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RESEARCH ARTICLE

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Production of Biogas from Waste Tea Leaves: A Case of Integrated Waste Management at DL Koisagat Tea Factory, Nandi Hills

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Abstract

Waste tea leaves from tea factories are used as manure and the rest discarded on the surface. Decomposition of these dumped wastes produce methane into the environment and affect the quality of ground water through coloration. Considering environmental degradation caused by tea factories, it prompted the need for waste management and alternative sources of energy other than wood in the tea factory. Waste tea leaves are 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. This study aimed at determining the quantity of waste tea produced daily in the factory. It also sought to determine the optimum conditions of retention time, pH, and temperature required in generation of methane gas. The factory waste tea 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)in the ratio of 1:2 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 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 produced biogas with 19% methane. The optimum conditions of pH, temperature and retention time have the potential to generate biogas from waste tea. Methane produced contained impurities of carbon dioxide, ammonia and hydrogen sulphide gases. Purification process of methane increased the cost of production. It was recommended that tea factories should use waste tea leaves for production of energy to run the factory instead of wood and for further research to enable the factory generate clean energy at lower cost.

Keywords: Biogas, Tea Leaves Waste, Integrated Waste Management and Factory

INTRODUCTION

Waste is unusable and unwanted substance and is regarded as a material that is of no purpose. Waste which exists in environment is 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 toxic, fluids, solid and hazardous. Societies are prone to problems associated with waste disposal. Waste management practices vary depending on the place of production like developing and developed countries, industries and residences, rural and urban areas.

Waste from agricultural sector maybe from the 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 have some harmful chemicals or other substances arising from the processing itself (Hilkiah *et al*., 2008). Coffee, tea, cotton and other agricultural products have wastes 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 biogas, which is clean source of energy, through anaerobic digestion. Biogas has the characteristics of being colourless and odourless gas with calorific value of 20 MJ/m^3 and ignition temperature range of 650 to 750^{o}C 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 increasingly been recommended for adoption as a clean source of energy. Biogas generation is mainly conducted under mesophilic conditions in dome shaped bio digesters 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 composition 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 to avoid environmental pollution of any kind. Waste management is the process of collection, transportation and disposal of sewage, garbage and other waste materials. 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.

In this study, a focus was on waste tea 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. This has resulted in most areas in the Rift valley region have embraced tea farming amongst other areas like Mount Kenya and other areas with favourable climate in the country. Various tea processing plants have been set across the country to help the farmers to 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 tea wastes that are mainly used as manure in tea farms because of less effective management technologies available. This waste can be converted into useful resources that enable both waste management and production of clean source of energy. Tea wastes are the wastes derived from tea factories as a result of tea losses. They include buds, leaves discarded and tender stems tea plant (Meres *et al.*, 2004). Tea waste if not properly disposed off, it will result in environmental pollution; ground water will be coloured increasing its turbidity, soil structure and texture will also be affected and increase in dust present in air.

There are two types of tea wastes that are produced and they include; Factory Tea Waste (FTW) and Decaffeinated Tea Waste

(DCTW). Mainly fiber part of leaves is not used during tea processing hence removed and discarded. This waste sometimes contains leaves and dust. Tannic acid presents 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) which is obtained after extraction of caffeine from waste tea contains less quantities of tannic acid.

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 *et al.*, 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 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 start to lose water and therefore wilt 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 in oxidation reaction.

Polyphenols, enzymes amino acids, carbohydrates, minerals methylxanthines, pigments and many aromatic compounds and volatile flavour are the compounds that give the fresh tea leaves aroma, taste, flavour 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.

A tea factory produces large quantities of tea waste, but tea waste management system is less effective in the country. These wastes accumulate in the factory dump sites to large quantities of waste. This result in pollution of ground water as it alters water turbidity. Also, the chemical composition of tea leaves leads 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 disposed off to the environment decay resulting in change in soil quality. Dust from waste tea is blown off by wind thus resulting in air pollution.

DL Koisagat uses various sources of energy like biofuels and electricity which are quite expensive. The fact that the factory uses 12 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 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 investigated the production of biogas from tea waste as an integrated waste management approach at DL Koisagat Tea Factory.

Industrialization comes with pollution, tea factories emit dust, produce waste tea leaves, use wood as the main source of energy and emission of stack 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 due to limited pollution from the factory and also supply of surplus of clean energy. The factory will be able to meet Environmental Act 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 offer an alternative to the use of wood and biofuels. 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.

RESEARCH METHODOLOGY

Study Area

The study area was DL Koisagat Tea Factory in Nandi County, Nandi Hills Sub-county, Kenya. Nandi County 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° 11' N, 35° 08' E. Koisagat Tea Factory is situated 14.7 km from Nandi Hills Town off Himaki road and some 307 km from Nairobi (capital city) at an altitude of 2047 m 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 enables it have two cropping seasons. Long rains season starts in February/ March to June while short rains starts in the month of August to November with annual rainfall range of 1020 mm and 1550 mm. The mean temperature of the area is between 16.20^0C and 21.60^0C. The main economic activity of Nandi Hills is farming; the residents major mainly in tea farming. The choice of the area was based on its accessibility.

Research Design

The study adopted an experimental research design which provided in both fact finding and formulation of significant principles of knowledge and solution. The main goal was to investigate the production of biogas from tea waste at DL Koisagat Tea Factory. The results achieved through descriptive statistics give 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.

Field Collection

Determinants of quality of waste tea leaves generated from as many different piles of waste as possible. Together with this, double the quantity of waste tea needed was sampled during each trip.

The main reason of these actions was to ensure that the sample collected was as representative as possible of the waste tea at the factory. 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.

Procedure Used for Biogas Production

The digestion procedure was obtained from Standard Operation Procedure (SOP) from Laboratory for Environmental Engineering of 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: 100 kg and 2 kg, 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 1:2 (Inoculum + water). Weight of 4.5 kg of waste tea was measured 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 50 cm 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 1.6 L mark in the reactors where the pH and temperature of each reactor was adjusted according to the table below. The reactor bottles were cocked then shaken gently to prevent clumping.

A combination of 27 experimental sets were tested after being set at various pH, temperature and retention time. The tests were done at a temperature of 25^0C, 37^0C and 50^0C. 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 for the days in the table above.

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 analysis.

Determination of Gas Quality

The GC-MS 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 were 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 250^0C and time for the separation as 10 minutes. The starting temperature was entered as 100^0C and hold time as 1 minute, ending temperature as 250^0C 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 was 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 were determined. Chromatogram enabled the calculation of peak areas. The mass that passed through the detector was proportional to the peak areas. This enabled in development calibration curve of the component.

RESULTS AND DISCUSSION

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 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.

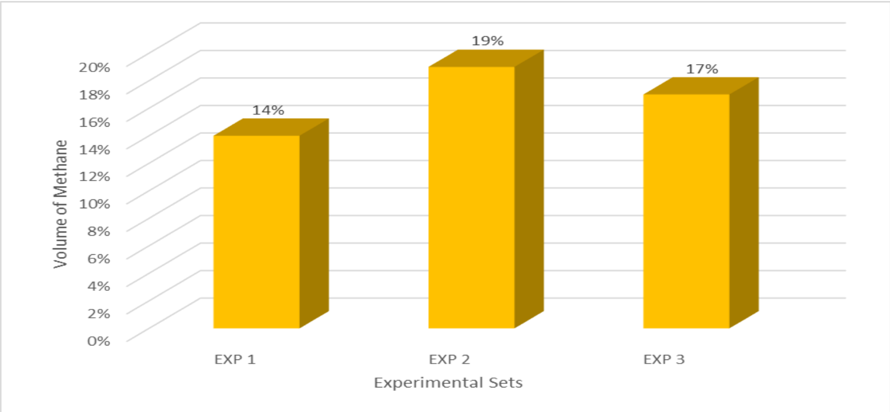

Figure 1: Content % of Biogas Composition on the Three Experimental Setups.

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 25^0C, set 2 at 37^0C while set 3 was maintained at 50^0C. Figure 2 above presents the averages in percentage volume of the biogas. From this figure 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. The means are calculated under all the set conditions of temperature pH and retention time.

Effect of pH on Volume of Biogas

From the results, it is clear that when pH was increased from 5-9, the volume of methane decreased from 18%-15% indicating an increase in pH led to decrease in methane volume. This indicates that a pH of 7 gave maximum yield of methane while an increase reduced its volume. Extremes of both acidity and alkalinity affected the methane bacteria. Therefore, the optimum pH value ranged between 6.6 to 7.6.

Effect of Temperature on Volume of Biogas

Evaluating the effect of temperature on the volume composition of biogas, it revealed that an increase in temperature from 25-37^0C led to an increase of methane gas by volume from 14%-19%. The volume reduced to 17% when the temperature increased to 50^0C. This indicates that 37^0C was the optimum temperature for methane gas. Gas production and rate of biomass conversion are related to temperature. It is evident that biogas generation was at peak at mesophilic conditions of 35°C (95°F). There is rapid decrease in biogas production at lower temperature of 25^0C and also at thermophilic conditions of 50^0C. The digestion process is exothermic therefore heat is released; to attain the mesophilic conditions less heat is required. A mesophilic bacterium is more stable than thermophilic bacteria.

Effect of Retention Time on Volume of Biogas

Adequate time is required for the digestion of the substrate this promotes microbial activity to transform biomass to biogas. Digestion time is determined by the quantity of bimass available in the digester. This study therefore sought to investigate the effects of retention time on biogas production.

Results revealed that methane gas increased from 16%-20% upon increasing retention days from 10-20 days. However, the volume decreased to 14% upon increasing the days to 30.

Factor Analysis

Factor analysis was used to 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 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 1 reveal that there is no significant effect of retention time, temperature and pH as the p-value is 0.918 which is greater than 0.05 significance value. Kaiser-Meyer-Olkin Measure of Sampling Adequacy value is 0.483 which is lower than 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 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 2 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. There p-value was 0.918 which was less than 0.1 significance level. There was a weak positive correlation between temperature and biogas volume produced. Retention time and pH had negative effect on the volume of biogas produced on the tested samples.

DISCUSSION

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. The research findings found out 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 compared 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 removed 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 gas 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 result clearly reveals that essential benefits will be achieved if conditions favouring optimum gas yield are met. Thus, the temperature, retention period and pH of the tea waste should be set for optimum biogas production.

CONCLUSION AND RECOMMENDATIONS

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%) were the gases with highest volume in the biogas. Hydrogen sulphide was 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 reduced its volume. On evaluating the effect of temperature on biogas production, the study revealed that an increase in temperature from 25-37^{0}C led to an increase of methane gas by volume from 14%-19%. The volume reduced to 17% when the temperature is increased to 50^{0}C. This indicates that 37^{0}C was 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.

Conclusion

The factory produces enough biomass for generation of biogas. The highest yield was obtained at 37^{0}C, pH of 7 and retention time of 20 days. 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 ways 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 involves 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. It was further concluded that optimum conditions of pH, temperature and retention time have a potential to produce methane gas.

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 off. 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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