas (L)			Methane (%)		
	25	30	35	25	30	35
4	0.28	0.17	0.32	12.6	17.1	19.7
5	0.32	0.10	0.4	23.8	29.0	33.4
10	0.6	0.33	0.63	31.9	37.6	43.2
14	0.64	0.93	0.79	32.0	37.7	43.3
15	1.16	0.97	0.98	33.8	39.8	45.8
16	0.88	1.23	0.95	35.1	41.3	47.5
17	0.94	0.87	0.98	35.4	41.5	47.8
18	1.08	0.63	0.93	34.5	40.6	46.7
19	0.71	0.47	0.76	37.4	43.8	50.3
20	0.76	0.75	0.98	38.1	44.6	51.3
30	0.23	0.08	0.18	34.2	40.3	46.4

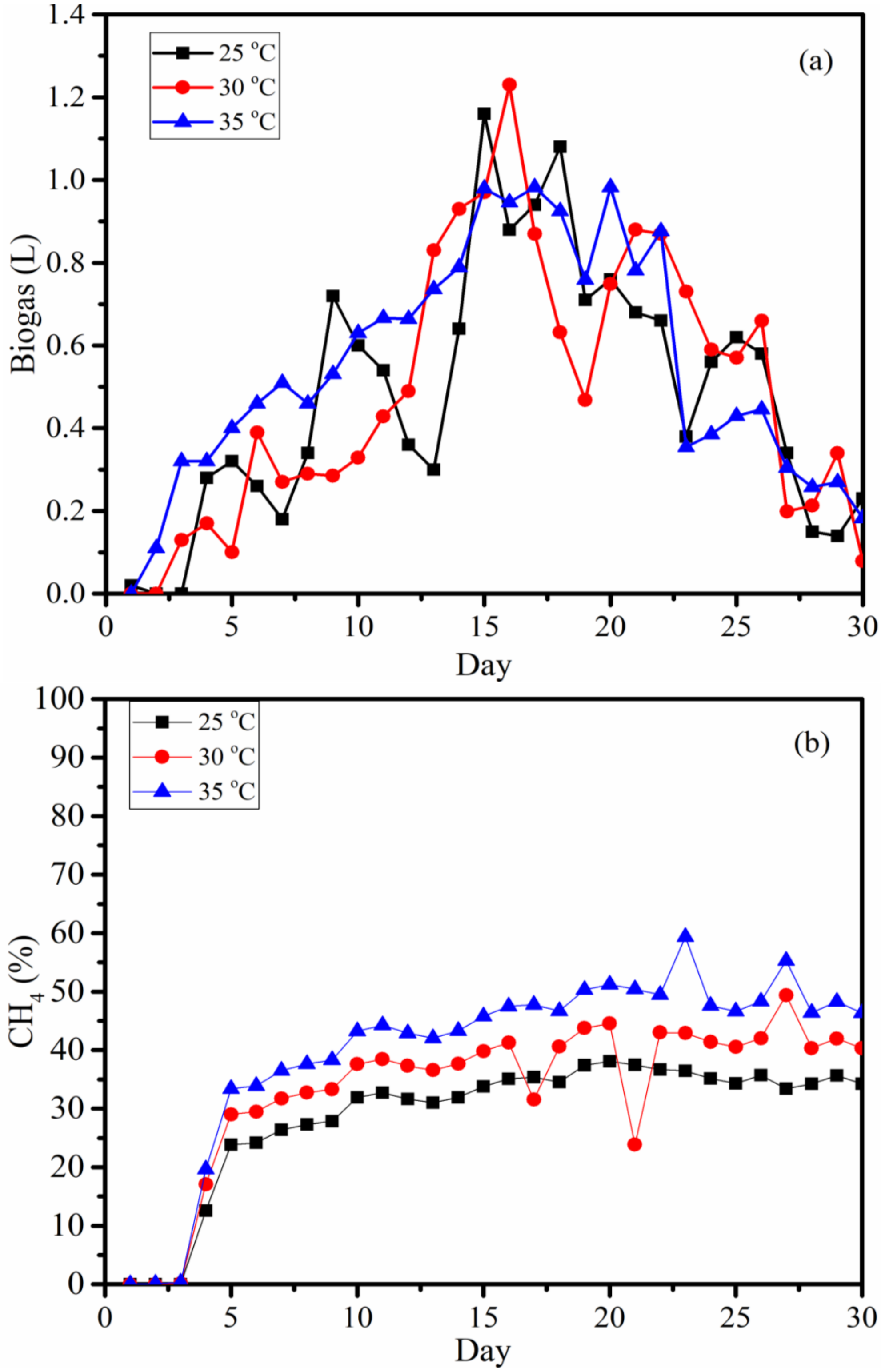


Figure 4-3: Effect of temperature on biogas generation and methane yield: a-biogas generation (L); b-methane yield (L CH_4/gVS) (C/N ratio=25, pH=7, TS=10 %)

4.2.4. Effect of sonication

It is soundly known that biogas production main is depending on the biodegradation capacity of the organic waste being used for the biogas production in this case fruit and vegetable wastes. Among the available methods to enhance the biodegradability of organic waste different scholars was used sonication (Kwarciak-Kozłowska and Worwąg 2021; Liu et al. 2021; Ma et al. 2021). In this work, the fruit and vegetable wastes were sonicated for 20 min., 40 min. and 60 min. before the digested in the anaerobic digesters. As indicated in Fig.4-4, cumulative biogas generation and methane yield were increased together with an increase in the sonication duration of the fruit and vegetable wastes. The biogas generation of 14.28.L, 14.48.L, 16.5 L, and 18.25 L for un-sonicated, 20 min., 40 min. and 60 min. sonication time, respectively (Table 10) while methane yield of 0.15, 0.25, 0.29, and 0.39 L CH_4/gVS for un-sonicated, 20 min., 40 min. and 60 min. sonication time, respectively (Table 4-3) was observed. According to Zeynali, Khojastehpour, and Ebrahimi-Nik, 2017, sonication was reported to increase the TS degradation of organic wastes and it had a direct relationship with biogas yield at different ultrasonic exposure times and concluded that ultrasonic had a major effect on the TS reduction (Zeynali, Khojastehpour, and Ebrahimi-Nik 2017).

Table 4-6: Effects of Sonication time

Day	Biogas (L)				Methane (%)			
	Un-sonicated	20	40	60	0	20	40	60
5	0.19	0.14	0.17	0.16	5.2	5.9	6.3	6.52
10	0.42	0.37	0.44	0.48	15.35	0.17	0.21	0.24
14	0.79	0.86	0.91	0.99	0.29	0.38	0.43	0.48
15	0.88	0.92	0.93	0.90	0.34	0.44	0.46	0.45
16	0.95	1.09	0.98	0.79	0.38	0.54	0.50	0.41
17	0.97	0.92	0.99	0.98	0.39	0.46	0.51	0.51
18	0.96	0.80	0.95	1.32	0.38	0.39	0.48	0.67
19	0.96	0.71	1.08	1.45	0.41	0.38	0.58	0.79
20	0.88	0.81	0.90	0.93	0.38	0.44	0.50	0.51
30	0.24	0.16	0.26	0.37	0.09	0.08	0.13	0.18

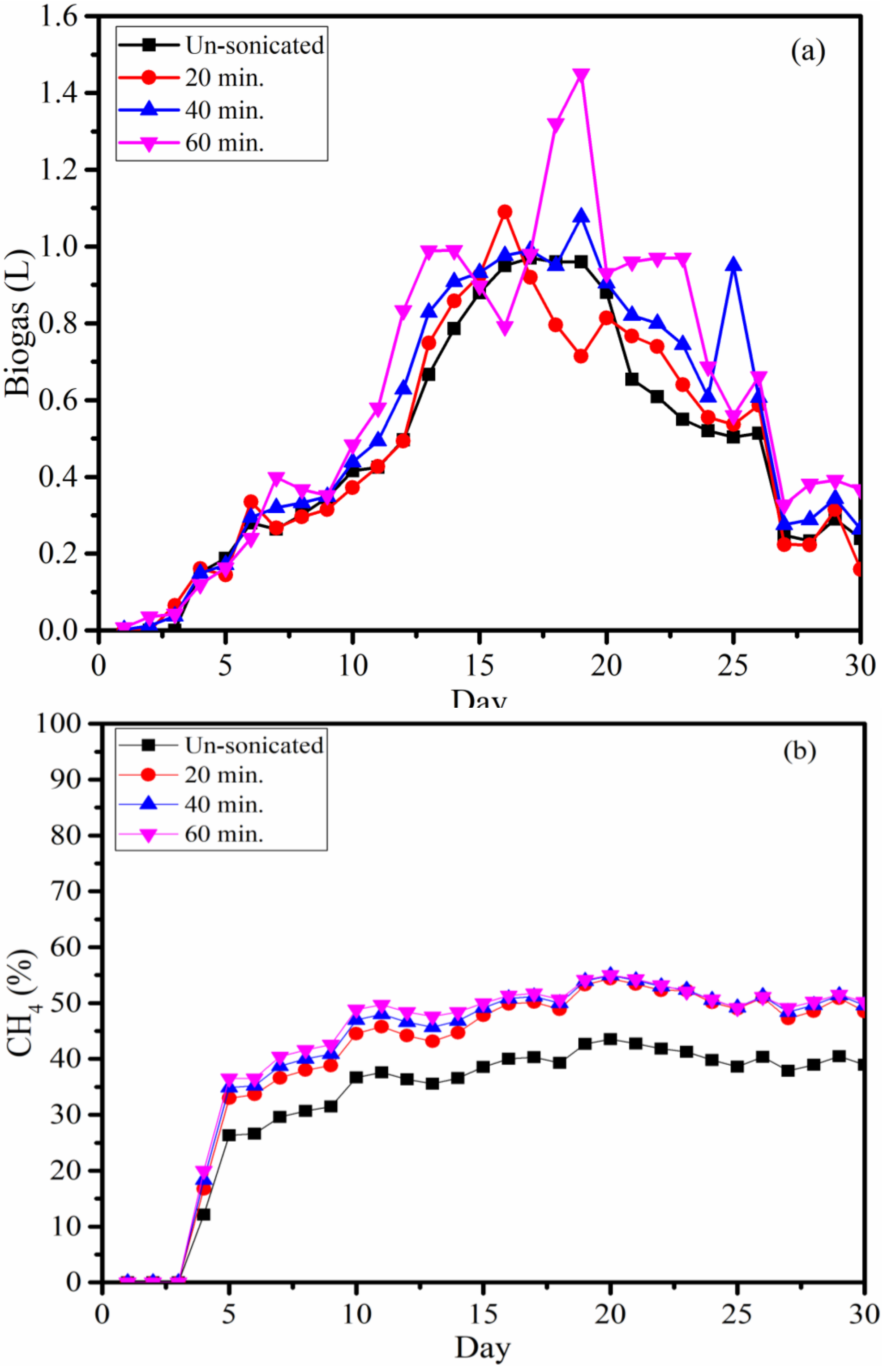


Figure 4-4: Effect of sonication time on biogas generation and methane yield: a-biogas generation (L); b-methane yield (C/N ratio=25, pH=7, at room temperature, TS=10 %)

4.3. Upgrading the methane content of the biogas generated using commercial biochar adsorption.

To increase the methane composition of the produced biogas, the product was allowed to pass through a fixed bed formed by packing 10 g activated carbon in a cylinder of an internal diameter of 2.8 cm, an external diameter of 3 cm, and height of 9 cm. The upgrading section consists of solutions of NaOH/KOH .Biogas was passed through the upgrading first flask where it reacts with NaOH of 0.1 moles. The biogas enters the moisture eliminating column after passing the H2S and CO2 removal unit. H2O is mostly adsorbed on silica without chemical reactions. The samples were taken on days between 15 to 20. As indicated in Table 4-7, the methane composition of the generated biogas increased as it passed through the activated carbon fixed-bed column while the composition of CO_2 decreased. This demonstrated that the CO_2 in the raw biogas was adsorbed in the activated carbon and hence its composition in the exit biogas decreased. H_2S is also observed to decrease as it passes through the adsorption column. In general, passing the generated biogas through the activated carbon, NaOH solution, and silica gel was observed to decrease CO_2 and H_2S and increase CH_4 in the exit biogas. A similar result to this observation was also reported by different researchers (Fahad et al. 2021; Mulu, Arimi, and Kiprop 2021).

Table 4-7: Biogas up-grading results

Day	Before adsorption			After adsorption		
	CH_4 (%)	CO_2 (%)	H_2S (ppm)	CH_4 (%)	CO_2 (%)	H_2S (ppm)
15	52.5	31	278	58.6	28.9	187
16	60.1	30.3	228	64.4	29	178
17	60	25.7	163	66.2	21.7	145
18	62.3	24.1	360	66.7	20.7	237
19	53.5	31.9	156	56.2	25.1	141
20	51.7	31.4	88	53.6	23.1	23

4.4.Experimental Results Data Analysis

Experimental result data analysis model annotated view was labeled as “significant.” This is arbitrarily based on SPSS program and computed F value compare with F tabulated and the F computed value was greater than that of F tabulate Value; the experimental Data analysis was Significant. (Table 4-8)

Table 4-8: ANOVA (One Way) Experiments data Analysis summary

Response :- Bio Gas						
	Sum of square	df	Mean square	F (Computed)	F (Tabular)	
			PH			
Between groups	0.176	2	0.088	0.879	0.419	Significient
With in Groups	8.712	87	0.1			
Total	8.888	89				
			C/N			
Between groups	0.247	2	0.124	0.967	0.384	Significient
With in Groups	11.11	87	0.128			
Total	11.357	89				
			Temperature			
Between groups	0.183	2	0.121	0.748	0.645	Significient
With in Groups	8.209	87	0.142			
Total	8.390	89				
			Sonication			
Between groups	0.347	3	0.116	1.037	0.379	Significient
With in Groups	12.955	116	0.112			
Total	13.302	119				

5. CONCLUSION AND RECOMMENDATION

5.1.Conclusion

This work biogas was generated from the fruit and vegetable wastes by mixing them based on their C/N ratio to balance the nutrient for the best anaerobic digestion. The effects of the C/N ratio, pH, temperature, and sonication time on the biogas generation and methane composition were examined. Biogas production and methane composition were observed to increase as the C/N ratio of the fruit and vegetable wastes increased from 20 to 25 while it was constant though the C/N ratio increased from 25 to 30. Methane yield was also observed to increase with the C/N ratio. Both biogas generation rate and methane yield were observed to increase as the pH increased from 6 to 7 and no significant change was observed between pH 7 to 8. Moreover, a relatively high yield was observed at pH 8. The maximum biogas was generated at days 18 to 20 for the three digestion temperatures. The fruit and vegetable wastes were sonicated for 20 min., 40 min. and 60 min. before the digested in the anaerobic digesters. Biogas generation and methane yield were increased together with an increase in the sonication duration of the fruit and vegetable wastes. The biogas generation of 14.28.L, 14.48.L, 16.5 L, and 18.25 L for un-sonicated, 20 min., 40 min. and 60 min. sonication time, respectively while methane yield of 0.15, 0.25, 0.29, and 0.39 L CH_4/gVS for un-sonicated, 20 min., 40 min. and 60 min. sonication time, respectively. In addition to that observed in this research, the generated biogas passes through the activated carbon, NaOH solution, and silica gel, the methane content increase by an average of 9 % related to before adsorption. Generally, it was observed that fruit and vegetable wastes have the potential to generate biogas and it could be increase methane content in biogas by using adsorption of biochar.

5.2.Recommendation

From this work, the following future works are further lab testing might be needed.

- Pilot testing of the fruit and vegetable wastes for the biogas generation
- In-depth examination on the effect of sonication on the digestion of the fruit and vegetable wastes
- Cost-benefit analysis for the feasibility of biogas generation from fruit and vegetable wastes
- Methane composition up-grading using adsorbent needs further research and get a better result..

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Appendix

Appendix 1: Effect of C/N ratio

Day	Biogas (L)			Methane (%)		
	20	25	30	20	25	30
1	0	0	0	0	0	0
2	0	0	0.1	0	0	0
3	0	0	0.12	0	0	0
4	0.17	0.21	0.22	11.2	11.5	13.9
5	0.14	0.17	0.18	23	36.2	32.1
6	0.23	0.28	0.29	27	34.4	33.2
7	0.43	0.52	0.55	25	42.3	36.2
8	0.32	0.39	0.41	27	43.6	37.8
9	0.31	0.38	0.39	27	45.3	38.7
10	0.39	0.47	0.50	29	55.8	44.9
11	0.53	0.64	0.67	32	56	46.5
12	0.64	0.77	0.81	29	55	44.5
13	0.63	0.76	0.80	27	54.5	43.3
14	0.67	0.81	0.85	32	53.7	45.4
15	0.57	0.69	0.72	42	52.1	49.6
16	0.65	0.79	0.83	47	52.4	52.2
17	0.98	1.19	1.25	47	53.1	52.6
18	0.87	1.05	1.11	45	52	51.0
19	0.86	1.04	1.09	53	54.8	56.4
20	0.47	0.57	0.60	55	55.5	57.8
21	0.96	1.16	1.22	53	55	56.5
22	0.76	0.92	0.97	52	53.5	55.3
23	0.97	1.17	1.23	57	49.3	55.7
24	0.23	0.28	0.29	52	48.9	53.0
25	0.1	0.12	0.13	53	45.7	51.9
26	0.15	0.18	0.19	55	48.4	54.2
27	0.21	0.25	0.27	43	50.1	49.1
28	0.21	0.25	0.27	45	51.3	50.7
29	0.21	0.25	0.27	52	50.5	53.8
30	0.21	0.25	0.27	45	51.2	50.6

Appendix 2: Effect of pH

Day	Biogas (L)			Methane (%)		
	8	7	6	8	7	6
1	0	0	0	0	0	0
2	0	0	0	0.1	0	0
3	0	0.15	0	0.1	0	0
4	0.12	0.23	0	16.2	16.4	17.7
5	0.28	0.26	0	28.0	34.6	39.2
6	0.38	0.41	0	32.0	35.7	38.8
7	0.47	0.40	0.1	30.0	38.7	44.2
8	0.46	0.39	0.16	32.0	40.3	45.7
9	0.26	0.33	0.33	32.0	41.2	47.0
10	0.58	0.56	0.28	34.0	47.4	55.4
11	0.52	0.58	0.43	37.0	49.0	56.3
12	0.9	0.77	0.62	34.0	47.0	54.8
13	1.3	0.99	0.67	32.0	45.8	53.9
14	1.28	0.93	0.64	37.0	47.9	54.5
15	1.06	0.86	0.73	47.0	52.1	55.8
16	0.74	0.62	0.65	52.0	54.7	57.3
17	0.74	0.81	0.76	52.0	55.1	57.8
18	0.16	0.51	0.74	50.0	53.5	56.5
19	1.32	0.90	0.76	58.0	58.9	60.6
20	0.46	0.87	0.95	60.0	60.3	61.6
21	0.48	0.62	0.68	58.0	59.0	60.8
22	0.45	0.65	0.44	57.0	57.8	59.4
23	0.48	0.36	0.54	62.0	58.2	57.5
24	0.76	0.43	0.87	57.0	55.5	55.9
25	0.72	0.44	0.72	58.0	54.4	53.8
26	0.68	0.45	0.98	60.0	56.7	56.3
27	0.34	0.28	0.31	48.0	51.6	54.6
28	0.45	0.33	0.35	50.0	53.2	56.0
29	0.54	0.38	0.29	57.0	56.3	57.1
30	0.53	0.30	0.23	50.0	53.1	55.9

Appendix 3: Effect of temperature

Day	Biogas (L)			Methane (%)		
	25	30	35	25	30	35
1	0	0	0	0.0	0.0	0.0
2	0	0	0.11	0.0	0.0	0.1
3	0	0.13	0.32	0.0	0.1	0.3
4	0.28	0.17	0.32	12.6	17.1	19.7
5	0.32	0.10	0.4	23.8	29.0	33.4
6	0.26	0.39	0.46	24.2	29.5	33.9
7	0.18	0.27	0.51	26.4	31.7	36.5
8	0.34	0.29	0.46	27.3	32.7	37.7
9	0.72	0.28	0.53	27.9	33.3	38.3
10	0.6	0.33	0.63	31.9	37.6	43.2
11	0.54	0.43	0.67	32.7	38.5	44.3
12	0.36	0.49	0.66	31.7	37.3	42.9
13	0.3	0.83	0.74	31.0	36.6	42.1
14	0.64	0.93	0.79	32.0	37.7	43.3
15	1.16	0.97	0.98	33.8	39.8	45.8
16	0.88	1.23	0.95	35.1	41.3	47.5
17	0.94	0.87	0.98	35.4	41.5	47.8
18	1.08	0.63	0.93	34.5	40.6	46.7
19	0.71	0.47	0.76	37.4	43.8	50.3
20	0.76	0.75	0.98	38.1	44.6	51.3
21	0.68	0.88	0.78	37.5	43.8	50.4
22	0.66	0.87	0.88	36.7	43.0	49.5
23	0.38	0.73	0.35	36.5	42.9	49.4
24	0.56	0.59	0.39	35.1	41.4	47.6
25	0.62	0.57	0.43	34.3	40.6	46.6
26	0.58	0.66	0.45	35.7	42.1	48.4
27	0.34	0.20	0.30	33.4	39.4	45.3
28	0.15	0.21	0.26	34.3	40.4	46.4
29	0.14	0.34	0.27	35.7	42.0	48.3
30	0.23	0.08	0.18	34.2	40.3	46.4

Appendix 4: Effect of sonication

Day	Biogas (L)				Methane (%)			
	Un-sonicated	20	40	60	0	20	40	60
1	0	0	0	0.01	0	0	0	0
2	0	0	0.01	0.04	0	0	0	0
3	0	0.07	0.04	0.04	0	0	0	0
4	0.15	0.16	0.15	0.12	0.02	0.03	0.03	0.02
5	0.19	0.14	0.17	0.16	0.05	0.05	0.06	0.06
6	0.28	0.34	0.29	0.24	0.07	0.11	0.1	0.09
7	0.26	0.27	0.32	0.4	0.08	0.1	0.12	0.16
8	0.3	0.3	0.33	0.37	0.09	0.11	0.13	0.15
9	0.35	0.32	0.35	0.35	0.11	0.12	0.14	0.15
10	0.42	0.37	0.44	0.48	0.15	0.17	0.21	0.24
11	0.43	0.43	0.49	0.58	0.16	0.2	0.24	0.29
12	0.5	0.49	0.63	0.83	0.24	0.32	0.38	0.47
13	0.67	0.75	0.83	0.99	0.29	0.38	0.43	0.48
14	0.79	0.86	0.91	0.99	0.29	0.38	0.43	0.48
15	0.88	0.92	0.93	0.9	0.34	0.44	0.46	0.45
16	0.95	1.09	0.98	0.79	0.38	0.54	0.5	0.41
17	0.97	0.92	0.99	0.98	0.39	0.46	0.51	0.51
18	0.96	0.8	0.95	1.32	0.41	0.38	0.58	0.79
19	0.96	0.71	1.08	1.45	0.41	0.38	0.58	0.76
20	0.88	0.81	0.9	0.93	0.68	0.74	0.78	0.76
21	0.65	0.77	0.82	0.96	0.71	0.76	0.79	0.79
22	0.61	0.74	0.8	0.97	0.69	0.76	0.78	0.76
23	0.55	0.64	0.74	0.97	0.23	0.76	0.78	0.8
24	0.52	0.56	0.61	0.69	0.21	0.28	0.31	0.35
25	0.5	0.54	0.95	0.56	0.19	0.26	0.47	0.27
26	0.51	0.59	0.61	0.66	0.21	0.3	0.31	0.34
27	0.25	0.22	0.28	0.33	0.09	0.11	0.13	0.16
28	0.23	0.22	0.29	0.38	0.09	0.11	0.14	0.19
29	0.29	0.31	0.34	0.39	0.12	0.16	0.18	0.2
30	0.24	0.16	0.26	0.37	0.09	0.08	0.13	0.18

Appendix 5: Methane yield

Parameters								
	L CH_4	TS%	Vsf	Vsi (fed)	Vsi-Vsf =Vs diff	TS=Vx%Ts	gVS=TS x Vs diff	L CH_4/gVS
C/N								
C:N								
20	5.46	10	22.9	89.00	66.1	50	33.05	0.17
25	7.98	10	24.6	88.00	63.4	50	31.7	0.25
30	8.06	10	35.6	86.00	50.4	50	25.2	0.32
PH								
pH								
8	7.62	10	40.19	87.49	47.3	50	23.65	0.32
7	7.43	10	28.09	87.49	59.4	50	29.7	0.25
6	7.47	10	17.09	87.49	70.4	50	35.2	0.21
Temperature								
^oc								
25	4.8	10	38.49	87.49	49	50	24.5	0.196
30	5.79	10	32.89	87.49	54.6	50	27.3	0.212
35	7.18	10	45.09	87.49	42.4	50	21.2	0.339
Sonication time								
min								
0	5.48	10	15.09	87.49	72.4	50	36.2	0.15
20	6.89	10	32.29	87.49	55.2	50	27.6	0.25
40	8.07	10	30.89	87.49	56.6	50	28.3	0.29
60	9.08	10	41.09	87.49	46.4	50	23.2	0.39