BIOGAS PRODUCTION FROM WASTE TEA LEAVES AS A WASTE MANAGEMENT STRATEGY AT DL KOISAGAT TEA FACTORY NANDI HILLS (KENYA)

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DECLARATION

Declaration by the Candidate

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DEDICATION

I would like to dedicate this work to my family and classmates for their invaluable support during my study period.

ABSTRACT

Most tea factories in Kenya utilize wood as the main source of energy. Wood is burned in boilers to produce steam that is used in unit operations in tea processing. The firewood produce stack gases that are emitted into the environment. DL Koisagat tea factory uses approximately 12 tons of wood daily, taking into consideration numerous tea factories in the country, contributing to rapid deforestation. Waste tea leaves from these factories are used as compost manure and the rest discarded on the surface. Decomposition of these dumped waste produces methane into the environment and affect the quality of ground water through coloration. Considering environmental degradation caused by tea factories it prompt the need for waste management and alternative sources of energy. Waste tea leaves can be anaerobically digested in a batch reactor to produce methane which is a clean source of energy and also reduce and reuse of waste from the factory. The study aim at determining the quantity of waste tea produced daily in the factory. Also determining the optimum conditions of retention time, pH, and temperature required in generation of methane gas. The factory waste tea leaves quantity was determined by measuring the weight of daily sweepings using industrial crane scale (KERN HFB). Waste tea leaves from the factory was mixed homogeneously with cow dung (inoculum) and fed into the digester. The digestion process took place under varying conditions of retention time, pH and temperature. The gas collected was pumped into gas samplers using vacuum pump for analyzing in the Gas chromatograph (FID) within 48 hours for methane quality determination. It was found that DL Koisagat produces approximately 2,847.00kg of waste tea leaves per month. The optimum conditions for biogas production from waste tea were pH of 7, temperature of $37^{o}C$ and retention time of 20 days. Though the highest yield of methane was obtained at pH of 5, temperature of $50^{o}C$ and retention time of 20 days, these conditions also promote production of high quantities of carbon dioxide gas. This impurity limits the quality of methane by hindering its combustion. Based on the results of the study, it was concluded that waste tea leaves produces biogas with 19% methane. From monthly production of waste tea, there is sufficient biomass for biogas production and also waste tea leaves from the factory have the potential to produce methane. The optimum conditions of pH, temperature and retention time have the potential to generate biogas from waste tea. Methane produced contains impurities of carbon dioxide, ammonia and hydrogen sulphide gases. Purification process of methane increases the cost of production.

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LIST OF ACRONYMNS

MSW	Municipal Solid Waste
DCTW	Decaffeinate Tea Waste
FTW	Factory Tea Waste
NEMA	National Environment Management Authority
EMCA	Environment Management and Coordination Act
EMS	Environment Management System
RET	Renewable Energy Technology
MT	Made Tea
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CTC	Cut Tear Curl
GC	Gas Chromatograph
FID	Flame Ionization Detector
SOP	Standard Operation Procedure
pH	Measure of the molar concentration of Hydrogen ions in solution
MS	Mass Spectrometer

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CHAPTER ONE

1.1 INTRODUCTION

Waste is regarded as unusable or unwanted substance and also referred as a material that is of no purpose to the user. Wastes which exist in environment are also known as garbage. Waste production can be from households, factories, or in business operations. Most waste is produced from production processes where raw materials are transformed to finished products (Battista *et al*, 2016). Wastes that are generated from industries, schools, households, hospitals and farms are classified as non-toxic, fluids, solid and hazardous. Societies are prone to problems associated with waste disposal. Waste handling depend on many factors which include characteristics and source of waste, as well as the state or local regulations that govern the management of waste. Waste management practices vary depending on the place of production like developing and developed countries, industries and residences, rural and urban areas. Municipal solid waste are mainly those wastes collected from hospitals, school, residential areas, light industries operations and commercial buildings (Chowdhury *et al*, 2016). This municipal solid waste (MSW) mainly contain food wastes, containers, yard trimmings, paper, inorganic wastes and containers. Some MSW contain industrial sludge which can be categorized as non- hazardous or hazardous, its main source being manufacturing processes, mining and construction.

There are other types of waste which include hazardous waste and e-waste. Solid, gas or liquid waste that is highly corrosive, toxic, flammable or reactive is known as hazardous waste (Cornejo & Wilkie, 2010). Though mainly the term hazardous is symbolize with two cross-bones with skull, these hazardous substance include products used in day-to-day activities such as detergents used in laundry, car oils, shoe polish, paints and batteries. Also some components used in everyday life produce hazardous waste during their use. E-waste are mainly electronic devices that are used by individuals or businesses which are approaching the end of their usefulness. They include televisions, phones, printers, scanners, shredders, faxing machines, keyboards and computers (Faerber & Herzog, 2010).

Waste from agricultural sector comes from farms or any agricultural related processes that are used in processing agricultural products to finished usable products. For instance, any crop processing procedure must have some residues that are treated as waste. This waste can contain some harmful chemicals or other residual substances arising from the processing itself (Hilkiah, 2008). Coffee, tea, cotton and other agricultural products have waste generated and this at some point may not be pure from the crop residues as at some point the chemicals used in the processes may remain in the waste produced.

Agriculture and food bio-wastes present an opportunity for conversion into methane, which is clean source of energy, through anaerobic digestion. Biogas has the characteristics of being colorless and odorless gas with calorific value of 20 MJ/m^3 and ignition temperature range of 650 to 750 and burns at approximately 60% efficiency (Maile *et al*, 2017). Biogas presents an opportunity as an alternative fuel for heating and cooking purposes as well as combined power generation and has been increasingly been recommended for adoption as a clean source of energy. Biogas generation is mainly conducted under mesophilic conditions in dome shaped bio digesters. Biogas and anaerobic digestate, also termed bio solids which can be further processed for fertilizer usage are obtained. The biogas produced is rich in bio-methane with compositions ranging from 55% to 70% and the other major component is carbon dioxide with composition ranging from 25% to 35%. The biogas calorific value can be enhanced by applying purifying techniques such as adsorption which separates the carbon dioxide to have bio methane content with more than 90% (Ziauddin & Rajesh, 2015).

Waste requires to be handled with care through management practices so as avoid environmental pollution of any kind. Waste management is the process of collection, transportation and disposal of sewage, garbage and other waste materials (Macharia, 2015). Waste management includes management of all stages and resources for proper handling of waste products, from maintenance of vehicles used to transport waste and dumping sites to compliance with health codes and environmental regulations (Savage, 2002). Waste management is mainly achieved through the 3R's which are; Reduce, Reuse, and Recycle. The 3R's are meant to reduce the quantity of waste that is produced while reducing their impact on the environment. The first R is reducing waste where the waste is produced and what is required for use is significant to the waste management (Savage, 2002). It implies that, when less waste is produce there is also minimum to reuse and to recycle. Reduction process of waste starts with examination of what is used for and what is being used. The second R is reusing where waste is taken back for reuse before disposing off it. This includes that waste which still has some value and in most cases is when they can be used for another purpose than the original one (Ziauddin & Rajesh, 2015.). For example after using cooking fat/oil in a container, then the container is converted into other uses of storing items such as grains, water or washing bucket. This will limit the quantity of waste dispose by making use of it. On the other hand, recycling is the third step in waste management. Recycling is the process of molding back the waste product to become the raw material of a new item.

The challenge facing recycling process is that, while the communities are willing to collect and sort the waste there are no proper plants to undertake the recycling process of transforming the waste into raw materials. (Thomsen *et al*, 2004). Efforts are underway to bring together the factories that produce waste and the industries to convert the waste into raw materials, for example detergent industry and oil industry. This will be achieved through incentive credits and agreement.

This study, focus on waste generated after processing takes place in the factory which is treated as an agricultural waste. Tea is one of the major cash crops in Kenya which plays a major role in economy. Most areas in the Rift valley region having embraced tea farming amongst other areas like Mount Kenya areas of Kiambu, Murang'a and other areas with favorable climate in the country. Various tea processing plants have been set across the country to help the farmers' process their product before taking it to the market. Most of tea factories in the country do not comply with the Kenya Tea Board regulations on disposal of tea waste. Tea factories produce waste tea mainly used as manure in tea farms because of less effective management technologies available. Waste can be converted into a useful resource that enable both waste management and production of clean source of energy. Tea wastes are the waste derived from tea factories as a result of tea losses and these include buds, leaves discarded and tender stems of tea plant. (Meres *et al*, 2004). Tea waste if not properly dispose off will cause result in environmental pollution on ground water will be colored increasing its turbidity, soil structure and texture will also be affected and increase dust in air.

According to Kenya Tea Board regulations, before holding, selling or exporting stock of waste tea, it has to be admix with urea of not less than five percent, slack lime, cow dung or any other denaturant that may be specified by the Board to denature it. Most solid waste of tea industries are tea waste which are sometimes used to extract caffeine (Liu *et al*, 2010). There are two types of tea waste that are produced these are; Factory Tea Waste (FTW) and Decaffeinated Tea Waste (DCTW). The fiber part of leaves is not used during tea processing hence removed and discarded because they affect tea quality. This waste sometimes contains leaves and dust hence causing environmental pollution. Tannic acid present in FTW limit the use of this tea by-product as pig and poultry feed which is much prevalent in the country (Faerber & Herzog, 2010). On the other hand Decaffeinated Tea Waste (DCTW) that is obtained after caffeine extraction from waste tea contains less quantities of tannic acid because most of the acid have been extracted.

1.1.1 Sources of biogas

Wastes that are rich for biogas production include: municipal and domestic wastes, agricultural and excreta wastes and industrial wastes. Methane is produced from decomposing landfills, thermal cracking of hydro-carbons, incomplete combustion of biomass, livestock gut, incomplete combustion of biofuels, wetlands and rice paddy fields and termites gut. (Bousquet *et al*, 2010)

1.1.2 Biogas Production from Waste Tea Leaves

In Kenya, tea industries are the major contributors to economy in agro-based sector. Tea waste can also be recycled through various processes like biogas production which is a source of clean/non-fossil energy through anaerobic degradation. Anaerobic digestion is achieved in absence of oxygen and is one of the best approaches to deal with tea waste issue by converting the waste tea leaves to biogas, and fertilizer as a by-product (Kumar, 2004). The waste materials including municipal waste and cellulosic material waste (e.g. wood and waste textiles) are examples of bio waste that can be used in the production of biogas as raw materials. Tea leaves contain many chemical compounds which can be extracted, when these compounds are broken down, they form complexes and other new compounds. Tea leaves are mainly composed of water, when plucked, these leaves starts to lose water and therefore wilt and this process known as withering in the tea processing plants. When tea leaves undergo withering process, their cells become flaccid and walls breakdown this leads oxygen coming into contact with the chemical compound inside the leaf, resulting oxidation reaction.

Gasification and pyrolysis methods can be used in generation of bio-char and bio-oil from processed tea waste as raw material. In pyrolysis process, a liquid fuel bio-diesel is produced. This can be used in running engines, in static heating and generation of electricity in turbines. While gasification process involves production of a fuel gas which can be burn to run engines or generation of electricity in turbines or heat generation. (Demirbas, 2010).

Thermo-chemical conversion of biomass is achieved through two main processes. Fluidized Bed Pyrolysis (FBP) method and Circulating Fluidized Bed (CFB) are the techniques that are used in conversion of biomass to thermally degraded products. These processes take place in limited supply of oxygen and varying operating temperatures. Primary vapors from pyrolysis process are adiabatically quenched to produce bio-oil. High quality bio-oil is obtained from Fluidized Bed technique since it has maximum potential. Oils obtained from biomass pyrolysis tend to have a number of complex organic chemicals. This enable them to have higher calorific value enabling to be used in industrial combustion systems. Gases obtained from biomass have energy content that range from 3.5–5.0 MJ/m^3 which can be used in industrial combustion by firing of furnace and power generation in diesel engines. Tea seed can be utilized as a fuel to fire cyclone boilers and for firing pulverized coal for power generation (Neves *et al*, 2011).

Polyphenols, enzymes amino acids, carbohydrates, minerals methylxanthines, pigments and many aromatic compounds and volatile flavor are the compounds that give the fresh tea leaves aroma, taste, flavor and appearance when processed. The chemical composition of tea leaves gives it an advantage of producing biogas through anaerobic digestion thus presenting a good opportunity to recycle the waste (Cheng, 2010). Therefore, the fact that tea leaves can produce biogas from its chemical composition through anaerobic digestion prompted this study to determine the production of biogas from tea waste as an integrated waste management approach at DL Koisagat Tea Factory.

1.1.3 Uses of Methane

Methane gas can be easily compressed into liquid form, stored and exported. Other applications include domestic use in homes for cooking and industrial use for generation of electricity in both external and internal combustion engines.

1.2 Statement of Problem

Tea factories produces a large quantities of waste tea leaves, but tea waste management system is less effective in the country. These wastes accumulate in the factory dump sites to large quantities of waste tea leaves. This can cause pollution of ground water as it may alters water turbidity. Also presents of waste tea leaves in water bodies can lead to change in water composition. This tea waste may be reduced by transforming into use by anaerobic digestion to provide clean source of energy and also improve environmental conservation through waste management. The waste tea leaves disposed off to the environment decay resulting in change in soil quality. Dust from waste tea when blown by the wind can cause air pollution.

DL Koisagat uses various sources of energy like biofuels and electricity which are quite expensive. The fact that the factory uses 12 metric tons of wood daily as source of energy, exposes the environment to the danger of degradation from heavy logging which is a double cut to the environment. Considering numerous tea factories in Kenya operating at the same rate pose environmental danger. Use of biofuels like diesel is also a source of pollution which also calls for attention of an alternative energy source to the factory. The fact that there is tea waste that causes harm to the environment offers a solution from the fact that through anaerobic digestion, the factory can generate biogas which can provide other source of energy to replace wood and biofuels used. The utilization of tea waste reduces direct pollution from the waste as well as the indirect pollution from wood and biofuels used. Therefore, use of wood to provide factory's energy and disposal of waste tea to the environment are major sources of pollution from the factory. Therefore, the study investigates the production of biogas from tea waste as an integrated waste management approach at DL Koisagat Tea Factory.

1.3 Project Justification

Industrialization may cause pollution, tea factories emit dust, produce waste tea leaves, uses wood as the main source of energy and emission of organic gases from generators. The study will be beneficial to numerous stakeholders. The tea factories owners being the first group to gain from the outcome of this study in that they will be in a position to implement the model of biogas production which will help them reduce energy costs of running the factories using available waste as raw materials. The surrounding community will benefit from limited pollution from the factory and also supply of surplus of clean energy. The factory will be able to meet Environmental Act 2015 requirements of attaining minimum waste production released to the environment from the factory through the 3R's; reusing the waste, reducing and recycling. Also, the production of renewable energy will also offer an alternative solution to the use of wood and biofuels. Despite production of GHGs (CO_2 and water vapor) during combustion of methane, forest conservation acts as sinks. The model of biogas production will also be beneficial to the national and county government as it will be able to implement it in a bid to reduce tea waste pollution in tea growing areas.

1.4 Objectives

The main objective of this study is to investigate the potential for biogas production using waste tea leaves at DL Koisagat Tea factory.

1.4.1 Specific Objectives

The research was carried out with the following specific objectives

1. To estimate the quantity of tea waste produced from DL Koisagat Tea Factory.

2. To determine the optimum condition of temperature, pH and retention time on production of biogas from waste tea leaves.

3. To estimate the potential of biogas production at DL Koisagat Tea Factory.

1.5 Research Questions

1. What is the amount of waste tea leaves generated at DL Koisagat Tea Factory?
2. What is optimum temperature, pH and retention time for biogas production from waste tea leaves?
3. What is the potential of biogas production at DL Koisagat Tea Factory?

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Concerns for environmental pollution, energy conservation and the availability of agricultural organic wastes in Kenya as waste materials, have made a renewed interest in the processing of these wastes for energy recovery and waste management. Of the several available types of energy conversion processes, anaerobic fermentation has been proved to be the best technique for many agricultural operations (Islam *et al*, 2016). Anaerobic degradation can transform most of agricultural wastes to produce biogas or methane gas.

Anaerobic digestion is a designed methanogenic transformation of organic material in absence or limited supply of oxygen and involves numerous different species of anaerobic micro-organisms that convert organic matter into biogas (Laskri *et al*, 2015). Anaerobic digestion uses in waste management results in importance that go beyond basic waste treatment. This importance includes energy conservation and energy production. In waste treatment, anaerobic digestion promotes environmental benefits which include, conservation of nutrients pathogen control, reduction of odor and reduction in greenhouse emissions (Islam *et al*, 2016).

Renewable resources use results in a closed carbon cycle and hence does not lead to increase in concentrations of carbon dioxide in the atmosphere compare with fossil fuel. Also renewable resources cut atmospheric pollutants which leads to acid rain which are mainly contributed by fossils. Therefore, anaerobic digestion is both a waste management method which enhance production of clean energy and improve environmental conservation.

2.2 Environmental Management System

Environmental Management System (EMS) is a set of control methods and sequence that enable a firm to minimize, manage and analyze its products, services and activities which causes environmental degradation so that the operate with high efficiency. EMS is universal, it is applicable in both private and public sector, small or bigger sizes organizations. EMS is built on ISO 14001 model that is designed to help one to sequentially control, identify and monitor environmental issues (Faerber & Herzog, 2010).

Most industries are changing towards cleaner production and ISO certification. In order for the companies to accomplish an integrated waste management, accurate data on the amount and quality of waste is needed. Reliable data and amount of waste produced determine the planning and success of operation of waste management system. (Faerber & Herzog, 2010). Designing proper pollution control methods, evaluation and formulation of waste management policy requires knowledge on composition and quantity of waste. Other factors that are considered include equipment needed to estimate the thermal chemical and physical properties of the waste, facilitate design process, identify the source of waste production and estimate product recovery potential and also align with the policy and legal framework.

Due to limited budget and improper management of records which have led to missing of data or lack of data update on waste composition and generation have resulted in lack of waste information from various sources. Without a proper estimate of amount of waste that can be projected, decisions about equipment and landfill space and recycling capacity within the factories cannot be well formulated. Developing countries have challenges in solid waste management an aspect that has contributed to environmental pollution due to the properties of solid waste which is not the same to that found in developed countries. About 0.4-0.6 kg per day of solid waste is generated in low income countries as opposed to 0.7 to 1.8kg per day in developed nations (Drapcho *et al*, 2008). The transportation of waste from industries and other sources of waste production is also a challenge. The issue of urbanization has compromised planning and limited time to accommodate swelling urban population. The garbage dumps have increased an aspect that has contributed to health concerns as well as environmental pollution.

2.3 Policy and Legal Framework that exist

In 2002, the Government of Kenya establish Vision 2030 which is a blueprint long-term plan in achieving and transforming Kenya to a middle level income country. This transformation is attainable through industrialization. Also essential to this is having a safe and clean environment. The Waste Management Regulations of 2006 offers comprehensive management practices of all wastes in the country. It is a requirement now that waste generators separate their waste as non-hazardous and hazardous waste and then disposing off the waste in an environmentally acceptable manner (Kumar *et al*, 2004). Also it is a requirement under the regulation to transport the waste in a vehicle licensed by NEMA as Waste Transporter.

In Kenya, Environmental Management and Coordination Act 1999/amended 2015 provides legal framework for institutional coordination in environmental management. Standard Enforcement Review Committee formation is provided in Section 70. This committee with the consultation with other relevant authorities advises National Environment Management Authority to develop methods for determining the quality water. Section 72 of the EMCA prohibits the discharge of radioactive and noxious waste into water bodies this contradicts the water pollution control standards. A person contravening this provision is liable to imprisonment for a term not exceeding two years or a fine not exceeding one million shillings, or both when convicted. Also it is the polluter responsibility to pay for restoration and removal cost which will include compensation of any aggrieved parties at the time of pollution of water body, reparation or restituting as in EMCA 1999.These policies and frameworks are important to the DL Koisagat tea factory as it taken as a guideline to dispose its waste generated from tea processing an aspect that would be key to observe during this study.

2.4 Solid Waste Management

Solid material that is useless or unwanted that is produced from combined commercial activities and residential is known as solid waste. Solid waste is classified according to its source, contents and potential hazard. Solid waste management promotes human and environmental health by reducing or eliminating adverse impacts on environment therefore enhance economic development (Faerber & Herzog, 2010). Solid waste management involves a number of stages such as collection, monitoring, recycling, processing, disposal and transportation.

Solid waste management methods differ from country to country depending on the levels of economic growth, population intensity and physical geographical (Afroz and Masud, 2011). Industrialized countries have systematic methods of disposal and collection of solid waste. Waste disposal regulations require disposal sites to have environmental conservation technologies. In developing countries, this regulation does not apply equally. They provide formal disposal and collection methods to a certain population.

The rural and urban poor population does not receive formal services of waste management or proper designated dumping sites (Jantsh and Mattiason, 2004). Even with designated site as dumping area, it is often open and unprotected area which poses serious threats to environment and public health.

2.5 Reduce, Reuse, Recycle

Waste management is achieved through the 3R's; waste reuse, waste reduce and recycling of waste. The use of these methods derive many environmental gains. (Shalini *et al*, 2000). Reduction of waste minimize pollutants, save energy, conserve resources, prevent greenhouse gas emission also limit requirement for landfill and treatment of waste.

Both waste reuse and reduction of materials are waste prevention methods. These methods ensure that no waste is generated at the source therefore reducing the requirements for waste management technologies. Waste reduction methods include practices such as choosing of reusable glass and plastic containers, donating unusable material rather than disposing off it as waste, manufacturing products with minimal packing materials, promoting public awareness to choose reusable materials. (Marcia *et al*, 2007). The most efficient method to manage waste is through reduction at the source of generation

Manufacturers are expected to produce less waste at their facilities which means they have to design products that have the minimal number of packaging which meets the consumer needs by making the product safe and it should be of high quality. All the techniques of waste control requires public participation for their input. (Oriere, 2014). The public should know their role in waste prevention though educational programs and training. Also policy making is the government responsibility to regulate quantity of packaging and the type used by manufacturers by ensuring that biodegradable materials are used.

Recycling is the conversion of waste into raw material by a manufacturer of a new product. There are three recycling phases; first phase is the sorting of waste and recyclables collected which are turned to starting materials of another process. Sorting is done at the source. Collected waste is turned into raw materials which are used in making other products (Walker *et al*, 2009). These wastes are processed in industry then transform into other different products or similar. Recycling includes both post-consumer waste such as plastic bottles, newspapers, aluminium cans and cardboard and pre-consumer waste which include shavings and factory cuttings. Recycling is a resource conservation method as well as energy saving

The process of solid waste management is very critical in this study in supporting the recycling process of waste tea leaves in Koisagat tea factory. This gives an insight on the processes of managing factory waste through various practices. Recycling is the main practice of solid waste management in tea industries as the waste tea leaves becomes the raw material for biogas generation thus eliminating the discharge of the waste into the environment.

According to the study of Impact of Industrial Pollution on Rural Communities on Environment and Accountability (Battista *et al*, 2016). In determining the impact of water pollution on human health, agriculture, livestock and the rural communities. The authors found that there was connection between industrialization and industrial pollution, damage to plants, changes in local environment, damage to animal husbandry which impacted negatively on the sanitation and health of local community.

In the study of Impacts of Effluent from Kapkoros Tea Factory discharged into Kipsonoi River on the local community (Tonui, 2018), the study used a descriptive survey design and a sample of 363 respondents was selected using random simple sampling. The data collected using the constructed questionnaires were well organized and analyzed using SPSS program. The findings revealed that the Kapkoros Tea Factory produces solid wastes from different stages of production like tea leaves from offloading bay, firing, withering, packaging and processing. Also liquid wastes are produced during factory cleaning process. Thermal wastes are as a result of heat loss to the surrounding. These wastes make the local communities surrounding to the factory vulnerable to diseases like cholera and typhoid. It was recommended that industrial effluent is mainly as a result of agro-industrial industries. Developing countries are facing myriad challenges as a result of poor waste management which impacted negatively on human and environment health.

Chowdhury (2016) studied tea waste management from West Bengal, India by selecting 20 sites of study out of 30 tea industries by employing random cluster sampling technique. These industries are spread within the major tea producing regions of Cooch Behar, Darjeeling, Alipurduar and Jalpaiguri. During data collection, primary and secondary data were documented using interviews, questionnaires, photographs and observation were taken. The author’s main objective was to bring out waste management. The study recommended that waste tea was having socio-economic value that can improve the livelihood of gardeners. The waste can be used in extraction of caffeine, as pig and poultry feed and compost manure in gardens.

Developing countries are vulnerable to diseases resulting from pollution due to environmental degradation (Cornejo, 2010). Diarrhea is the most common that 3-5 million cases are reported yearly. This leads to loss of working days because of workers absence from duty. Developing countries are prone to water-borne disorders due to unsafe drinking water as a result of industrial pollution.

Inoti (2016) estimated the potential of renewable energy utilization within a tea factory. Biodegradable waste thermal potential was estimated as a result of amount of waste produced while the monthly wind and solar data for Nyeri was sourced from Renewable Energy Technology (RET) screen 4 software data base. RET screen software was used to model and carry out financial analysis of the renewable resources identified in the tea factories. The results of the study show energy intensities ranged from 32.40 MJ per kg Made Tea (MT) to 38.31 MJ per kg MT and cost intensities from USD 163.05 to 214.72 per ton of MT.

Continuous disposal of industrial waste on land and water bodies leads to increase in pollution load which result in pollution of ground water (Speece, 1996). In the Mettupalayam taluk Tamilnadu study, he postulated that shallow open wells surrounding the industrial places had their water quality deteriorated and when this polluted water is used for irrigation, it resulted in increase in soil salinity.

The assessment of waste management structures for tea factories in Nyasiongo tea factory in Kisii Kenya (Tonui, 2018) found the sources and types of thermal, solid and liquid. These wastes produced during tea processing were identified through observation. Solid wastes produced at every processing stage were identified, sampled, weighed while recording their weights. Liquid waste which is mainly water was sampled for experimental analysis for pH, COD, electrical conductivity and BOD. For thermal source, boiler was sampled and analysed to determine its efficiency. The authors found that Nyansiongo tea factory produces solid waste of 0.01% of the total tea processed. Also found that the minimum solid waste is produced at the off-loading bay while the highest is the withering compartment due to spillage of leaves. The factory had no proper mechanism of disposing off solid waste produced in the factory and the wastes were not well separated for different disposal methods.

Aksay *et al* (2018) sought to develop ways of disposing off and reuse of tea waste from households. A co-digestion was used to determine the potential of biogas production from household tea waste. Co-digestion was carried out in a laboratory scale batch digester under mesophilic conditions for 80 days. The digesters were fed with wastes with different mixing ratio and varying stirring speed. Results obtained revealed that digestion has positive results on biogas generation and methane yield. 296.89mL/g VS of biogas was obtained at optimum conditions and digester with 25% tea waste and 75% cattle manure and stirring speed of 100rpm yield 77.10% methane. From the results, co-digestion of household waste tea and cattle manure have positive impact in production of biogas and methane yield.

2.5.1 Types of Waste Tea leaves

Tea is one of the Kenya's leading cash crops and makes important contribution to the country economy. 399 metric tonnes of black tea were produced in 2010 and the figure has since then increased. Over 95% of the tea that was exported in bulky earning over 97 billion in foreign exchange (Kenya Tea Directorate, 2011). The tea products are commercially available and are dictated by the method of processing. The two most common varieties of tea products are Instant tea and black tea. Black tea is produced by Cut, Tear and Curl (CTC) method of manufacture which accounts for 99% of the tea produced in the country. DL Koisagat tea factory produces black tea which makes it a typical factory in the country. Instant tea accounts for the remainder (Islam et al., 2016). The production of tea from the factory gives forth to tea waste which can be classified into various types. Most waste from tea factories are as a result of by-products. These waste can be used to extract caffeine.

Macharia (2015) indicated that solid waste is collected from the packaging and sorting area and the dry leaves from the weighing section in the factories. The highest amount of solid waste is produced from the withering process due to spillages, and at the offloading area. Solid waste produced from factories may be poorly disposed off and not properly separated. The biodegradable and non-biodegradable waste is collected together and has no clear tracking of the amount generated. The main source of liquid waste in tea industries is from cleaning processes. It is estimated that during major clean-ups in the factories $40m^3$ of waste water is produced. Most tea industries in Kenya do not have proper Effluent Treatment Plants (ETPs) and the water is discharged into nearby rivers causing pollution. For instance, an experimental analysis of wastewater for Nyansiongo Tea Factory found out that BOD5 levels measured 150 mg/L while the COD levels measured 505.5 mg/L against the NEMA recommended maximum discharge limits of 30 mg/L and 50 mg/L respectively.

There are two types of tea waste that is produced and they are: Decaffeinated Tea Waste and Factory Tea Waste (Islam et al., 2016). In the factory during tea processing operation fiber part is remove and disposed in turn this fiber contains dust and small parts of the leaf. Factory Tea Waste (FTW) have some quantities of tannic acid which limit its application for use as pig and poultry feed which is much prevalent in the country (Islam et al., 2016). Decaffeinated Tea Waste (DCTW) is mainly available after extraction of caffeine in caffeine industries.

2.5.2 Optimum Conditions for Biogas Production from Waste Tea Leaves

2.5.2.1 pH

The pH range of about 6.8-8.0 work best for anaerobic digestion i.e. near neutral. Extreme pH of both alkalinity and acidity retard fermentation process. Most biomass when introduced into the digester, lower the pH since they are acidic in nature. This will retard digestion rate until when the acids have been consumed by the bacteria (Laskri et al, 2015). Carbon dioxide production is promoted by high pH. Acidic medium affects methanogens more than acidogenic bacteria.

2.5.2.2 Carbon: Nitrogen ratio

Carbon intake is higher than nitrogen therefore the ratio of carbon to nitrogen in biomass is set at 30:1 for high yield of methane. Lower ratio make nitrogen available after all carbon has been consumed (Inoti, 2016). The residual nitrogen then dissolves digestate thus affecting fertilizer quality. While high ratio of carbon to nitrogen makes the bacteria to die due to nitrogen starvation. This makes the bacteria return nitrogen into the substrate thus retarding the rate of the process.

2.5.2.3 Temperature

Mesophilic bacteria work best at a temperature of between 29^0C and 41^0C while thermophilic bacteria work best at a temperature of between 49^0C and 60^0C. At these temperature range, bacteria reproduce at a high rate resulting in more rapid digestion

(Laskri *et al*, 2015). Temperatures of between 32^0C and 37^0C has been proven to produce the highest yield of methane but above or below this range, biogas will constitute of mainly carbon dioxide and other gases. At thermophilic condition, the digester operates at high loading rate and also desirable for pathogen destruction. This result in shorter retention time but this condition has disadvantage of being easily contaminated by toxicants.

2.5.2.4 Retention time

Retention time of anaerobic process is influenced by some factors such as environmental conditions and characteristics of organic waste. Hydraulic retention time (HRT) should not be short to allow bacteria enough time to digester the biomass (Ziauddin & Rajesh, 2015). Retantion time of most thermophilic and mesophilic range between 25 days and 30 days.

2.6 Anaerobic Biochemistry

Anaerobic digestion (AD) is the degradation of organic materials by micro-organisms in the absence of oxygen. From the process engineering point of view, anaerobic digestion is relatively simple. Since the process uses a ‘mixed culture’ of ubiquitous organisms, no sterilization steps are required and product separation is unnecessary as the biogas separates itself from the aqueous phase. Indeed, since the methane produced is relatively insoluble, it does not accumulate to inhibitory concentrations in the fermentation mixture. However, the biochemical processes involved are very complex.

It is a multi-step biological process where the organic carbon is mainly converted to carbon dioxide and methane

(Angelidaki *et al*., 2003). The process can be divided into four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis.

Hydrolysis

Hydrolysis is the first step in anaerobic digestion processes. During the hydrolysis step, complex organic matters, such as carbohydrates, proteins and lipids are hydrolyzed into soluble organic molecules such as sugars, amino acids and fatty acids by extracellular enzyme, i.e. cellulase, amylase, protease or lipase (Parawira *et al*., 2005). Hydrolytic bacteria, which hydrolyze the substrate with these extracellular enzymes, are facultative anaerobes. Hydrolysis can be the rate-limiting step if the substrate contains large molecules (particulates) with a low surface-to volume ratio (Vavilin *et al*., 1996). While if the substrate is readily degradable, the rate-limiting step will be acetogenesis and methanogenesis (Björnsson *et al*., 2001). When the substrate is hydrolyzed, it becomes available for cell transport and can be degraded by fermentative bacteria in the following acidogenesis step.

Acidogenesis

In the acidogenesis step, the soluble organic molecules from hydrolysis are utilized by fermentative bacteria or anaerobic oxidizers (Garcia-Heras, 2003).

These microorganisms are both obligate and facultative anaerobes. In a stable anaerobic digester, the main degradation path way results in acetate, carbon dioxide and hydrogen. The intermediates, such as volatile fatty acids and alcohols, play a minor role. This degradation path way gives higher energy yield for the microorganisms and the products can be utilized directly by methanogenic microorganisms (Schink, 1997). However, when the concentration of hydrogen and formate is high, the fermentative bacteria will shift the path way to produce more reduced metabolites (Angelidaki *et al*., 2002). The products from acidogenesis step consist of approximately 51% acetate, 19% H_2/CO_2, and 30% reduced products, such as higher VFA, alcohols or lactate (Angelidaki *et al*, 2002). Acidogenesis step is usually considered the fastest step in anaerobic digestion of complex organic matter (Vavilin *et al*, 1996).

Acetogenesis

Intermediates formed during acidogenesis, consist of fatty acids longer than two carbon atoms, alcohols longer than one carbon atom and branched-chain and aromatic fatty acids. These products cannot be directly used in methanogenesis and have to be further oxidized to acetate and H_2 in acetogenesis step by obligated proton reducing bacteria in a syntrophic relationship with hydrogen utilizers. Low H_2 partial pressure is essential for acetogenic reactions to be thermodynamically favourable (Schink, 1997). The products from acetogenesis are then the substrates for the last step of anaerobic digestion, which is called methanogenesis

Methanogenesis

In methanogenesis step, acetate and H_2/CO_2 are converted to CH_4 and CO_2 by methanogenic archaea. The methanogenic archaea are able to grow directly on H_2/CO_2, acetate and other one-carbon compound, such as formate and methanol (Schink, 1997). In the normal anaerobic digesters, acetate is the precursor for up to 70% of total methane formation while the remaining 30% originates from H_2/CO_2. Moreover, the inter-conversion between hydrogen and acetate, catalyzed by homoacetogenic bacteria, also plays an important role in the methane formation pathway. Homoacetogens can either oxidize or synthesize acetate depending on the hydrogen concentration in the system.

Hydrogenotrophic methanogenesis functions better at high hydrogen partial pressure, while aceticlastic methanogenesis is independent on hydrogen partial pressure. At higher temperatures, the acetate oxidation pathway becomes more favourable (Schink, 1997). It has been reported that methane formation through acetate oxidation can contribute up to14% of total acetate conversion to methane under thermophilic conditions (60°C).

2.7 Bacteria Involved in Anaerobic Digestion

Consortia of microorganisms, mostly bacteria, are involved in the transformation of complex high-molecular-weight organic compounds to methane. Furthermore, there are synergistic interactions between the various groups of bacteria implicated in anaerobic digestion of wastes. Although some fungi and protozoa can be found in anaerobic digesters, bacteria are undoubtedly the dominant microorganisms. Large numbers of strict and facultative anaerobic bacteria are involved in the hydrolysis and fermentation of organic compounds. There are four categories of bacteria that are involved in the transformation of complex materials into simple molecules such as methane and carbon dioxide. These bacterial groups operate in a synergistic relationship in as much as group 1 has to perform its metabolic action before group 2 can take over,

Group 1: Hydrolytic Bacteria - Consortia of anaerobic bacteria break down complex organic molecules (proteins, cellulose and lipids) into soluble monomer molecules such as amino acids, glucose, fatty acids, and glycerol. The monomers are directly available to the next group of bacteria. Hydrolysis of the complex molecules is catalyzed by extra cellular enzymes such as cellulases, proteases, and lipases. However, the hydrolytic phase is relatively slow and can be limiting in anaerobic digestion of waste such as raw cellulolytic wastes, which contain lignin.

Group 2: Fermentative Acidogenic Bacteria - Acidogenic (i.e. acid-forming) bacteria convert sugars, amino acids, and fatty acids to organic acids (e.g., acetic, propionic, formic, lactic, butyric, or succinic acids), alcohols and ketones (e.g., ethanol, methanol, glycerol, and acetone), acetate, CO_2, and H_2. Acetate is the main product of carbohydrate fermentation. The products formed vary with the type of bacteria as well as with culture conditions (temperature, pH, redox potential).

Group 3: Acetogenic Bacteria - Acetogenic bacteria convert fatty acids (e.g. propionic acid, butyric acid) and alcohols into acetate, hydrogen, and carbon dioxide, which are used by the methanogens. This group requires low hydrogen tensions for fatty acid conversion; and therefore a close monitoring of hydrogen concentrations is necessary. Under relatively high H_2 partial pressure, acetate formation is reduced and the substrate is converted to propionic acid, butyric acid and ethanol rather than methane.

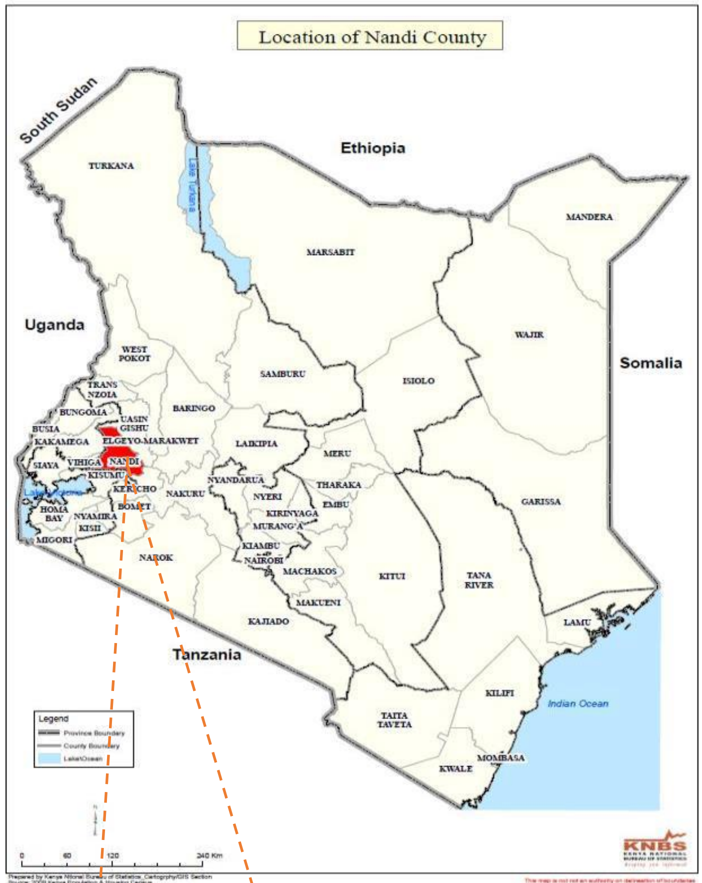
Group 4: Methanogens - Anaerobic digestion of organic matter in the environment releases 500-800 million tons [453.6 - 725.75 metric tons] of methane per year into the atmosphere and this represents 0.5% of the organic matter derived from photosynthesis. This group of bacteria is composed of both gram-positive and gram-negative bacteria with a wide variety of shapes. About two thirds of methane is derived from acetate conversion by methanogens. The other third is the result of carbon dioxide reduction by hydrogen.

CHAPTER THREE

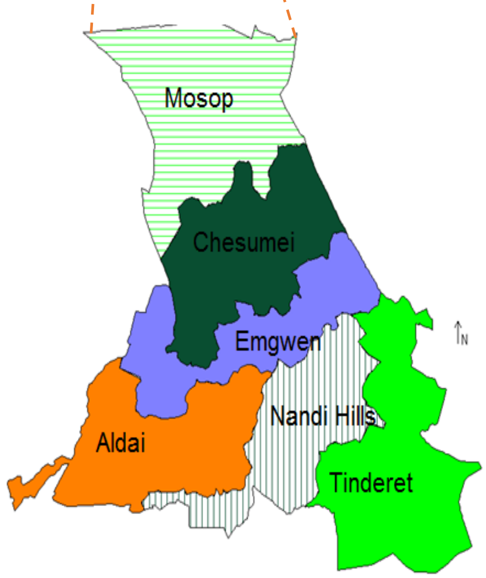
RESEARCH METHODOLOGY

3.1 Study Area

The study area is DL Koisagat Tea Factory in Nandi County, Nandi Hills sub county, Kenya. Nandi County that is located in the Rift Valley region in western Kenya bordering Uasin Gishu County. The total area of the County is 2,884 km² and lies on 0.1836° N, 35.1269° E. Koisagat Tea Factory is situated 14.7 km from Nandi Hills Town off Himaki road and some 307km from Nairobi (capital city) at an altitude of 2047m above sea level. The factory is well served with all-weather roads making it easy to access from Nandi Hills town. Nandi Hills area where the factory is situated enjoys bi-modal rainfall which enable it have two cropping seasons. Long rains starts in February/ March to June while short rains starts in the month of August to November with annual rainfall range of 1020mm and 1550mm. The mean temperature of the area is between 16.20^{0}C and 21.60^{0}C. The main economic activity of Nandi Hills is farming. The choice of the area was based on its accessibility to the researcher. Figure 3.1 shows the map of the study area.



Map 3.1: Map of Kenya



Map 3.2: Map of Nandi County

Map 3.3: Map of DL Koisagat Tea factory in Nandi Hills

3.2 Research Design

The study adopted an experimental research design which provide in both fact finding and formulation of significant principles of knowledge and solution in investigating the production of biogas from tea waste at DL Koisagat Tea Factory. The results achieved through descriptive statistics gives the general picture of the ability of the tea factory to generate biogas as way to mitigate environmental pollution generated from tea processing and obtain alternative clean source of energy.

3.3 Field Collection

The samples of waste tea leaves were obtained from the factory floor as swept. The samples were collected in the morning just as the waste was dumped. A shovel was used to scoop the sample of waste tea leaves from five different sides of the pile and put in polythene bags and taken to University of Eldoret Biotechnology Laboratory. This was carried out every Wednesday for four weeks to obtain a representative sample

Plate 1: Dumped waste tea leaves at DL Koisagat Tea Factory

(Source: Author, 2015)

3.3.1 Procedure of Waste Tea Leaves Quantity Estimation

The quantity of waste tea produce in a day was estimated by determining the weight of factory swept collected. A hanging scale with the accuracy of 0.01 kg was used. All waste tea collected as swept were put in gunny bags and weighed. Weight of empty gunny bag was determine using a weighing scale and recorded as W_1. Then the weight of gunny bag with waste tea was weighed and also recorded as W_2. The difference in the two weights gave the weight of the waste tea as W_a.

Weight of waste tea: $W_a = W_2 - W_1$ …………………………. (a)

The above procedure was repeated for four weeks to obtain W_b, W_c and W_d

The mean weight is used in determination of average production of waste tea leaves at the factory. To obtain the average quantity produced, arithmetic mean is used.

The daily estimate of waste tea generated in the factory was determined by obtaining the mean. The mean of the waste tea distribution $\overline{W}$ is the sum of all weight $\sum W$ obtained in different days and divided by the number of days (n). This is obtained using equation 1 below:

$$\overline{W} = \frac{W_a+W_b+W_c+W_d \ldots W_i}{n} \quad or\ \overline{W} = \frac{\sum W}{n} \qquad \text{Equation 1}$$

Where:

W= Distribution individual value

ΣW= Sum of the values of W

n = Number of values present in distribution

$\overline{W}$=The mean value

3.3.2 Procedure Used for Biogas Production

Biogas production procedure was obtained from *Standard Operation Procedure* (SOP) Laboratory for Environmental Engineering (Biolley; 2014).

Apparatus

The following apparatus were used during the study

Measuring cylinder, Water bath / incubator, Oven, two-liter plastic bottles with corks, weighing balance, Bags: 100kg and 2kg, Gas Chromatograph (FID), NaOH, Inoculum, NaCl, HCl, PVC tubes, Shove, Vacuum pump, Personal protection equipment (gloves, glasses, dust coat and safety boots.), 100 mL Beaker with 50 mL distilled water,100 mL Beaker with 30-50 mL Acetone, , and 100-250 mL Wastewater beaker.

Procedure

The contaminants in waste tea (substrate) were removed using physical separation method mainly screening. Self-activity of the inoculum (control) was carried out in the ratio of 1:1 (Inoculum + water). Weight of 4.5kgs of waste tea was measure using bench scale. Then the substrate preparation was done by mixing Inoculum + water + substrate. Then labelling of the reactor bottles for identification and drilling of bottle cocks using bit drill to enable fixing of PVC tube was done in the lab. Then cutting of PVC tube each into 50cm and fixing into the cork and paste to avoid gas leakage.

Water was filled into the incubator and its temperature set at 50^0C. The reactor bottles were checked for cracks and other damages. The mixture of inoculum, substrate and water was filled to 1.6L mark in the reactors where the pH and temperature of each reactor was adjusted. The reactor bottles were cocked then shaken gently to prevent clumping.

A total of 27 experimental sets were tested after being set at various pH, temperature and retention time. The tests were done at a temperature interval of 25, 37 and 50 degrees Celsius. pH values were set at 5, 7 and 9 where the retention time was set at 10, 20 and 30 days. These parameters were done to estimate the optimum biogas production at various set of conditions.

Each gas tubing was connected tightly using rubber band to a balloon for holding the gas generated in the reactor. Shaking of reactors and checking water level in incubator was done every morning.

At the end of every experiment, a vacuum pump was used to empty the gas from a balloon to a gas sampler (vial). The samplers containing gas were stored in cool box and taken to Government Chemist – Nairobi for Gas Chromatography (GC FID) analysis.

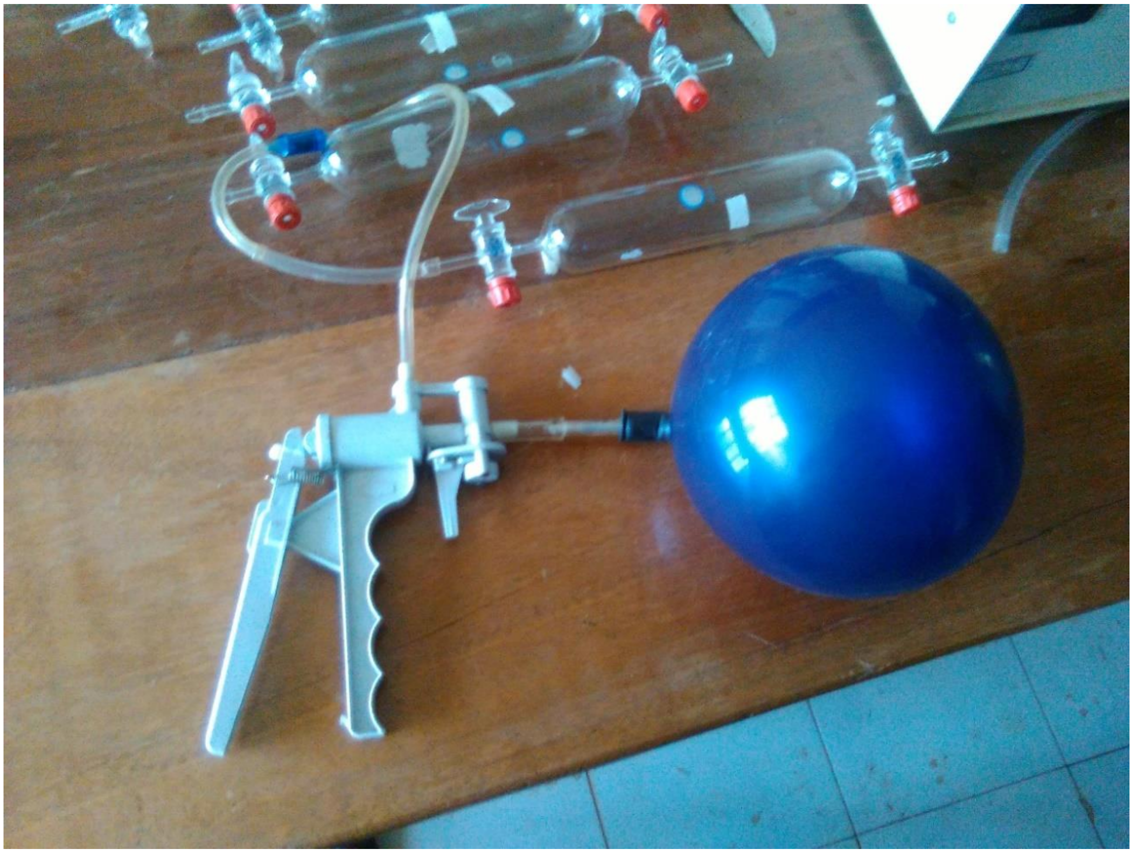


Plate 2: Biogas pumped into gas sampler for further analysis (Source: Author, 2015)

3.3.3 Determination of Gas Quality

The GC-FID was turned on followed by air and nitrogen gas carrier also adjustments of pressure gauges were carried out. The column oven was turned on to a temperature of 250 °C to bake in the column to enable removal of any contaminants this ran for about 30 min before running a sample. Auto sampler settings were set. These include number rinses starting with the pre-run rinse followed by post-run rinse, and then sample rinse. The main purpose of these rinses are to clean the column between different samples. A split ratio was carried out by dividing the samples into portions to avoid column overload.

The temperature programming was entered. The temperature of the separation was entering as 250^{0}C and time for the separation as 10 minutes. The starting temperature was entered as 100^{0}C and hold time as 1 minute, ending temperature as 250^{0}C and hold time as 3 minutes, the ramp speed was at 50°C/min. Between runs, the column was allowed to cool to original initial temperature by setting equilibration time. Hydrogen gas was turned on and pressure gauge was set correctly then flame of the Gas Chromatograph was lit.

On the auto sampler rack, wash vial was filled with wash solvent (acetone). To enable the auto sampler syringe to pick the sample, the vial is filled to half full with the sample. The sample vial(s) were loaded into the auto sampler rack while noting on the paper the position of each vial. Files were collected by a single run then the "start" button was hit and a file was made. The GC analyze the data using software program. Peak area, retention time and peak height are the parameters that are determined. Chromatogram enabled the calculation of peak areas.

The mass that pass through the detector is proportional to the peak areas. This enabled in development calibration curve of the component.

Plate 3: Gas Chromatography-FID at Government Chemist (Source: Author, 2015)

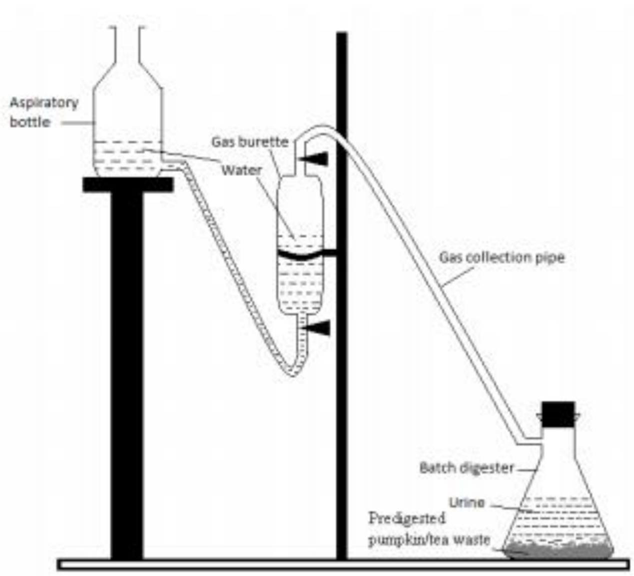


Fig 3.4: Schematic diagram of digester set up for tea waste

CHAPTER FOUR

RESULTS AND INTERPRETATION

4.1 Quantity of Waste Tea Leaves Produced at DL Koisagat Tea Factory

The amount of waste tea was identified through measurement and observations in various stages of tea production for one month.

W_a = 113.61 kg

W_b = 124.50 kg

W_c = 97.15 kg

W_d = 102.73 kg

Where:

W_a, W_b, W_c and W_d are the daily weight of waste tea obtained.

The weights of tea waste collected for the four days within the one month are as indicated above. To get the daily average weight of waste tea, the sum of the four collected days is divided as shown below. Daily average weight of waste tea produce in the factory is obtained by:

$$\overline{W} = \frac{113.61 + 124.50 + 97.15 + 102.73}{4} = \frac{437.99}{4}$$

$$\boldsymbol{\overline{W} = 109.50\ kg}$$

This is the daily average weight of tea waste collected on daily basis from the factory. The analysis of the collected data indicates that high amounts of tea waste over the specified days. This variation of waste generated was as a result of season variation through the year. During the peak season of tea production, the waste generated is expected to be high as well as low amounts when there is low tea production.

4.1.1 Optimum Conditions of Temperature, pH and Retention Time of Biogas Production

The study sought to establish the optimum conditions of pH, Temperature and retention time of biogas production at DL Koisagat tea factory. Figure 4.1 below presents the average content percentage of the biogas composition for the three different experimental set ups. Experiment 1 had samples ranging from 1-9, experiment 2 included samples 10-18 while experiment 3 included samples 19-27.

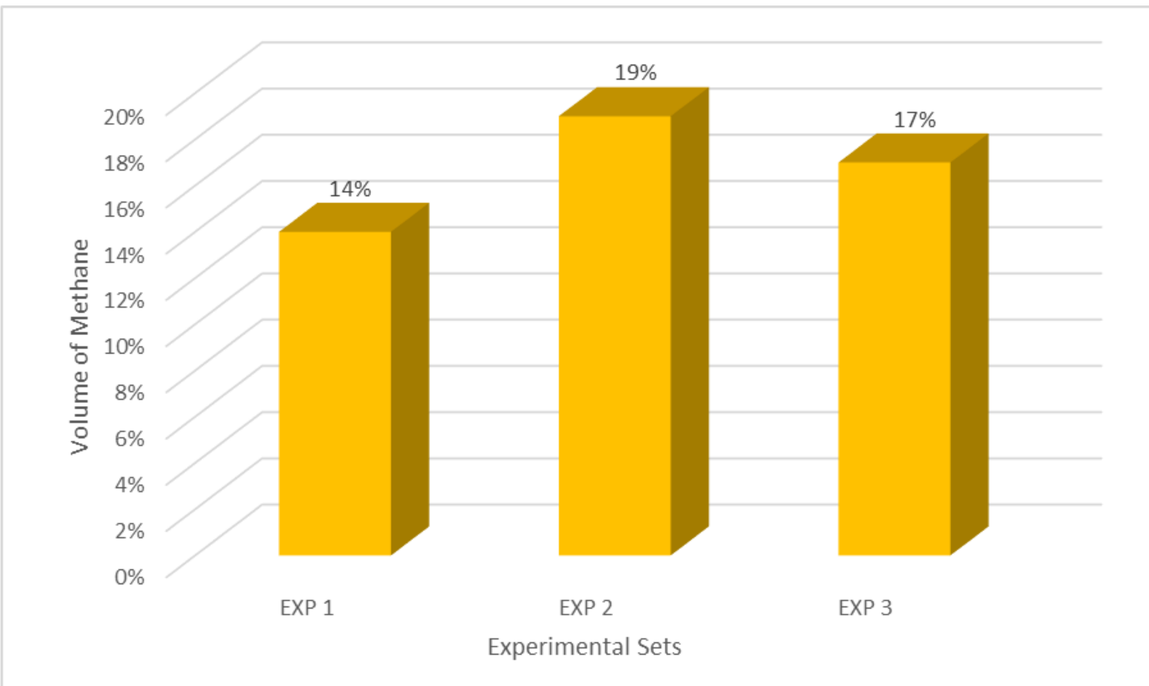


Figure 4.1: Content % of biogas composition on the three experimental set ups

The biogas produced was composed of five gases namely; methane, nitrogen, carbon dioxide, ammonia, hydrogen sulphide and oxygen. This study focused on the methane gas. In set 1, the temperature was maintained constant at 25 ^{o}C set 2 at 37 ^{o}C while set 3 was maintained at 50 ^{o}C. Figure 4.1 above presents the averages in percentage volume of the methane gas. Figure 4.1 indicates that experiment 1-9 had an average of 19% methane followed by experiment 3 which had an average of 17% while experiment 2 recorded 14% methane content. Other gases including carbon dioxide, Nitrogen, Ammonia, Hydrogen sulphide and oxygen were produced but were not the interest of the study. The means are calculated under all the set conditions of temperature pH and retention time.

4.2 Effect of pH on Volume of Biogas

In evaluating the effect of pH on volume of the biogas, a chart is presented in Figure 4.2 below.

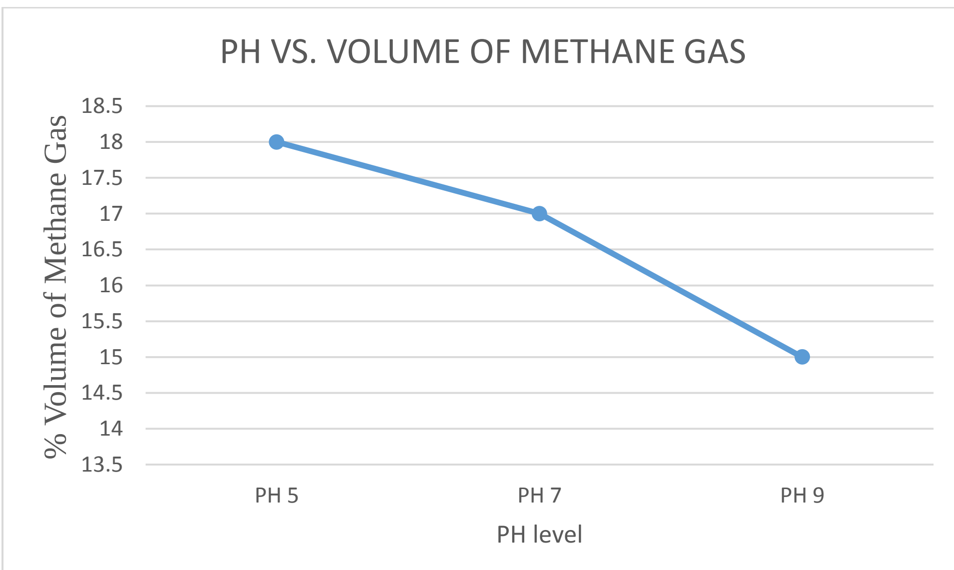


Figure 4.2: Effect of pH on Volume of Biogas

From the results presented above, it is clear that when pH is increased from 5-9, the volume of methane decreases from 18%-15% indicating an increase in pH leads to decrease in methane volume. This indicates that a pH of 5 gives the maximum yield of methane while an increase reduces its volume. Extremes of both acidity and alkalinity affects the methane bacteria. Therefore the optimum pH value range between 6.6 to 7.6.

4.2.1 Effect of Temperature on Volume of Biogas

Evaluating the effect of temperature on the volume composition of biogas, Figure 4.3 below displays the results.

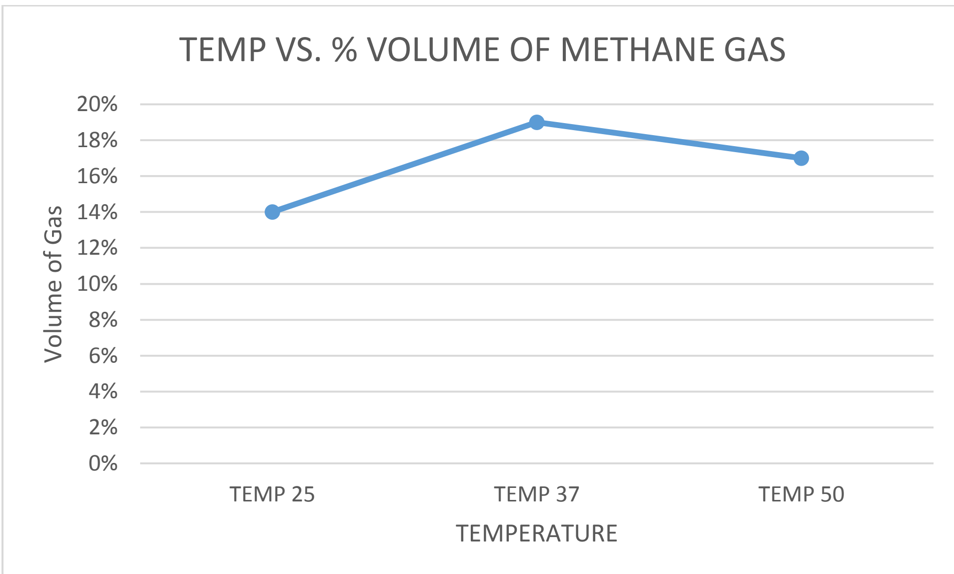


Figure 4.3: Temperature vs Volume

Results as indicated in Figure 4.3 reveal that an increase in temperature from 25-37 ^{0}C leads to an increase of methane gas by volume from 14%-19%. The volume reduces to 17% when the temperature is increased to 50 ^{0}C. This indicates that 37 ^{0}C is the optimum temperature for methane gas. Gas production and rate of biomass conversion are related to temperature. It is evident that biogas generation is at peak at mesophilic conditions of 35°C (95°F). There is rapid decrease in biogas production at lower temperature of 25^{0}C and also at thermophilic conditions of 50^{0}C. The digestion process is exothermic therefore heat is released, to attain the mesophilic conditions less heat is required. Mesophilic bacteria is more stable than thermophilic bacteria.

4.2.2 Effect of Retention Time on Volume of Biogas

Adequate time is require for the digestion of the substrate this promotes microbial activity to transform biomass to biogas. Digestion time is determine by the quantity of biomass available in the digester. This study therefore sought to investigate the effects of retention time on biogas production. In evaluating the retention time and its effects on biogas volume, Figure 4.4 below presents the results.

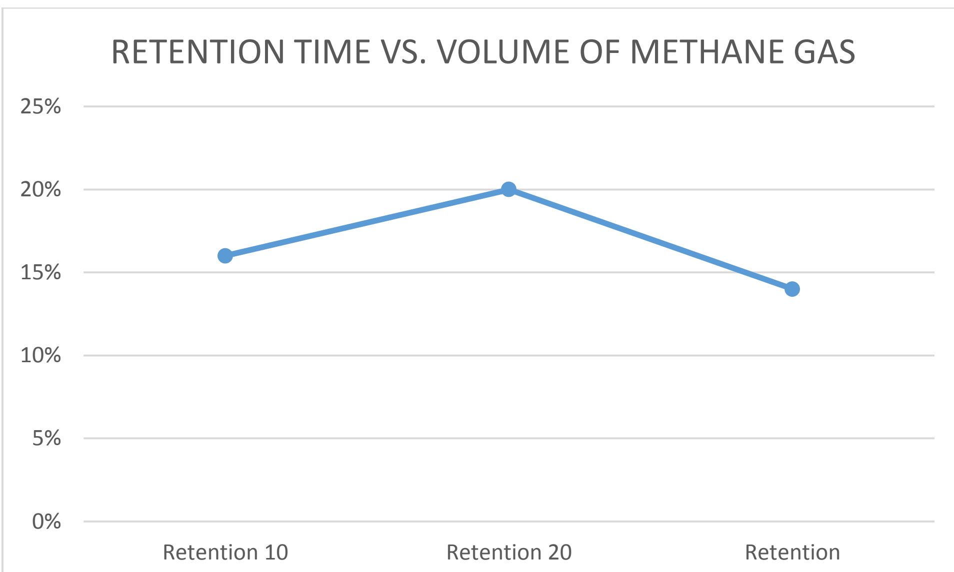


Figure 4.4. Retention time vs. Biogas volume

Results as indicated in Figure 4.4 above reveal that methane gas increases from 16%-20% upon increasing retention days from 10-20 days. However, the volume decreases to 14% upon increasing the days to 30.

4.2.3 Factor Analysis

Factor analysis was used reduce the large number of variables from the sample tests that were done at various temperatures, pH, and retention time. There were 27 sets of experiments done on the samples. The factor analysis utilized principal component analysis as the extraction method.

Table 4.3 below presents the results.

Table 4.1 KMO and Bartlett's test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.483
Bartlett's Test of Sphericity	Approx. Chi-Square	2.020
	df	26
	Sig.	.918

Results presented in Table 4.2 reveal that there is no significant effect of retention time, temperature and pH as the p-value is .918 which is greater than 0.05 significance value. Kaiser-Meyer-Olkin Measure of Sampling Adequacy value is 0.483 which is lower the minimum 0.6 which is suggested. Bartlett's Test of Sphericity value is 2.02 which indicates that the identity matrix has failed and thus the test fails for these variables to support the production of biogas in the samples collected.

Table 4.2 Correlation Matrix

Correlation Matrix					
		Temperature	pH	Retention time	Methane
Correlation	Temperature	1.000	0.000	0.000	.221
	pH	0.000	1.000	0.000	-.162
	Retention time	0.000	0.000	1.000	-.081
	Methane	.221	-.162	-.081	1.000

Results as indicated in the Table above reveal that there is a weak correlation of temperature on biogas production on the samples taken from the factory. Temperature has a weak positive correlation while pH and retention time are negatively correlated with Biogas production for the samples tested.

Study results indicate that there is an insignificant effect of control group variables (temperature, pH and retention time) on the volume of biogas produced. Their p-value was 0.918 which was less than 0.05 significance level. There was a weak positive correlation between temperature and biogas volume produced.

CHAPTER FIVE

DISCUSSION

The study sought to investigate the production of biogas from tea waste at DL Koisagat tea factory. The objectives guiding the study focused on estimating the quantity of tea waste at the factory, determine the optimum conditions of Temperature, pH and retention time on biogas production and estimate the potential of biogas production at the factory.

In estimating the quantity of tea waste produced at the factory, the study found out that the factory had a daily average of waste tea produced of 109.50kgs. This indicated that the amount of tea waste produced by the factory was high enough to be utilized in biogas generation. In establishing the optimum conditions of biogas production, the study found out that three conditions were most prevalent and would have an impact on biogas production. The study found out that temperature, retention time and pH played a role in biogas production since it utilized anaerobic digestion process which works on limited conditions. The study tested samples and carried out the process of biogas production at varied conditions of temperature, pH and retention time. It was found out from the research that an optimum pH of 7 yielded the highest amounts of biogas while a temperature of 25-37^{0}C was found to yield more volumes. An increase in temperature was found to reduce the biogas volumes. The optimum retention time was found to be between 10-20 days as this yielded the maximum biogas volumes while an increase in days above 20 had no effect on the volumes produced.

Production of biogas from waste tea leaves is a viable process, at pH 5 the production is higher compare with pH of 7 and 9. At this pH of 5 also oxygen, nitrogen and ammonia are relatively higher than methane. Growth of micro-organisms in anaerobic digester is affected by pH. Therefore to promote the rate of biogas generation, the digester is maintained at optimum pH of between 6.8-7.2 by monitoring loading rate. As fermentation process takes place CO_2 and fatty acids produced as by-products of the process lower the digester pH.

Methane gas is highly produced at the temperature of 37 ^{0} C compared with temperatures of 25^{0}C and 50^0 C, although oxygen, nitrogen and ammonia are still higher. The findings concur with (Trowbridge, 2013), that the digester temperature affects the quantity of biogas produced. Within the three temperature ranges of thermophilic, mesophilic and psychrophilic, mesophilic works best for digester microbes.

Waste tea leaves substrate at retention time of 20 days produces relatively high methane. This indicates that micro-organisms and substrate are at equilibrium. Efficiency of methane gas can be improved by removing the gas mixture. Ammonia can be remove by condensation of the gas mixture through cooling water to absorb ammonia gas. Carbon dioxide will be separated by passing the gas through NaOH solution to absorb it. While hydrogen sulphide will be eliminated by scrubbing the gas using Iron or Steel wool. Oxygen is removed by passing the gas through Iron (II) oxide which gets oxidized by consuming oxygen. Nitrogen is eliminated by contacting the gaseous mixture with lithium.

For longer retention time, large volume digesters are required which increase the capital investment costs, while short retention time can cause washout of active micro-organism population. For optimum conditions of production, medium digesters are best because of cost and proper utilization of microbes.

In establishing the potential of the tea factory to produce biogas, the study findings reported that the tested samples yielded very little gas volumes as the three optimum conditions reached had no significant influence on the increase on gas volumes. The samples taken in this case despite the optimum conditions, resulted to low percentage of methane gas that would allow large scale production of biogas. The results clearly reveals that essential benefits will be achieved if conditions favoring optimum gas yield are met. Thus, the temperature, retention period and pH of the tea waste should be set for optimum biogas production.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This section presents the summary and conclusion of the results that were obtained in the study. The study aimed at investigating the production of biogas from tea waste at DL Koisagat Tea factory. The study focused on three key objectives which included; estimating the amount of waste produced at the factory, determining the optimum conditions of temperature, pH and retention time on biogas production and estimating the potential of biogas production at the factory.

6.2 Summary

The study sought to investigate the production of biogas from waste tea leaves at DL Koisagat Tea Factory in Nandi hills. The study was guided by three objectives which included; estimating the amount of waste tea produce at the factory, determining the optimum conditions of temperature, pH and retention time of biogas production and estimating the potential of biogas production at the factory.

The study findings established that the daily average weight of tea waste collected on daily basis from the factory was 109.5 kgs. The study findings revealed that the biogas produced was composed of five gases namely; methane, nitrogen, carbon dioxide, ammonia, hydrogen sulphide and oxygen. Nitrogen and Ammonia with 25% while oxygen (23%) are the gases with highest volume in the biogas. Hydrogen sulphide has the lowest with 17%. The means are calculated under all the set conditions of temperature, pH and retention time. An increase in pH led to decrease in methane volume. This indicated that a pH of 7 gave the maximum yield of methane while an increase reduces its volume. On evaluating the effect of temperature on biogas production, the study revealed that an increase in temperature from 25-37^{0}C leads to an increase of methane gas by volume from 14%-19%. The volume reduces to 17% when the temperature is increased to 50^{0}C. This indicates that 37^{0}C is the optimum temperature for methane gas. The findings also established that methane gas increases from 16%-20% upon increasing retention days from 10-20 days. However, the volume decreased to 14% upon increasing the days to 30. Results from the factor analysis indicated that there was no significant effect of the optimum conditions on volume of biogas produced from the tested samples. The volumes of methane were found to be too low to allow commercial production of the gas.

6.3 Conclusions

As per the results reported in this study, the factory produces approximately 2847.00kgs per month. This quantity of waste is sufficient to cause environmental degradation. Also the factory produces enough biomass for generation of biogas. The highest yield was obtained at 37 degrees Celsius, pH of 7 and retention time of 20days. This was attributed to the rapid growth of bacteria required to breakdown organic matter into biogas and also the digester stability. The highest quantity of methane was achieved at pH of 7, temperature of 50^{o}C and retention time of 20 days but also with high impurity of carbon dioxide which inhibits combustion.

Biogas technology from tea waste provides a very attractive way of utilizing certain groups of agricultural biomass for satisfying energy needs. Proper biogas systems provide solution to environmental degradation due to tea industry solid wastes and also enhance clean energy source. Biogas is produced from anaerobic degradation which is an ancient technology used in industrial waste treatment and sludge stabilization. The anaerobic digestion process involve a group of microorganisms which depend on other factors such as pH, retention time and temperature making the process slower. Other limitations of the digester include low loading rate, Lack of process stability and time taken to recover after failure. Based on this, the anaerobic digestion process is a slow process prompting design of large digester hence increasing cost.

6.4 Recommendations

The quantity of waste generated from the factory on daily average was a significant amount enough to cause environmental degradation if not properly disposed. Therefore, the factory management should ensure that there are proper solid waste management practices that will help in preventing possible pollution from such waste. However, upon carrying out various tests, the waste tea had potential to produce 19% of methane. Comparing the quantity of methane produced with its use as a source of energy, methane generation with purification will enable the factory to save the cost of energy and also conserve environment. The study findings therefore recommend that the tea waste produced to be mixed with other materials to increase the methane gas volume to allow biogas production from the plant. Also, the study recommends that the factory should consider employing cleaner production techniques like waste segregation and waste reduction at the source. For a proper reuse of the tea waste, the factory management can also consider solidifying and using the tea waste as fuel in the factory. Additionally, there is need for further research to improve on the gas quality of methane.

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APPENDICES

Appendix I: Quantity of waste tea

Date	Quantity of tea processed (kgs)	Weight of gunny bag (kgs)	Weight of gunny bag + waste tea (kgs)	Weight of waste tea (kgs)
24/08/2016	61,287.92	0.63	114.24	113.61
31/08/2016	83,686.67	0.57	125.07	124.50
07/09/2016	62,732.50	0.62	97.77	97.15
14/09/2016	71,387.69	0.60	103.33	102.73

Appendix II: Percentage by Volume

Experiment Sets	CH4
PH-5	**18%**
TEMP-25	**15%**
10	14%
20	17%
30	15%
37	**16%**
10	14%
20	18%
30	17%
50	**22%**
10	16%
20	35%
30	14%
7	**17%**
25	**12%**
10	10%
20	15%
30	10%
37	**26%**
10	34%

20	27%
30	16%
50	**13%**
10	12%
20	12%
30	14%
9	**15%**
25	**14%**
10	10%
20	20%
30	11%
37	**16%**
10	12%
20	19%
30	16%
50	**17%**
10	18%
20	16%
30	16%
Average	**17%**

LEGEND

Color codes:

Temperature pH Retention time

Appendix III: Similarity Index/Anti-Plagiarism Report

Turnitin Originality Report

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