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Biogas Production Potential from Coffee Wastewater

A case study of Gatomboya Wet Coffee Factory

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Abstract

Kenya is a major producer of coffee in east Africa with about 70% production done by small scale farmers (Mutua 2000). Among the arrears where coffee farming and production is done is at Karatina town in Nyeri County. This research with Gatomboya wet coffee factory in Karatina as the focus of the case study.

Wet coffee processing is the most widely used technique in almost all factories in Kenya, with Gatomboya being inclusive. It is estimated that coffee processing generates about 9million m^3 of wastewater and 600,000 tons of husks annually in East Africa region (Amelia et al., 2010). Such a large amount of wastewater can be used to generate bioenergy. This would ensure less water goes to waste since it is being recycled and the energy produced can even be used for the coffee wet processing altogether.

The aim of the research was to evaluate the feasibility of biogas production potential from coffee wastewater. This was through doing a case study on Gatomboya wet processing mill in Nyeri County whereby sample collection is done from the above factory. Laboratory tests such as COD and BOD were determined for the wastewater sample and the BOD/COD ratio calculated to determine whether the wastewater sample is biodegradable hence suitable for biogas production.

The BOD/COD ratio of the wastewater sample collected was found to be 0.49 which inferred that the coffee wastewater sample is biodegradable hence a potential of biogas production (Gilbert, E., 1987).

Dedication

This project is dedicated Dr. Daniel Munga and Mrs. Agnes Mturi

Acknowledgement

My deepest gratitude also goes to my project supervisor Eng. Kandie Kipkoros for the assistance and willingness to supervise my research, for his guidance and useful comments.

I would like to thank the management at Gatomboya coffee factory in Karatina, for their assistance and hospitality during my visist there for information and sample collection.

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Contents

List of Tables

List of Figures

Acronyms

GHS	Green House Gases
GW	Gigawatt
KWh	Kilowatt-hour
MWh	Megawatt-hour
DM	Dry matter
VS	Volatile solids
CO_2	Carbon dioxide
CSTR	Continuous flow stirred-tank reactor
UASB	Uplow Anaerobic Sludge Blanket

Chapter 1

1.0 Introduction

1.1.Background of the Proposed Project

In the 20th century, the world economy has been dominated by technologies that depend on fossil energy, such as petroleum, coal, or natural gas to produce fuels, chemicals, materials and power. The continued use of fossil fuels to meet the majority of the world's energy demand is threatened by increasing concentration of CO_2 in the atmosphere and concerns over global warming. The combustion of fossil fuel is responsible for 73 % of the CO_2 emission (Wildenborg and Lokhorst, 2005).

The heightened awareness of the global warming issue has increased interest in the development of methods to mitigate greenhouse gases (GHG) emission. Much of the current effort to control such emissions focuses on advancing technologies these are

- (i) reduce energy consumption,
- (ii) increase the efficiency of energy conversion or utilization,
- (iii) switch to lower carbon content fuels,
- (iv) enhance natural sinks for CO_2, and
- (v) capture and store CO_2.

Reducing use of fossil fuels would considerably reduce the amount of CO_2 produced, as well as reduce the levels of pollutants. As concern about global warming and dependence on fossil fuels grows, the search for renewable energy sources that reduce CO_2emissions becomes a matter of attention.

Interest in alternative transportation fuels are growing due to oil supply insecurity and its impending peak, and the imperative to lower GHG emissions from fossil fuel use in order to stave off adverse global climatic changes (Farrell *et al.*, 2006). The main contributors to air pollution are vehicular emissions of GHG and particulate matter. Renewable energies are essential contributors to the energy supply portfolio as they contribute to world energy supply security, reducing dependency of fossil fuel resources, and providing opportunities for reducing emissions of GHG. Energy security and climate change imperatives require large-scale substitution of petroleum-based fuels as well as improved vehicle efficiency.

Replacing petroleum with biofuel can reduce air pollution, improve rural economies by creating job opportunities and raising farm incomes, diversify energy portfolios, minimize dependence on foreign oil and improve trade balances in oil-importing nations. To reduce the net contribution of GHGs to the atmosphere, bioethanol has been recognized as a potential alternative to petroleum derived transportation fuels and cooking fuels.

Biomass is a potential renewable energy source that could replace fossil energy for transportation. Biomass is solar produced organic matter such as wood, agricultural byproduct energy crops such as fast-growing trees and grasses, municipal wastes, paper mill sludge and living-cell materials (algae, sewage, etc.). Biomass is naturally plentiful and renewable. Coffee pulp is also among the potential biomass resources for bioethanol production**.**

Bio refining of waste biomass involving the integrated production of chemicals, materials and bioenergy is a potential alternative for adding significant economic value to the waste as a bio resource. In the21st century and beyond, bio-resource based economy is envisaged globally as a strategy towards achieving social, economic and environmental sustainability. Agriculture will be core to the bio-resource based economy, providing source of raw materials, which are sustainable, plentiful and inexpensive for utilization in bioprocesses for the production of bio products. In the Eastern Africa's (EA) economy, agriculture is the mainstay and currently accounts for about 80% of the rural incomes, and coffee is among the important cash crops. East Africa is currently producing about 600,000 tons of coffee beans annually. Crop production and processing activities are generating huge quantities of organic waste.

Coffee processing done by wet and dry methods discard away 99% of the biomass generated by the coffee plants at different stages from harvesting to consumption. This includes cherry wastes, coffee parchment husks, sliver skin, coffee spent grounds, coffee leaves, and wastewater. Wet processing uses up to15 m^3 of water to produce one ton of clean beans and for every ton of beans produced, about one ton of husks is generated. It is estimated that coffee processing is generating about 9 million m^3 of wastewater, and 600,000 tons of husks annually in the East Africa region (Amelia et al., 2010)

The increasing rate at which fossil and residual fuels are releasing CO_2 into the atmosphere has raised international concern and has led to intensive efforts to develop alternative, renewable, sources of primary energy.

The solar energy stored in chemical form in plant and animal materials is among the most promising alternative fuels not only for power generation but also for other industrial and domestic applications on earth.

Biomass absorbs the same amount of CO_2 in growing that it releases when burned as a fuel in any form. The term ‘biomass’ refers to all biodegradable organic matter that can be recycled into energy or returned to soil: agricultural waste and residues or by-products from the food and beverage industry, sludge from municipal and industrial wastewater treatment plants, wood from forests and recycling processes, the organic fraction of domestic waste, as well as energy crops, algae, etc. Biomass contribution to global warming is zero. In addition, biomass fuels contain negligible amount of sulphur, so their contribution to acid rain is minimal. Over millions of years, natural processes in the earth transformed organic matter into today's fossil fuels: oil, natural gas and coal. In contrast, biomass fuels come from organic matter in trees, agricultural crops and other living plant material. CO_2 from the atmosphere and water from the earth are combined in the photosynthetic process to produce carbohydrates that form the building blocks of biomass. The solar energy that drives photosynthesis is stored in the chemical bonds of the structural components of biomass. If we burn biomass efficiently oxygen from the atmosphere combines with the carbon in plants to produce CO_2 and water. The process is cyclic because the carbon dioxide is then available to produce new biomass.

Unlike any other energy resource, using biomass to produce energy is often a way to dispose of biomass waste materials that otherwise would create environmental risks. Today, there are ranges of biomass utilization technologies that produce useful energy from biomass.

- Direct Combustion
- Gasification
- Anaerobic Digestion
- Methanol & Ethanol Production

There are a number of challenges that inhibit the development of biomass energy. In this regard, formulation of sustainable energy policy and strategies in addressing these challenges is of importance for the development and promotion of biomass energy.

1.2.Statement of the problem

Due to the increase in the price of petroleum, crude and products, and environmental concerns about air pollution caused by the combustion of fossil fuels, the search for alternative fuels has become vital. The use of food crops (like maize) for biofuel production may cause inflation of cost of these crops leading to food insecurity. To alleviate such problems, alternative and non-edible agricultural products must be investigated.

The coffee plant, which is indigenous to Kenya, produces coffee fruit (bean) at different seasons per year. The bean represents about 40 % of the fruit; the other 60 % is generally discarded as waste (pulp and mucilage). Coffee pulp represents the most abundant and nonedible agricultural waste obtained after pulping ripe fruit**.** Kenya is currently producing about 50,000 tons of coffee beans on average for the past 6 years. Use of coffee wastewater and other by-products has become a priority in coffee producing countries for economic, ecological and social reasons.

1.3. Goal and Objectives

The goal of this study is to determine energy production potential / opportunity in coffee wastewater.

There are several barriers that need to be overcome in order to promote large-scale biogas use and production in Kenya. The main obstacles for uptake of this technology so far have been a lack in awareness on the side of potential investors and policy makers about the viability of biogas as a source of electricity and other sources of energy. There are specific goals and objectives arising from these barriers.

1.3.1. Specific Goals and Objectives

1. To provide estimates of the potential of biogas in Kenya based on a site-specific data for small-scale farmers in Nyeri County referring here to Gatomboya wet coffee factory as the area of case study.
2. Measure the BOD/COD ratio of the coffee wastewater sample, as an indication of its biodegradability.
3. To evaluate the suitability of coffee wastewater for biogas production.
4. Establishment of an integrated model of bioethanol and biogas production from coffee pulp and coffee wastewater from a wet coffee processing factory.

1.4 Brief approach methodology

1. A field visit to Gatomboya coffee factory
2. Establish sampling points for sample analysis
3. Laboratory testing to determine the potential production of biogas from the coffee wastewater sample

1.5. Limitations of study

The above study is limited only to a small sample size hence problems that may arise due to large-scale bioenergy production will not been known. Also, large-scale production is less efficient hence a lesser amount of the biofuel is produced.

In addition, Gatomboya coffee factory mentioned above has no upflow anaerobic sludge blanket or any biogas reactor that is able to recycle the waste biomass into useful energy for use at the factory.

Chapter Two

2.0 Literature Review

2.1. General

"We're not going to be able to just drill our way out of the problem of high gas prices…If we are going to control our energy future, then we've got to have an ***all-of-the-above-strategy***. We've got to develop every source of American energy—not just oil and gas, but wind power and solar power, nuclear power, ***biofuels***." President Obama speaks of American energy supporting an "all-of-the-above" energy policy at the GBEP seminar da Bioenergia on March 20, 2013. (Gerald J. Ostheimer, Ph.D., USDA Foreign Agricultural Service.) "All-of-the-above" for bioenergy means developing agricultural resources where they do best. "All-of-the-above" is important for Bioenergy and Agriculture in West Africa. In parts of East Africa, it is important too though it is utilized on small scale. There are many sources of biofuels around the globe from plants, animals and their wastes. These include palm oil trees and guavas, which are a major source of biofuel in West Africa. In the US and the rural America livestock wastes are a major source of biofuel. In Honduras and Colombia USDA is promoting biogas as means to energy access and bio waste management and the main emphasis is coffee waste.

In the 21st century, the world economy has been dominated by technologies that depend on fossil energy such as petroleum, coal, or natural gas for fuels, chemicals, materials and power production. As concern about global warming due to dependence on fossil fuels grows, increase in the price of petroleum and crude oil products, the search for renewable energy sources has becomes a matter of great importance. Replacing petroleum with biofuel can reduce air pollution, improve rural economies by creating job opportunities and raising farm incomes, diversify energy portfolios, minimize dependence on petroleum and improve trade balances in oil-importing nations.

To reduce the net contribution of greenhouse gases to the atmosphere, bioenergy has been recognized as a potential alternative to petroleum-derived transportation fuels and cooking fuels. Biomass is a potential renewable energy source that could replace fossil energy for transportation. The use of food crops for biofuel production may however cause inflation of cost of these crops leading to food insecurity. To alleviate such problems, alternative and non-edible agricultural products must be investigated.

Use of biomass from waste and waste water would be a great alternative and as such is the main objective of this proposed project. This entails refining of waste biomass involving the integrated production of chemicals, materials and bioenergy, and this is a potential alternative for adding significant economic value to the waste as a bio-resource. In the 21st century and beyond, bio-resource based economy is seen globally as a strategy towards achieving social, economic and environmental sustainability. Agriculture will be core to this bio-resource based economy, providing source of raw materials, which are sustainable, plentiful and inexpensive for utilization in process of production of bio-products. In the Kenyan economy for example, agriculture is the mainstay and currently accounts for about 80% of the rural incomes, with coffee among the important cash crops. Kenya is currently producing about 50,000 tons of coffee beans on average for the past 6 years. Crop production and processing activities are generating huge quantities of organic waste.

2.2 Potentials for biogas in Kenya

The data below is on theoretical potentials from 3 selected groups of biomass available from the agro-industrial business in Kenya and for municipal solid waste in Nairobi. Since the data is necessarily incomplete, and since future potentials are not considered, the actual potential could well be higher. Most promising sectors for electricity production from biogas from anaerobic digestion are:

Table 1 Possible installed electric capacities for major biogas potentials considered in this study

Potential installed capacity [MW]

	Mean	Min	Max
Municipal solid waste	37.5	11	64
Sisal production	20	9	31
Coffee production	10	2	18
Total all sub-sectors	67.5	22	113

The total potential installed electric capacity of all sub-sectors ranges from 29 to 131 MW, generating 202 to 1,045 GWh of electricity, which is about 3.2 to 16.4 % of the total Kenyan electricity production of 6 360 GWh as of 2007/08. The extent of actual realization of this potential will depend on the incentives provided for investment, in particular the tariff framework.

2.2.1. Background to Anaerobic Digestion

Anaerobic digestion is the conversion of bio-organic non-woody material, the feedstock (or the substrate), by micro-organisms in the absence of oxygen into stable and commercially useful compounds. The process is similar to composting except that composting is aerobic, involving oxygen in its breakdown of organic matter and does not produce useful energy. AD feedstock is often unwanted wastes such as slurry or deliberately produced energy crops (such as maize silage) grown specifically for feeding the AD plant. The products from the digestion process are:

- Biogas. This is a mixture of about 60% Methane (CH_4), 40% Carbon Dioxide (CO_2) together with trace amounts of other gases. This is then combusted to generate electricity, heat or used as a road fuel.
- Digestate (soil conditioner, organic fertilizer). This is an inert and sterile wet product with valuable plant nutrients, such as ammonium compounds, and organic humus. It can be separated into liquor and fibre for application to land or secondary processing.

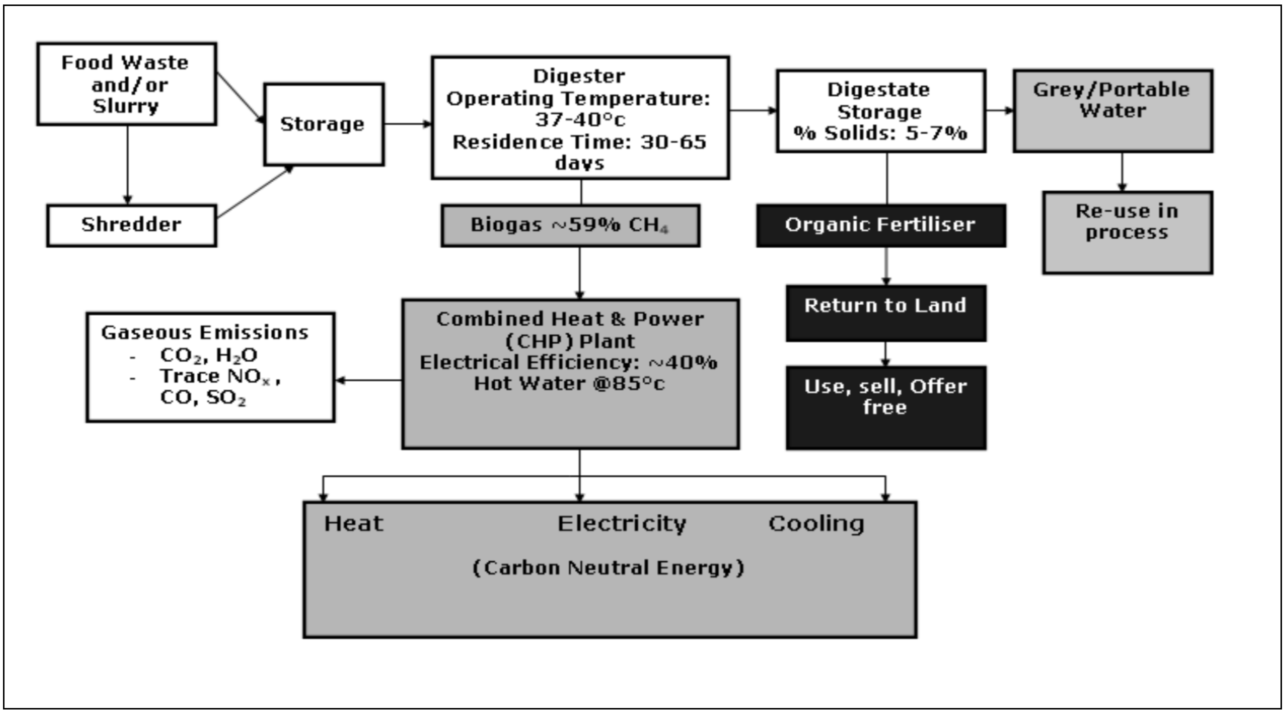

Figure 1 Anaerobic digestion

2.2.2 Anaerobic Digestion Process

The concept of anaerobic digestion simply involves putting a load of organic matter into a warmed airtight container and leaving it for a few days. The microbes in the matter will digest the non-cellulosic feedstock releasing methane (CH_4) and carbon dioxide (CO_2).

However, it is more complex than that if the operator is to achieve an efficient performance from the digester.

There are 4 key biological and chemical stages of Anaerobic Digestion:

1. **Hydrolysis;** is the process that breaks down the long chain carbohydrates into simpler soluble organic compounds (i.e. glycerol). This is the step in AD that takes the longest therefore it determines the retention time to be held in the digester vessel.
2. **Acidogenesis (acid fermentation)** bacteria then break the compound down directly into acetic acid.
3. **Acetogenesis.** If not broken down directly to acetic acid, it is first broken down to propionic butyric acid and long chain volatile fatty acids.
4. **Methanogenesis;** the hydrogen then binds with carbon molecules released from the acid digestion to make methane.

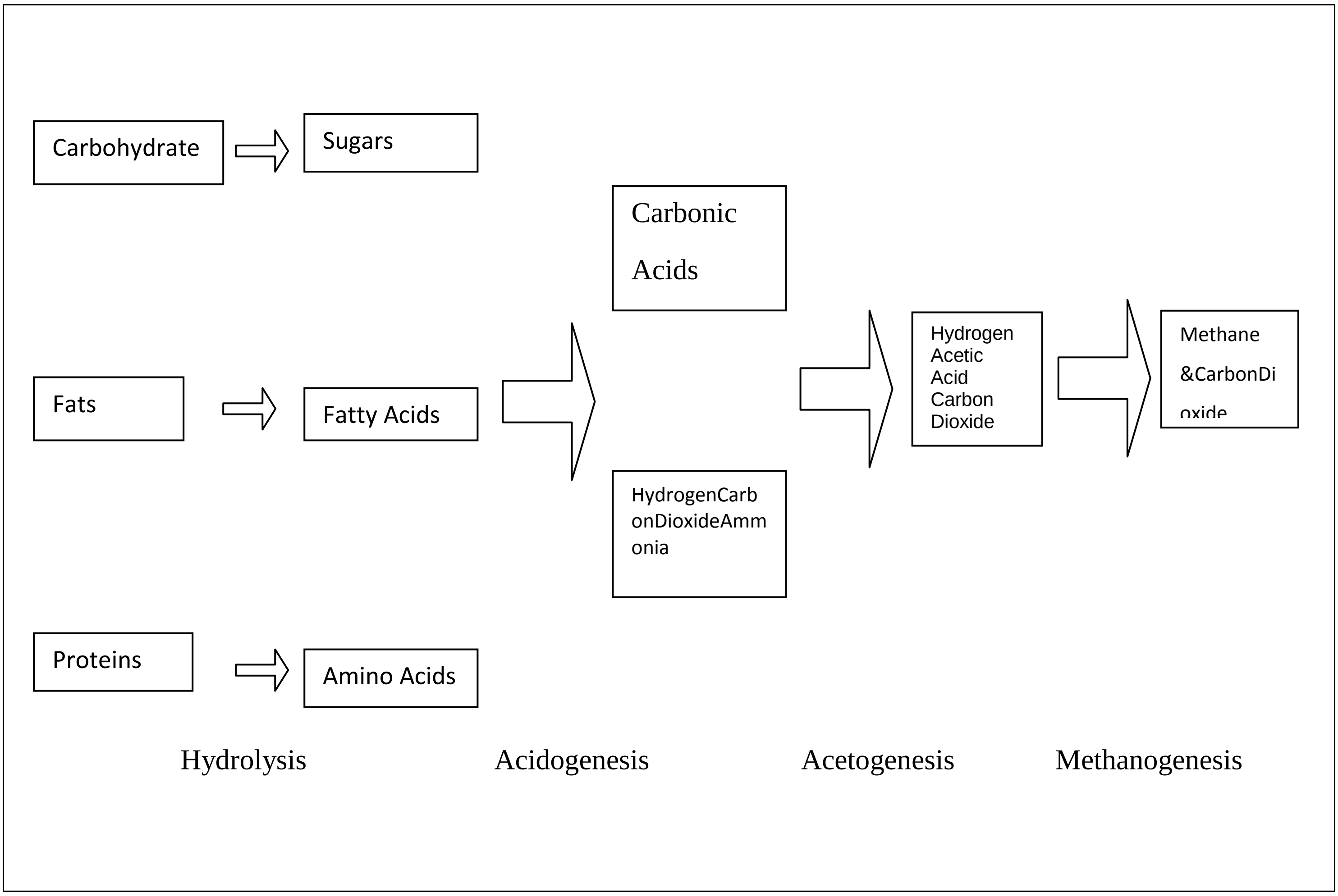

Figure 2 Biological and chemical stages of Anaerobic Digestion

The biogas product is primarily, 55-65%, Methane (CH_4) with the balance being Carbon Dioxide (CO_2) together with some minor gases such as hydrogen sulphide (H_2S) and ammonia (NH_4) and some moisture.

2.3. Characterization of substrates in biogas production

A list of the substrates and their average characteristics examined in this study is presented in Table 2 for solid substrates and in Table 3 for wastewaters. The suitability of different solid substrates for anaerobic digestion can be expressed by the methane potential per ton of fresh matter (FM). (DM = dry matter, VS = volatile solid)

Table 2 Characteristics (mean values) of solid agro-industrial wastes for anaerobic digestion

Substrate	**DM content [% FM]**	**VS content [% DM]**	**Biogas potential [m3/ton VS]**	**Methane content [%]**	**Methane potential [m3/ton VS]**	**Methane potential [m3/ton FM]**
Coffee pulp	20	93	390	63	244	45
Tea waste	78	97	358	55	201	54
Sisal pulp	12	85	523	60	330	37

For wastewaters the methane potentials per m^3 of wastewater are much lower compared to solid substrates due to the low content in organic material and high water content. Values range from 0.7 m^3 for nut processing wastewater to 22 m^3 for distillery stillage. Those values may vary strongly depending on specific technical preconditions of the processing.

Table 3 Characteristics (mean values) of agro-industrial wastewaters for anaerobic digestion

Substrate	**COD in wastewater [g/l]**	**COD degradability [%]**	**Biogas potential [m3/ton COD_{rem}]**	**Methane content [%]**	**Methane potential [m3/ton COD_{rem}]**	**Methane potential [m3/ton FM]**
Coffee processing wastewater	14.3	90	375	70	265	4.3
Nut processing Wastewater	4.3	70	330	75	250	0.7
Distillery Stillage	90	66	390	73	290	22
Sisal Decortications wastewater	11.5	87	475	84	400	4.3

The major disadvantage of wastewaters is the low energy density, but considering technical aspects they are easier to pump and to stir than solid substrates. If wastewaters are used in CSTR (Continuous stirred tank reactor) biogas plants a large digester volume for the fermentation process is needed. Thus, wastewaters are treated in customized wastewater treatment systems like UASB (Up flow anaerobic sludge blanket; the most common system), fluidized bed, fixed film, sequencing batch etc. Those systems are working with an immobilization of the microorganisms whereby the retention time and digester volume can be reduced.

2.4. Coffee Production and processing

This section presents a small review on the coffee process: from the moment when the grain is mature in the coffee plantation until it is ready to be exported. In addition, special attention is given to wastes derived from the coffee processing and the water use and the contamination caused by it.

2.4.1. The importance of coffee

Coffee is one of the most commercialized commodities worldwide. According to FAO coffee is among the 20 commodities that generated most money compared to other commodities in 2007. In total, 5.8 million tonnes were exported worldwide generating a value of 13.7 billion USDX.

The cultivation of coffee is the most important source of income for a large part of the rural population. During times of harvest (plucking), thousands of families go to the coffee plantations to offer their cheap labour and in this way earn some money. The coffee industry of Kenya is noted for its cooperative system of production, milling, marketing and auctioning coffee. About 70 percent of Kenyan coffee is produced by small scale holders. It was estimated in 2012 that there were about150000 coffee farmers in Kenya and other estimates are that six million Kenyans were employed directly or indirectly in the coffee industry. The major coffee growing regions in Kenya are the high plateaus around Mt. Kenya, The Aberdare Ranges, Kisii, Nyanza, Bungoma, Nakuru, Kericho and Ruwenzori Mountains.

2.4.2. Coffee plant

There exists a large variety of coffee plants. However, only two of them have been widely commercialized: the genus *coffea Arabica* and *coffea Canephora* (commonly known as *Robusta*). The first genus is categorized by its slow growth, delicate in growth and with less productivity rates than the *Robusta*; it is cultivated in mountainous regions. The high plateaus of Mt Kenya plus the acidic soil provide excellent conditions for growing coffee plants. The genus *Robusta* has higher production rates and it can be cultivated in less mountainous regions than the A*rabica*. The latter one characterizes itself for producing a fine and aromatic coffee XII. Coffee from Kenya is one of the ‘mild Arabica’ type.

2.4.3. Coffee fruit

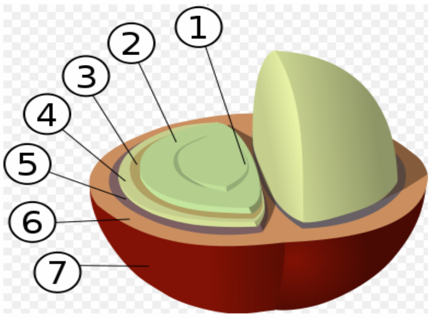

Figure 3 Coffee fruit

The fruit or cherry from the coffee, as is shown in the figure above consists of two grains which face each other with their flat surfaces. The pulp (6) or mesocarp and the external skin (7) or epicarp covers both grains. Each grain of coffee is covered by 3 layers, from the exterior to the interior these are: a layer of pectin (5), parchment (4) or endocarp and the silver skin (3) or spermoderm. Beneath these layers the green coffee bean is encountered.

The harvest season lasts for approximately 90 days. During this season, the workers (cherry cutters) spend several days close to the same coffee plant cutting those grains that have matured (red). After filling one basket of grains they pour the grains in a bag which after being filled is brought to the mill where the grain is being processed. There are two different methods which can be used to process the coffee cherries: the dry mill and the wet mill.

In the dry mill process, almost exclusively applicable to the genus *Robusta*, the grains are left in the open field to be sun-dried. After the grains have lost almost all their water content (from 65 % to 10-12 %.)After the cherries are dry, they are put through a dry mechanical pulping (or decorticating) process in which the green coffee bean is separated from the outer residue material (skin and husk) of the cherry. The dry process removes the upper hardcover (the husk) and the inner skin (parchment) in the milling process.

A mass of 100 kg of red cherries picked at 65 % moisture content will result in approximately 40kg of sun-dried coffee cherries delivered to the processing plant. Of this mass, about 17 kg will become sun-dried coffee beans while the remaining 23 kg will end up as residue at the processing plant (Yishak Seboka *et al*., 2009).

The process in the wet mill begins by bringing the coffee cherries in the previously described bags (filled by baskets) to a reservoir. From here on the cherries are transported by gravity to the de-pulping machines. This step can be enhanced with water, or can be performed dry (more environmentally friendly) when the reservoir has been designed to this purpose. In Nicaragua, the transport to the de-pulping machines is brought forth by water (and gravity). One major advantage of this method is that dirt, not-ripe and overripe grains will float on the water surface. In the de-pulping machines the cherries are selected based on their size and de-pulped, which is the process in which the pulp and the outer skin are removed. There remains a slimy layer around the coffee bean with a varying thickness of 0.5 to 2 mm. (Gieljam Schutgens, 2010)

For 100 kg of ripe cherries delivered to a washing plant, 60 % by mass ends up as washed coffee pulp with the remaining 40 % consisting of the green bean and endocarp (parchment). Of this 40% washed coffee cherry, only 20 kg remains after sun-drying of the bean and parchment. This is then shipped to the washed coffee processing facility where the parchment is removed. The result is 16 kg of washed coffee beans ready for export and 4 kg of parchment as residues (Yishak Seboka *et al*., 2009).

The average residue production per metric ton of wet red cherry is about 600 kg, i.e. based on green coffee bean production, the residue potential would be 1.4 times the mass of green beans produced (ESMAP, 1986). A wet processing result in a better quality of coffee products, as a result its share of the market is growing (Mutua, 2000).

Coffee is one of the most important agricultural cash crops in Kenya. It is produced by small scale farmers, cooperatives and large scale estates. The main harvest season is from October to December. After harvesting the coffee cherries are mainly processed by wet fermentation to obtain the parchment coffee (dried beans covered by paper-like coating). During this process large amounts of organic wastes like pulp and wastewater are produced. The pulp can be used as organic fertilizer. According to the Coffee Research Foundation in Kenya for each ton of parchment about 2.15 tons of pulp and 80 m^3 of wastewater (without recirculation of process water) are produced. In case of future change to more optimized fermentation methods with recirculation of process water the amount of wastewater would decrease drastically, but the amount of COD would be roughly the same.

The feasibility of anaerobic digestion of coffee wastes has been documented by many authors but the biogas yield tends to vary in literature. *Hofmann and Baier* reported a biogas yield of 380 m^3/t VS (57-66 % methane) from coffee pulp (16.2 % DM, 92.8 % VS) in lab scale batch experiments and a biogas yield of 900 m^3/t VS for semi continuous experiments. *Kivaisi and Rubindamayugi* reported methane potentials of 650 and 730 m^3/t VS of Robusta and Arabica coffee solid waste (mixture of pulp and husks). Different digester designs like CSTR, plug-flow and two stage systems (CSTR for hydrolysis, UASB for methanogenesis) can be used for the anaerobic digestion of solid coffee wastes.

The anaerobic treatment of wastewaters can be done by high performance reactor systems for wastewater treatment with immobilization of microorganisms. Due to fermentation processes, sugar compounds in the wastewater are converted into acids, leading to very low pH values in the wastewater. Thus, neutralization may be necessary before the anaerobic treatment.

The potential of biogas production from coffee wastes in Kenya is as below: according to the Coffee Board of Kenya 57,000 tonnes of parchment coffee were produced. Because 90% is processed by wet fermentation in Kenya, 51,300 t of parchment coffee are obtained by this fermentation method. Assuming that each ton of parchment is producing 2.15 t of pulp and 80 m^3 of wastewater the total amount of residues would be 145,125 t of pulp and4,104,000 $m^3$of wastewater per year. Table 2-4 summarizes the potential electricity production from coffee residues in Kenya.

Table 4 Potential methane yield, heating oil equivalent, electricity production and installed capacity from coffee wastes in Kenya

	Methane yield [m^3/a]	**Heating oil equivalent [tons/a]**	**Electricity production [kWh/a]**	**Installed Capacity [MW]**
Min	4,227,000	3,500	12,681,000	2
Max	41,027,000	34,000	147,698,000	18
Mean	**22,627,000**	**18,750**	**80,189,500**	**10**

2.5. Wastewater production process

Waste water from coffee processing is majorly produced from wet mill coffee processing method. The dry mill processing mainly utilises sunlight to dry coffee cherries.

The process in the wet mill begins by bringing the coffee cherries in the previously described bags (filled by baskets) to a reservoir. From here on the cherries are transported by gravity to the de-pulping machines. This step can be enhanced with water, or can be performed dry (more environmentally friendly) when the reservoir has been designed to this purpose. In some places for instance Nicaragua, the transport to the de-pulping machines is brought forth by water (and gravity). One major advantage of this method is that dirt, not-ripe and overripe grains will float on the water. In the de-pulping machines the cherries are selected based on their size and de-pulped, which is the process in which the pulp and the outer skin are removed. There remains a slimy layer around the coffee bean with a varying thickness of 0.5 to 2 mm. The separated pulp is then used for a variety of purposes or discarded as junk (increasingly rare) after which the grains are transported to fermentation reservoirs.

In the fermentation reservoirs the grains remain between 12 and 36 hours, depending on the temperature, the thickness of the mucilage layer and the concentration of enzymes. The mucilage layer is fermented through a combination of microbial activity and the work of endogenous enzymes contained within the mucilage. The process is finished after the grains are washed to eliminate the last remnants of decomposed mucilage. Afterwards the grains are put in bags to be transported to the dry mill. The coffee is brought to this mill to be sun-dried. This process can last from 8 to 10 days depending on the region and on the weather conditions. When it is dried the parchment is manually or mechanically removed. Later on, the green coffee is stored in silos and ready. The process is demonstrated below.

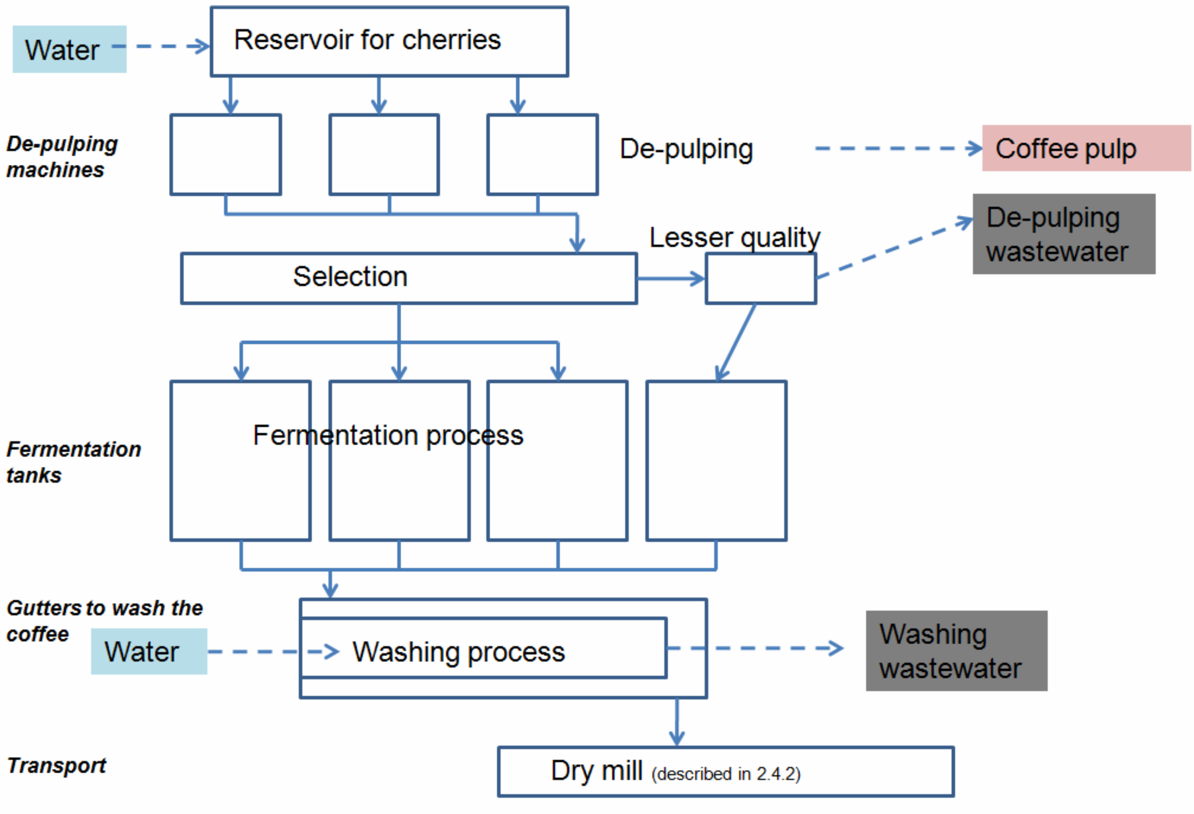

Figure 4 Wastewater production process

2.5.1. Water use at the wet mill

As can be seen in figure above, the water use at the wet mills is diverse in both quantity and purpose. The first place where water is being used is at the reservoir for the coffee cherries, which, according to the way in which the reservoir has been designed, uses a lot of water or hardly any. The water used in this step transports the cherries to the de-pulping machines and after removing the pulp from the cherry combines itself with the pulp and part of the mucilage. This is where the first wastewater flow is generated: the de-pulping wastewater. In previous times, this wastewater flow went directly to the open water courses without any treatment. This had a great effect on the downstream farms and villages. In the 70's and 80's in parts of Nicaragua a large introduction of facultative lagoons took place. While this made a significant contribution to the reduction of pollution, presently these lagoons do not work adequately if at all. It must be mentioned that this water contains a large percentage of tannins and resin acids which are toxic to aquatic life.

The second flow of wastewater is generated the next day when the cherries that had been harvested, after being de-pulped, have been left to ferment. During this phase the fermented grains are washed many times with abundant amounts of water to eliminate the decomposed mucilage. The coffee wastewater generated in this process normally ends up in the same place where previously the de-pulping wastewater had flown to. From there on these wastewaters can be treated together or employed for biogas production as will be described later.

According to Wasser, who has performed research on the use of water in the coffee processing, 30% of the water is utilized for the de-pulping process and 70% for the washing of the fermented grains. From this 70%, 20% is used for eliminating the decomposed mucilage and the remaining 50% is very clean wastewater that is used to finish cleaning and selecting the grains. (Schutgens 2010)

2.5.2 Coffee wastewater characteristics

2.5.2.1 Water Quantities

Depending on the processing technology applied, quantities of coffee wastewater is varying. Modern mechanical mucilage removal machines producing semi-washed coffee use only about 1 m^3 per tonne fresh cherry (without finish fermentation and washing) whereas the traditional fully washed technique without recycling uses up to 20 m^3 per tonne cherry (Mburu et al, 1994).

2.5.2.2 Organic Components

Pulping water consists of quickly fermenting sugars from both pulp and mucilage components. Pulp and mucilage consists to a large extend of proteins, sugars and the mucilage in particular of pectins, i.e. polysaccharide carbohydrates (Avellone et al, 1999). Depending on the processing method applied, further waste water evolves in the form of hydrolyzed pectins from fermentation and washing. During fermentation, long chain pectins are split by enzymes (pectinase, pectase) into short chain pectin oligosaccharides. Oligosaccharides are soluble in alkaline and neutral solutions, but in acid conditions they are thrown out of solution as Pectic acid. (Rothfos 1979, Treagust 1994). In the presence of calcium or other multivalent ions, the pectic acid fragments are cross linked into a non-soluble gel of calcium pectate (Treagust 1994).

Waste water from mechanical mucilage removers contains a certain amount of sugars (disaccharide carbohydrates), but its apparent gel like texture comes from the segments of undigested mucilage and pectic substances which have been removed from the parchment by mechanical means.

Below is a mass balance wet coffee processing showing the various wastewater characteristics

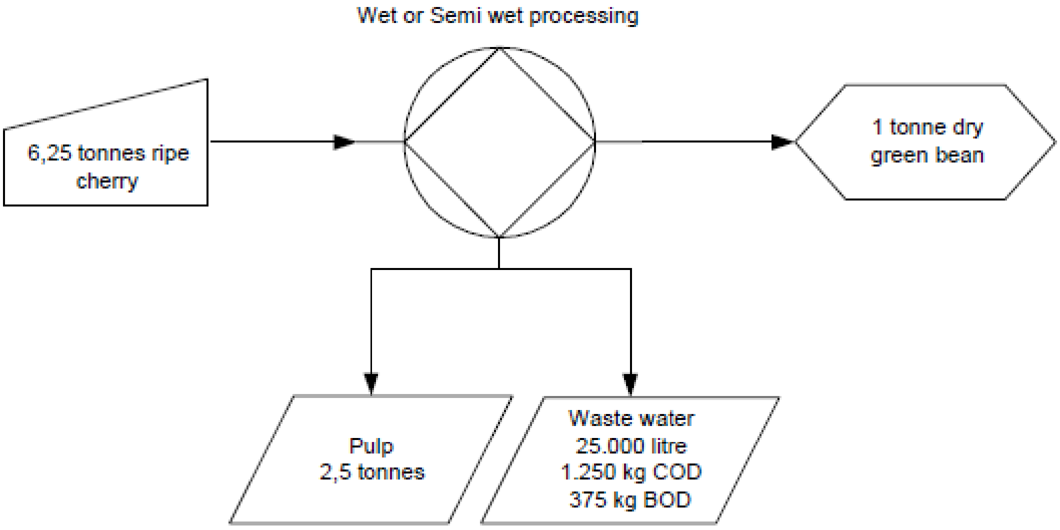

Figure 5 Mass balance coffee processing

2.6 Biogas production from coffee wastewater

The two major waste products from coffee processing, pulp and wastewater (80%), can be utilized to produce sufficient quantities of biogas. This is due to the high content of organic matter and acidity. The major process of biogas is through anaerobic process in the pulp and waste water.

2.6.1 Anaerobic digestion of waste water

Anaerobic waste water treatment is the biological treatment of waste water without the use of air or elemental oxygen. Organic pollutants are converted by anaerobic microorganisms to a gas containing methane and carbon dioxide, known as biogas.

Methane is the main constituent of biogas, being responsible for its calorific value. This work objective was to present the analysis of methane concentration in the biogas originated from anaerobic treatment system of wastewater of coffee wet processing (CWP) at laboratory scale, using coffee coconut. The methane concentration was performed by gas-solid chromatography (GSC) analyses.

COD values in waste water vary between 18,000 and 30,000 milligrams per liter. This is according to research conducted in Central America. The flow chart below shows the course of action during the process.

<u>The case for action</u>

Country that processes 91.000 MT of coffee per harvest.

⇩

91.000 m^3 of waste water

⇩

16.000 metric tons of organic waste

⇩

2.780 metric tons of CH4 (Methane)

= 68.000 tons of carbon dioxide

The set up used for this process in large scale is a bioreactor with an upper and lower part. Through the upper part, the neutralized waste water (pH7) enters in the lower part of the bioreactor, where the bacteria "eats" the organic matter, thereby cleaning the water and producing biogas. For smallholders producing in small scale the same process occurs but a

biodigestor which is more simpler form of a bioreactor is a more is used. Below is a picture of a typical simplified biodigestor.

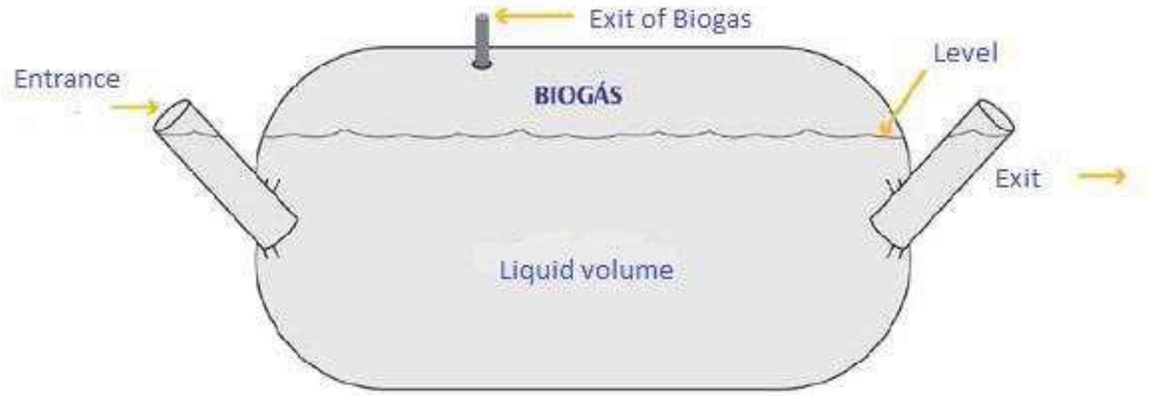

Figure 6 Biodigestor

2.7 Properties and uses of biogas

In nature, biogas (methane and carbon dioxide) is produced in oxygen-depleted environments such as swamps, lake sediments *etc*., The gas is produced by microorganisms of different domains that contribute in successive steps to degrade organic compounds. Fermentative bacteria convert complex biopolymers to smaller molecules in several steps (see below). The final step of methane production, the methanogenesis, is performed by an obligate anaerobic group called methanogens, belonging to the domain of *Archaea* (Madigan *et al.* 2006).

Biogas has traditionally been considered to be a by-product of anaerobic digestion of sewage sludge, treated for volume and odor reduction, at WWTPs (waste water plants) . Thus, the biogas has typically either been burned off, when the energy released has been used for heating facilities, or used to generate electricity. Development of the utilization and collection of biogas has lead to more modern biogas productions plants and optimization of the biogas process to derive at the maximal amount of biogas possible for a certain substrate. Still a majority of the biogas plants in Sweden are connected to WWTP, but more substrates are constantly being evaluated to find new sources of biogas.

Table 5 Typical biogas composition (Yishak Seboka *et al.*, 2009)

Compound	**Chemical formula**	**%**
Methane	CH_4	50 – 70
Carbon dioxide	CO_2	30 – 49
Nitrogen	N	0 – 1
Hydrogen	H	0 – 5
Hydrogen sulphide	H_2S	0.1 – 0.3
Water	H_2O	Saturated

2.7.1 Industrial use of biogas

Biogas produced by the AD process is quite similar to “natural” gas as it is extracted from the wellhead. However, in addition to methane, natural gas also contains a variety of other hydrocarbons such as butane, ethane, and propane. As a result, natural gas will always have a higher calorific value than pure methane. The particular characteristics of methane, the simplest of the hydrocarbons and the principal component of biogas, make it an excellent fuel for many uses.

Biogas can be used in all applications designed for natural gas. Today, it is commonly burned in an internal combustion engine to generate electricity. According to a publication by AEA Technology Environment, Culham, Abingdon, Oxfordshire, UK (2001), practical experience with small-scale internal combustion engines with a rated capacity of less than 200-kW indicate an electrical conversion efficiency up to 25 percent. Larger internal combustion engines (up to 1.5-MW) have much higher electrical conversion efficiency, 30-35 %.

When biogas is used to produce electricity, there is the added potential for heating water from the engine’s exhaust and cooling systems. Combining hot water recovery with electricity generation can provide an overall conversion efficiency of 65-85 percent. Biogas is also burned in boilers to produce hot water and steam used for other industrial uses.

A promising near-term application for electrical generation is the use of gas turbines. For larger-scale systems, combined cycle power stations consist of gas turbines, steam turbines, and waste heat recovery boilers all working together to produce electricity. Modern gas turbine plants are small, extremely efficient, environmentally friendly and visually unobtrusive. Units as small as 200-kW are available, but only at scales of greater than 800-

kW does their electrical conversion efficiency equal or surpass an internal combustion engine-based system. However, the use of a gas turbine allows a greater fraction of the waste heat to be recovered as more steam that is valuable. In this fashion, overall gas turbine efficiency can be greater than 70 percent. In the future, fuel cells and the Stirling engine may be able to use biogas to cost-effectively generate electricity and recover process heat.

2.7.2 Information needed for calculation of wastewater biogas potential

For the calculation of potentials from wastewater for biogas production, the following information is needed:

- Amount of wastewater (m^3 per year)
- Seasonal availability of the wastewater
- Chemical oxygen demand (COD) of the wastewater (mg COD/l)
- Biological oxygen demand (BOD) of the wastewater (mg/l)
- BOD/COD biodegradability ratio of the wastewater sample

2.8 Biodegradation

It is the change in form of compounds carried out by living creatures such as microorganisms. Biodegradation of wastewater occurs when they serve as the primary source of food and energy to naturally occurring wastewater bacteria (USEPA, 1999). Under the right conditions, microorganisms can cause or assist chemical reactions that change the form of the contaminants so that little or no health risk remains. Biodegradation is important because many important components of wastewater contamination can be destroyed by biodegradation, biodegrading microorganisms are found almost everywhere, and biodegradation can be very safe and effective (USEPA, 1999).

2.8.1 Determination of coffee wastewater biodegradability

The evaluation of biodegradability of organic compounds in aqueous medium can be performed by many options including activated sludge simulation, biochemical oxygen demand (BOD), dissolved organic carbon (DOC), total organic carbon (TOC), chemical oxygen demand (COD), metabolism and identification of transformation products (ISO, 2003).

The ratio of BOD/COD has also been used as a measure of biodegradability. The BOD/COD ratio gives a gross index of the proportion of the organic materials present which are aerobically degradable within a certain period of time, e.g. 5 days for BOD_5 (Mantzavinos et al., 1996). BOD is a measure of the oxidation occurring due to microbial activity while COD measures the highest extent of oxidation a material may undergo. Details of BOD and COD are given in the following two sections.

The BOD_5/COD ratio is a commonly used indicator of biodegradability improvement, where a value of zero indicates non-biodegradability and an increase in the ratio reflects biodegradability improvement (Alvares et al, 2001). Low BOD_5/COD values (usually less than 0.1) indicate their resistance to conventional biological treatment (Koch et al., 2002, Imai et al., 1998). Chun and Yizhong studied photo catalytically treated wastewater contaminated with azo dyes from the processing of wool. They found when the ratio of BOD_5/COD was more than 0.3 the wastewater had a better biodegradability. Similar statements were made for a BOD_5/COD ratio of 0.4 using non-biodegradable substituted aromatic compounds (Gilbert, 1987).

2.8.2 Biological oxygen demand

Biochemical Oxygen Demand (BOD) is the amount of oxygen required by bacteria while breaking down decomposable organic matter under aerobic conditions. The most widely used parameter of organic pollution to both wastewater is the 5-day BOD i.e. BOD_5. This determination involves the measurement of the dissolve oxygen used by the microorganisms in the biochemical oxidation of organic matter. The BOD test results are used to:

i. Determine the approximate quantity of the oxygen that will be required to biologically stabilize the organic matter present.
ii. Determine the size of waste-treatment facilities.
iii. Measure the efficiency of some treatment processes
iv. Determine compliance with wastewater discharge permits

The BOD test is an empirical bioassay-type procedure which measures the dissolved oxygen consumed by bacteria and other microbial life while the organic substances are present in the solution. The BOD standard test conditions are incubation at 20^oC in the dark for a specified period of time, mostly five days. The reduction in the dissolved oxygen concentration during this incubation period is a measure of the biochemical oxygen demand and is expressed in mg/l oxygen or mg/l BOD. The actual environmental conditions of temperature, biological population, water movement, light conditions and oxygen concentration cannot be accurately reproduced in the laboratory.

A blank sample of distilled water is usually treated and incubated in the same way as the rest of the samples as a control. The measurement of the dissolved oxygen can be carried out by the wrinkler method.

2.8.2.1 Principle

If sufficient oxygen is available, the aerobic biological decomposition of an organic waste will continue until all of the waste is consumed. A number of distinctive activities occur. First, a portion of the waste is oxidized to end products to obtain energy for cell maintenance and the synthesis of a new cell tissue. Simultaneously, some of the waste is converted into new cell tissue using part of the energy released during oxidation. Finally, when the organic matter is used up, the new cells begin to consume their own cell tissue to obtain energy for cell maintenance. This third process is called endogenous respiration. Using the term COHNS – representing the elements carbon, oxygen, hydrogen, nitrogen and sulphur – to represent the organic waste and the term $C_5H_7NO_2$ to represent cell tissue, the three processes are defined by the following generalized chemical reactions:

Oxidation:

$COHNS + O_2 - \text{bacteria} \rightarrow CO_2 + H_2O + NH_3 + \text{other end products} + \text{energy}$

Synthesis:

$COHNS + O_2 + \text{bacteria} - \text{energy} \rightarrow C_5H_7NO_2\text{(new cell tissue)}$

Endogenous respiration:

$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O$

If only the oxidation of the organic carbon that is present in the wastewater is considered, the ultimate BOD is the oxygen required to complete the three reactions given above. This oxygen demand is known as the ultimate carbonaceous BOD.

The BOD test is widely used to determine the “pollution strength” of domestic and industrial wastes in terms of the oxygen that they will require after being discharged into natural water systems. It is also important in the design of treatment plants and in monitoring their efficiency.

2.8.3 Chemical oxygen demand

COD test is a measure of quantity of oxygen required to oxidize the organic matter in a wastewater sample, under specific conditions of oxidizing agent, temperature and time. COD test is extensively used in analysis of industrial wastes and wastewater.

COD measures pollution potential of organic matter. Decomposable organic matter results in consumption of DO.

COD does not differentiate between biologically degradable & nondegradable organic matter.

As a result, COD values are greater than BOD values and may be much greater when significant amounts of biologically resistant organic matter are present (Sawyer and McCarty, 1978).

Chapter Three

3.0 Methodology and Materials

3.1. Fieldwork

3.1.1. Reconnaissance

A preliminary visit to Karatina was made on 26th March, 2014 to familiarize with the area and establish a coffee processing factory for sample collection. It was agreed that the Gatomboya factory that was yet to process its coffee would be the preferred site. An appointment with the manager was made prior to the actual site visitation.

3.1.2. Descriptions of the Experimental Site

The experimental materials (coffee pulp and wastewater) were collected from Gatomboya Factory, a wet coffee processing factory, on 3rd March, 2014, whereas the experimental process was undertaken at the University of Nairobi, College of Architecture and Engineering at the Public Health Engineering labs of Civil and Construction Engineering department. Gatomboya is located in Karatina, a small town in Nyeri County, Kenya, with a population of 6852 (1999 Census). It is 20km to the east of Nyeri town at an altitude of 1868m above sea level and at a longitude of 36.767 degrees. The mean annual temperatures range from 12 to 27 degrees Celsius and the annual rainfall varies from 550mm to 1500mm. March to April characterizes the small rainy season while the long rainy season extends from October to December. Most of the coffee produce is realized during the long rainy season and thus large-scale wet coffee mill process is carried out around the same time. Karatina lies on a plateau directly below the southern side of Mount Kenya. It is fed radially by flowing streams running from Mount Kenya towards the lower slopes of the mountain and is marked by Tana River, the longest river in Kenya.

3.1.3. Site Visitation

A visit to Gatomboya wet coffee processing factory was carried out on 3rd March, 2014. The plant manager, one Mr. Munene, guided the tour. Below is a case study of the Gatomboya wet coffee processing mill giving a detailed description of the activities that took place from the point where the farmers brought the coffee to the point where we collected samples.

Case Study: Gatomboya wet coffee processing mill.

Gatomboya factory is a wet coffee processing mill that serves the Barichu Farmers' Cooperative Society, one of the many cooperative societies in Karatina. Gatomboya factory was an initiative from local farmers started in 1985 and has served farmers in the area since then. A study of the wet coffee milling process was conducted under the supervision of the plant manager Mr. Munene. The wet coffee milling process is a sequential process operated manually by a machine operator. During the large-scale processing, the whole process is monitored from a computer while during the low season the process is monitored manually by sight observation. The whole process has distinct stages from the coffee grading process to the waste collection point.

Stage 1

The farmers bring in their coffee berries which are graded to remove the bad berries. The bad berries are used as manures by the farmers. The good berries are weighed and then emptied into the cherry hopper. See images below.

Figure 7 Grading coffee berries and the cherry hopper

Stage 2

The berries in the cherry hopper empty into the pulping unit by gravity. The pulping unit consists of the pulping machine. Here the pulp is separated and removed from the coffee bean by the running water in the pulping machine. The pulping machine is operated by electricity. The flow of water also separates the beans into different grades.

Figure 8 Pulping machine

Figure 9 Coffee pulp separated

Stage 3

The coffee bean that has been separated from the pulp is driven by the water to the fermentation tanks. Here the beans are allowed to ferment for about 45 hours or less depending on the time it takes the remaining layer surrounding the bean to clear off. The beans are then washed twice and taken by the flowing water to dry in the drying cables.

Figure 10 Fermentation tank

Figure 11 Drying cables

Once dry the beans are taken to the bean shed and are packed in 50kg bags.

The waste water from the coffee processing is recycled in the recirculation pump house by a pump and used over and over again until it cannot be used anymore and the dumped in the soak pits. The pulp is dumped directly into the soak pit.

Figure 12 Recirculation pump house

Figure 13 Soak pit

3.1.4. Sample Collection

Fresh wet coffee processing waste pulp and wastewater was collected in plastic bottles and an open plastic container respectively and kept fresh in an icebox ready for laboratory testing.

3.2 Determination of BOD_5 and BOD_u

Objective: To determine the Biochemical Oxygen Demand – BOD_u and BOD_5 – of a given sample of coffee wastewater

Apparatus and Reagents

Reagents

For dilution water:

- Phosphate buffer solution
- Ferric chloride solution
- Magnesium sulphate solution
- Calcium chloride solution

For dissolved oxygen determination by azide modification:

- Manganoussulphate solution
- Concentrated sulphuric acid
- Starch indicator solution
- Standard sodium thiosulphate solution 0.025

Apparatus

- Burettes
- Pipettes
- BOD bottles
- Beakers
- Conical flasks

Procedure

1) 6 litres of dilution water was made up by adding:

    - 6 ml of phosphate buffer solution
    - 6 ml of ferric chloride solution
    - 6 ml of magnesium sulphate solution and
    - 6 ml of calcium chloride solution

to 6 litres of distilled water kept aerated in the aspirator bottle. The solution was mixed well and aeration continued.

2) 3 samples A and B were used (sample A being treated water in fermentation tank for reuse and sample B being wastewater in soak pits fresh from being used in depulping the coffee beans).The volume of the sample to be taken in each bottle which when filled with dilution water would result in dilutions of 1:10, 1:25, 1:50, 1:100 for samples A and dilutions of 1:100, 1:140, 1:200, 1:280 for sample B.

3) Four sets of BOD bottles each set containing three bottles were arranged and labeled with the dilution factors mentioned above

4) Calculated amounts of sample were transferred to each bottle as appropriate.

5) The bottles were then filled with dilution water without overflowing and stoppered without trapping any air-bubbles.

6) Another set of three bottles were taken, identified as dilution water blank and then filled as before with dilution water without any sample.

7) The dissolved oxygen concentration was determined in one bottle from each of the five sets of bottles as follows:-

    a) The stopper was removed and in quick succession 2 ml each of manganoussulphate solution and alkali azide-iodide reagent added, with the tip of the pipette well below the water level in the bottle. The stopper was again replaced taking care not to trap any air bubbles.

    b) The contents of the bottle were mixed by inverting the bottle several times and letting the precipitate settle half-way down the bottle. The contents were mixed again and the precipitate allowed to settle as before.

    c) 2 ml of concentrated sulphuric acid was added using a bulb, to the contents of the bottle, with the tip of the pipette just below the water level. The stopper was then replaced and the content mixed again till all the precipitate had dissolved.

    d) 203 ml of solution was measured from the bottle and transferred to an erlenmeyer flask. The solution was then titrated against standard sodium thiosulphate solution till the color changed to pale yellow. About 1 ml of starch indicator solution was then added. Titration was continued till the blue color disappeared.

8) The remaining bottles were incubated at 20^{o}C for four days in the incubation cabinet.

9) The dissolved oxygen concentration in each bottle was determined in each bottle at the end of the incubation period.

3.3 Determination of COD of a coffee wastewater sample

COD test is a measure of quantity of oxygen required to oxidize the organic matter in a wastewater sample, under specific conditions of oxidizing agent, temperature and time. COD test is extensively used in analysis of industrial wastes and wastewater.

COD measures pollution potential of organic matter. Decomposable organic matter results in consumption of DO.

COD does not differentiate between biologically degradable & nondegradable organic matter.

As a result, COD values are greater than BOD values and may be much greater when significant amounts of biologically resistant organic matter are present (Sawyer and McCarty, 1978).

Reagents:

- Distilled water
- Standard potassium dichromate solution, 0.025N

- Sulphuric acid concentrated reagent containing silver sulphate
- Standard ferrous ammonium sulphate (FAS), 0.025N
- Powdered mercuric sulphate
- Phenanthroline ferrous sulphate (indicator)

Apparatus:

- Reflux apparatus with ground glass joint
- 250ml Erlenmeyer flask with ground glass joints
- Pipettes

Procedure:

1. 20ml of the sample was placed in 250 ml refluxing flask.
2. 1gm of mercuric sulphate, several glass beads were added into the solution. 5ml of H_2SO_4 (concentrated sulphuric acid) was added slowly while mixing to dissolve the mercuric acid.
3. The sample was mixed while cooling to avoid possible losses of volatile materials.
4. 25ml of 0.0471M $K_2Cr_2O_7$ solution was added and mixed thoroughly.
5. The samples were then transferred to the Liebig condenser apparatus. The remaining sulphuric acid reagent (70ml) was then added through the open end of the condenser.
6. The samples were continuously stirred while adding the acid reagent.
7. The reflux mixture was mixed thoroughly by applying heat to prevent local heating of the flask bottom and a possible blow out of the flask contents.
8. The open end of the condenser was covered with a foil to prevent foreign materials from entering the refluxing mixture.

9. Refluxing was then carried out for 2hours.
10. The condenser was thereafter cooled and washed down using distilled water.
11. The reflux was then disconnected and diluted to about twice its original volume with distilled water.
12. This mixture was then cooled to room temperature (due to the exothermic nature of the reaction). The excess $K_2Cr_2O_7$ was then titrated using FAS using 0.1-0.15ml (2 to 3 drops) ferroin indicator.
13. The same volume of ferroin indicator was used for all titrations.
14. The end point of the reaction was taken as the first sharp change in colour, from blue-green to reddish brown.
15. Similarly a blank of equal volume to sample, distilled water was titrated against FAS.

Chapter Four

4.0 Results and Discussion

4.1 BOD results and analysis

4.1.1 Results

Sample A (treated water in fermentation tank for reuse)

Dissolved Oxygen Concentration before Incubation

1:50…………………7.5 ml

1:25…………………7.4 ml

1:10…………………7.2 ml

Dissolved Oxygen Concentration after Incubation

1:50…………………6.3 ml

1:25…………………6.2 ml

1:10…………………6.1 ml

Sample B (wastewater in soak pits fresh from being used in depulping the coffee beans)

Dissolved Oxygen Concentration before Incubation

1:280…………………6.6 ml

1:200…………………6.5 ml

1:140…………………6.4 ml

1:100…………………6.3 ml

Dissolved Oxygen Concentration after Incubation

1:280………………….5.8 ml

1:200………………….5.6 ml

1:140………………….5.4 ml

1:100………………….all oxygen was used up

4.1.2 Calculations

5 – Day, 20^{o}C BOD = $(D_1 – D_2) / P$ mg/l

Where: D_1 = DO in diluted sample before incubation

D_2 = DO in diluted sample after incubation

P = decimal fraction of the sample in the BOD bottle

$$BOD_u = \frac{BOD_5}{1-e^{-kt}}$$

Where: k = 0.10 day^{-1}

t = 5days

Decimal fractions of samples (P)

P_{blank} = 0.00

$P_{1:280}$ = 0.0036

$P_{1:200}$ = 0.005

$P_{1:140}$ = 0.0071

$P_{1:100}$ = 0.01

$P_{1:50}$ = 0.02

$P_{1:25}$ = 0.04

$P_{1:10}$ = 0.1

BOD_5

Sample A

1:50 $= \frac{7.5-6.3}{0.02}$ = 60 mg/l

1:25 $= \frac{7.4-6.2}{0.04}$ = 30 mg/l

1:10 $= \frac{7.2-6.1}{0.1}$ = 11 mg/l

Average $BOD_5 = \frac{60+30+11}{3}$ = 33.7 mg/l

$BOD_u = \frac{33.7}{1-e^{-0.10\times5}}$ = 85.6mg/l

Sample B

1:280 $= \frac{6.6-5.8}{0.0036}$ = 224 mg/l

1:200 $= \frac{6.5-5.6}{0.005}$ = 180 mg/l

1:140 $= \frac{6.4-5.4}{0.0071}$ = 140 mg/l

1:100 : no oxygen was left after day 5 of the experiment

Average $BOD_5 = \frac{224+180+140}{3}$ = 181.3 mg/l

$$\text{BOD}_u = \frac{181.3}{1 - e^{-0.10 \times 5}} = 460.8\text{mg/l}$$

4.2 COD results and analysis

4.2.1 Results and analysis

$$\text{COD in mg/L} = \frac{(\,a - b\,) \times m \times 8000}{\text{ml of sample}}$$

Where:

a = ml, of titrant used for blank water

b = ml, of titrant used for sample water

m = molarity of the FAS

Sample A (treated water in fermentation tank for reuse)

$$\text{COD}_A = \frac{(23.2 - 21.2) \times 0.1 \times 8000}{20} = 80 \text{ mg/l}$$

Sample B (wastewater in soak pits fresh from being used in depulping the coffee beans)

$$\text{COD}_B = \frac{(25.2 - 16.0) \times 0.1 \times 8000}{20} = 368 \text{ mg/l}$$

4.3 BOD/COD ratio (biodegradability, α_s)

Biodegradability of sample, $\alpha_s = \frac{BOD_5}{COD}$

Sample A

$$\alpha_s = \frac{33.7 mg/l}{80 mg/l} = 0.42$$

S**ample B**

$$\alpha_s = \frac{181.3 mg/l}{368 mg/l} = 0.49$$

4.4 Discussion

The Biochemical Oxygen Demand theoretically takes an infinite time to be completed because the rate of oxidation is assumed to be proportional to the amount of organic matter remaining. Within the 5-day period used for the BOD test, oxidation is from 60 to 70 percent complete.

From the test results it can be realized that the BOD of the sample increases with an increase in dilution of the samples. Also, it can be noted that highly concentrated samples tend to deplete their oxygen faster than less concentrated samples as evidenced by the most concentrated dilutions of sample B(1:100 dilution) whereby after 5 days the sample turned white indicating that all the oxygen has been used up.

The Chemical Oxygen Demand of the samples A and B were found to be higher than the BOD values of the same samples. This is because BOD is usually the amount of oxygen in organic matter only hence depend on the dissolved organic matter in the wastewater samples, whereas COD tests involve strong chemical agents to degrade both organic and inorganic matter present in the wastewater samples. Also COD values are always higher than BOD values because COD includes both biodegradable and non-biodegradable substances while BOD contains only biodegradable substances.

For sample A, the high COD value of 80mg/l and relatively low BOD value of 33.7mg/l indicates that the treated water at the fermentation tank contained more inorganic than organic matter present.

It should also be noted that the biodegradability value of sample A and C are 0.42 and 0.49 respectively. BOD/COD ratio of 0.4 and above is considered to be biodegradable (Gilbert, 1987) hence so for the above samples A and B.

4.4.1 Integrated model

Coffee pulp and coffee wastewater are the major wastes of wet coffee processing. Geoffrey Mwalili, Ojwando Kelvin and I were undertaking the research of converting these wastes into energy. It was found out that biogas and ethanol are the major sources of energy as a result of conversion of coffee pulp and coffee wastewater to the aforementioned bioenergy. A joint integrated model was thus formulated for the derivation of biogas and ethanol. See appendix 1.

Chapter Five

5.0 Conclusion and Recommendations

5.1. Conclusion

The values of COD of 80mg/l for sample A and 368mg/l for sample B and BOD value of, 33.7mg/l for sample A and 181mg/l for sample B and BOD/COD ratios of 0.42 and 0.49 for A and B respectively infer that the above samples are a potential source of biogas since a BOD/COD ratio of 0.4 and above a sample is considered to be biodegradable (Gilbert, 1987).

According to Mshandete, et.al, coffee wastewater has a biogas potential of 375m^3/ton COD$_{rem}$ which is a very high value of energy production hence further concluding that Gatomboya coffee factory a potential source of bioenergy.

The utilization of coffee wastewater as an alternative energy production source reduces the environmental pollution and reduces the overdependence on oil and petroleum in Kenya. This also provides an alternative energy source for small scale factories such as Gatomboya. However, further study needs to be done to improve on this research.

5.2. Recommendations

- Further research needs to be done on the proper conditions for optimum biogas production from coffee wastewater.
- Further investigations should be carried out on the possibility of implementation of the integrated model for joint utilization of coffee waste pulp and waste water for bioethanol and biogas production.
- The Ministry of Energy should come up with ways of ensuring small scale factories such as Gatomboya are able to come up with bioreactors so as to utilize the bioenergy produced form coffee wastewater and coffee pulp from the wet processing.

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APPENDICES

Appendix 1: Integrated model of bioethanol and biogas production derived from coffee processing wastes