International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 6, Issue 1, January 2017)

Design and Development of Biogas Production System From Waste Coffee Pulp and its Waste Water Around Tepi

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***Abstract* -Many coffee producing enterprises dispose coffee by-product like coffee pulp and its waste water after washing to the environment and which cases environmental pollution by bad smell and visual pollution. These by-products of coffee production mainly coffee pulp and waste water impure discharge to the nearby surface water and also underground water and damages it.**

This project research primarily conducted to come-up with detail design of bio gas digester to get clean useful bio gas from coffee wastes like coffee pulp, and its waste water based on the data of the overall environmental conditions of Tepi. Therefore, the problems indicated in the above would be corrected by utilizing of unnecessary wastes during coffee preparing for its quality and useful methane and organic fertilizer after digestion will be got.

A bio gas digester is designed for waste coffee pulp in both wet and dry case and its waste water. The system design conducted by using 300 liter plastic water tank and internal tire of Bajaj conduit used to collect the output bio gas from the digester tank. Therefore, for the total volume the digester, the amount of daily fresh discharge estimated after its retention time (32 days) is 5 kg, and required proportional mount of water is 2.5 liter for wet and 53.61 liter of water for dry case. Accordingly the estimation, bio gas production rate is plotted. However, the production rate of bio gas production differs as environmental temperature change the daily production amount of methane rich gas maximum 24.35 liter in wet case and 8.70 liter in dry case. Therefore, for the design and construction of bio gas digester in any size can easily estimate as the requirement of bio gas energy.

Producing bio gas from waste coffee pulp and its waste water through anaerobic digestion system solves the environmental polluting problems of coffee preparing enterprises around Tepi town.

***Keywords*-- Bio gas, Bio gas digester, Coffee producing enterprises, Coffee pulp**

I. INTRODUCTION

The demand of energy for human life is increasing time to time as the standard of life increase, thus it extended with the use of fossil fuels for cooking, lighting, and industrial purposes and as far as in turn its combustion results contributes global warming effect.

In case of most rural areas use wood for their energy demand and in similar way results deforestation and change of environmental ecological imbalances. Considering these effects of energy sources, green energy application like biogas from waste materials, solar energy, wind, and like are globally accepted and all agreed campaign.

The world market for bio gas is increased considerably in the last years and many countries developed modern bio gas production technology and competitive national bio gas markets throughout decades of intensive research and development complemented by substantial governmental intervention and public support. A bio gas plant supplies bio gas energy and organic fertilizer. It improves hygiene and protects the environment by utilizing unwanted waste materials and converting it in to useful clean bio gas energy and organic fertilizer.

Therefore, this research project is to develop useful biogas energy production system from waste coffee pulp and its waste water during coffee preparation process in the specified area by anaerobic digestion process. All coffee preparing enterprises are simply discharge coffee waste both dry and wet coffee pulp, and water after wash to the nearby environment as shown figure 1 below. In addition to polluting the community with bad smell, it also holds their working place and draining to nearby rivers pollution.

Figure.1: Waste coffee pulp and waste water from its process

A. Coffee Waste Characteristics

In coffee producing countries, coffee wastes and by-products constitute source of severe contamination and a serious environmental problem. For this reason, since the middle of the last century, efforts have been made to develop methods for its utilization as a raw material for the production of foods, beverages, vinegar, biogas, caffeine, pectin, pectic enzymes, protein, and compost. The fact from various studies, fresh or processed coffee pulp and waste water can be used in a variety of ways [2].

Waste Water Characteristics

The environmental impact of wet and semi-wet processing of coffee is considerable. Problems occur through large amounts of effluents disposed into water courses heavily loaded with organic matter rather than inherent toxicity.

Based on the techniques of coffee processing used, content of coffee waste and its waste water is different. Modern mechanical mucilage removal machines producing semi-washed coffee use only about $1m^3$ per tones fresh cherry (without finish fermentation and washing) whereas the traditional fully washed technique without recycling uses up to 20 m^3 per ton cherry [2]. In order to treat waste water properly and at reasonable costs, the amounts of waste water used must be minimized.

Organic Components waste water

The main pollution in coffee waste water stems from the organic matter set free during pulping when the mesocarp is removed and the mucilage texture surrounding the parchment is partly disintegrated [3]. Water after coffee treat consists of quickly fermenting sugars from both coffee pulp and its mucilage components. Coffee pulp and its mucilage have a large extend of proteins, types of sugars and the mucilage in particular of pectin, i.e. polysaccharide sugar [4].

B. Biogas of coffee pulp and its waste water

The water from wet coffee cherry is another potential source of biogas production. Appropriate technologies and other procedures lower its pH value and further neutralization process gives rise to CO_2 foam (mainly acetate salts and raise the pH from 3.8 to 6.1) therefore the formed materials will suspend out more solids, mainly dark coloured tannins, and polyphenolics.

Evolution of CO_2 foam formation at this point enables the later high production of a methane-enriched biogas with only half of the usual level of inert CO_2.

Figure 2: Hard degradable part of coffee waste

Coffee production in our country, Ethiopia is a long time tradition and Ethiopia is the world's seventh largest coffee producer, and Africa's top producer, with 260,000 metric tons in 2006. Ethiopia is the place where coffee Arabica found, first time the coffee plant originates. Ethiopia itself shares for around 3% of the global coffee market. Coffee is important to the economy of Ethiopia which account around 60% of foreign income comes from coffee, probably 15 million of the population relying on some aspect of coffee production for their livelihood. In 2006, coffee exports earned about $350 million, equivalent to 34% of that year's total exports as Ethiopia domestic report shows.

The main coffee producing regions in Ethiopia are Illababor, Bebeka benchimaji zone, Tepi Sheka, Gimbi, Wollega Nekempt-Jimma harrar, Sidamo, and Yirgacheffe. Despite of this, it is known that coffee production has many environmentally unfriendly waste products such as coffee pulp and waste water from the production. Most of the time these coffee producers what they do is they burns the pulps and also drains the waste water to the nearby river or nearby open space and this leads to water pollution (surface and underground water), bad odors and concentration of toxic elements in soils, which results in decreased land productivity and increased use of chemicals for its solution, and also releases Carbon monoxide and Carbon dioxide to the atmosphere from the burning of coffee pulp and contributes its part for global warming.

So we need to find solution to solve the above mentioned problems. The main purpose of the paper is to produce biogas energy from waste coffee pulp and waste water for coffee drying and to make the environment safe.

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Figure 3: Coffee pulp accumulation in the coffee production enterprise

II. Bio Gas Digester

A biogas plant is an anaerobic digester of organic material for the purposes of treating waste and concurrently generating biogas fuel. The fermented waste of coffee is a nutrient-rich, nitrogen-rich fertilizer while the biogas is mostly methane gas with inert gases including carbon dioxide and nitrogen. Biogas plants are a preferred alternative to burning dried animal dung, bushes, wood as a fuel and can be used for the treatment of human waste, house hold wastes, and coffee pulp commonly. a millions of biogas plants have constructed in the developing countries for management of organic wastes, alternative energy supply to direct burning in the home, and overall enhancement of human health and the environment. Many considerations take in to account for selection of feedstock and site selection must be researched before deciding to install a biogas plant. Therefore, this project research for the generation of methane rich gas from waste coffee pulp and its waste water would be in company of coffee preparing enterprises.

Biogas is a combustible mixture of gases (see table I). It consists mainly of methane (CH_4) gas and carbon dioxide (CO_2) gas and is formed from the anaerobic bacterial decomposition of organic compositions, i.e. with oxygen free envronment. The gases formed are the waste products of the respiration of these decomposers and the contents of the gases depends on the material that is being decomposed. If the materials consists mainly carbohydrates rich, such as glucose and other simple sugars and high-molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low and high if there fat.

Methane gas, and other additional hydrogen there may be, makes up the combustible part of biogas. Methane gas is a colourless gas and odourless gas with a boiling point temperature of -162°C and it burns with towards a blue colored flame. Methane gas is also the mainly consists of (77-90%) of natural gas [5] .

Chemical structure of methane is the class of alkanes with on carbon atom. At atmospheric standard temperature and pressure, it has a density of 0.75 kg/m^3. Pure methane has an higher heating value of 39.8 MJ/m^3, and which equibalent to 11.06 kWh/m^3 [5].

TABLE I:
COMPOSTION OF BIOGAS [5]

Gas	*%*
Methane (CH_4)	*55 -70*
Carbon dioxide (CO_2)	*30- 45*
Hydrogen sulphide (H_2S) *Hydrogen (H_2)* *Ammonia (NH_3)*	*1-2*
Carbon monoxid (CO)	*Trace*
Nitrogen (N_2)	*Trace*
Oxygen (O_2)	*Trace*

Its actual make-up depends on what is being decomposed, the envronmental factors, and control and construction process of bio gas digester.

A. Steps of bio gas production process

The biogas process is often divided into three steps: Hydrolysis, acidogenesis and methanogenesis, where different groups of bacteria are responsible for each step.

TABLE II:
ENERGY YIELD OF METHANOGENS FROM DECOMPOSITION OF DIFFERENT SOURCES

Source	*Process*	*Energy yield kJ/mol methane*
Hydrogen	$4H_2 + CO2 = CH_4 + 2H_2O$	*131*
Formic acid	$4HCOOH = CH_4 + 3CO_2 + 2H_2O$	*145*
Methanol	$4CH_3OH\ 3CH_4 + CO_2 + H_2O$	*105*
Acetic acid	$CH_3COOH\ CH_4 + CO_2$	*36*

International Journal of Recent Development in Engineering and Technology
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B. Process Parameters for a biogas Plant

In order for a biogas process to be effective and productive, there are a number of parameters that have to be optimized during the production process. If these conditions are not at the optimal level, the quantity and quality the required biogas will be changed. These are anaerobic environment, optimal temperature, acidity (pH), substrate (feedstock), Comminution, dry mater content, and carbon/nitrogen ratio.

C. Inhibitors of the Biogas production process

Inhibitors are a substance has a negative effect on bacteria without directly destroying them. The inhibition process can be seen in many ways and are often divided into endogenous and exogenous causes. Endogenous inhibition effect is caused by the conditions or material formed during the process and exogenous inhibition is caused by external conditions.

Nitrogen as inhibitor

The most significant endogenous inhibitor of bio gas production is ammonia (NH_3). Ammonia may be formed during the degradation of nitrogen-containing substances such as proteins by microorganisms like bacteria. Nitrogen is important for growth of methane producing bacterial growth and also ammonia is source of this nitrogen. But ammonia above the required concentrations is very toxic to the methane producing bacteria. In an aqueous solution ammonia is always found in equilibrium with ammonium (NH_4^+). This equilibrium is determined by the acidity, pH and temperature of the environment and, as ammonium is not as toxic as ammonia, this equilibrium is important:

$$NH_4^+ \text{-} NH_3 + H^+$$

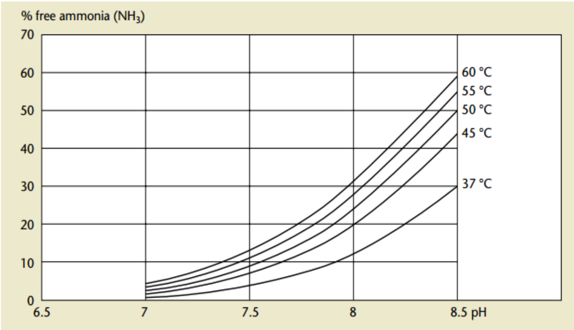

Figure 4: **Effects of pH and temperature on the balance between ammonium and toxic ammonia (NH_4^+/NH_3) [5]**

As a pH increase, the ammonium equilibrium is shifted to the right side, and the situation will be more toxic to bacteria growth.

Similar way as temperature increase also shifts this equilibrium of the process to the rightward. This is a thermophilic biogas generate process in which all other things held constant and has more effect than a mesophilic stage inhibition by ammonia (see figure 4 above).

Antibiotics and others inhibitors

Among the exogenous causes, antibiotics and disinfection agents are obvious inhibitors of the process, because both are toxic to and are used to kill microorganisms. Both substances are used in livestock production to treat sick tame animals and to keep animal houses and milking parlous clean and can therefore also be found in the slurry, but apparently only at low concentrations they do not have a negative impact on the biogas plant. A slow adaptation to these substances can also take place if the supply is fed in continuously.

D. Anaerobic digestion

Anaerobic digestion is a natural biological process where organic material is decomposed by anaerobes in absence of air to yield methane rich biogas. The general technology of biomethanation of complex organic matter is well known and has been applied for over 60 years as part of domestic sewage treatment to stabilize organic wastes. Anaerobic process is more advantageous than aerobic process in solid waste treatment because of high degree of waste stabilization, low production of excess biological sludge, low nutrient requirement and high production of methane gas as a useful by-product. Various studies have been conducted for evaluating different process parameters and model equations on biomethanation process but only few are reported on catalytic biomethanation process.

The bio gas bacteria are active in landfills materials where they are process degrading homemade food wastes and other biomasses. The process occurs in an anaerobic (oxygen-free) environment through the activities of acid and methane forming bacteria that break down the organic materials and at end produce methane (CH_4) gas and carbon dioxide (CO_2) in a usually known as biogas.

Chemical composition of coffee pulp

Good quality silage was finding from coffee pulp alone and in combination with the forages. Composition of lignin, lignified protein, and caffeine percent were highest in pure pulp silage and will decrease diluting by forages in the others. Silage method improved overall feed application comparing to fresh coffee pulp waste but good knowledge on modification having the silage process would allow getting the way to better improve the nutritive value of coffee pulp waste.

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According to Bressani [6], fresh coffee pulp can be ensiled with 4-6% sugar cane molasses. But it can be directly ensiled; good quality will found if moisture is around 75%. A trench silo of well-packed coffee pulp holds an average of 325 kg/m^3 of coffee pulp. Other method includes mixing coffee pulp with (10%) urea, (0.3-0.5%) sodium metabisulphite, (2%) calcium hydroxide, and (10% HCl + H_2SO_4) mixtures of inorganic acids. The silage of either of coffee pulp wastes alone or mixed with grasses which are ready to be used in normally about 3 weeks and it can be preserved for up to 18 months if it is well packed. The silage from coffee pulp alone or mixed with other forages can be used as such, or it can be dehydrated (but this operation is not necessary) [6].

Chemical compositions of coffee hulls, coffee pulp (dehydrated), coffee oil meal, and by product of essential oil extraction are showed in Tables III and IV below.

TABLE III:
NUTRIENTS, MINERALS AND CAFFEINE CONTENTS OF COFFEE HULLS [8]

Nutrient	Value
Dry matter (DM) (%)	*88.4 – 91.6*
Protein (% DM)	*9.3 -1030*
Fiber (% DM)	*37.2 -44.8*
Ash (% DM)	*6.5 -8.7*
Mineral value	
Calcium (% DM)	*0.44 -0.71*
Phosphorus (% DM)	*0.12 - 0.19*
Potassium (% DM)	*2.26 -3.39*
Sodium (% DM)	*0.02*
Magnesium (% DM)	*0.09 -0.13*
Zinc (mg/kg DM)	*31 -46*
Copper (mg/kg DM)	*8.0*
Iron (mg/kg DM)	*20 -2 1*

TABLE IV:
NUTRIENTS, MINERALS, AMINO ACIDS AND ANT NUTRITIONAL FACTORS CONTENTS OF COFFEE PULP, DEHYDRATED [8].

Nutrients	*value*
Dry matter (DM) (%)	*91.8 -94.6*
Protein (% DM)	*11.3 -13.2*
Fiber (% DM)	*18.5 -20.2*
Ash (% DM)	*8.9 -11.7*
Mineral Value	
Calcium (% DM)	*0.32 -0.35*
Phosphorus (% DM)	*0.13*
Amino acid Value	
Lysine (% protein)	*3.4 -4.5*
Threonine (% protein)	*3.1 -3.5*
Methionine (% protein)	*O.3 -0.4*
Cystine (% protein)	*0.3*
Isoleucine (% protein)	*3.3 -4.0*
Valine (% protein)	*3.7*
Leucine (% protein)	*4.7 -4.8*
Phenylalamine (% protein)	*3.0 - 3.2*
Tyrosine (% protein)	*1.9 -2.4*
Histidine (% protein)	*2.5 -3.0*
Arginine (% protein)	*2.8 -3.6*
Alanine (% protein)	*3.5*
Aspartic acid (% protein)	*7.1*
Glutamic acid (% protein)	*7.7*
Glycine (% protein)	*4.2 -4.6*
Serine (% protein)	*3.3*
Proline (% protein)	*3.7*
Antinutrtional factors	***Value***
Tannins, generic (% DM)	*0.92*
Caffeine (% DM)	*0.82 -0.92*

There are sufficient nutrients in the coffee pulp, in parts ratio of carbon nitrogen and phosphorous is (C:N:P = 250:10:1) at a temperature of 36 ^{o}C during mesophile batch test [8].

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III. Materials And Methods

A. Description of the study area and materials

The study was conducted in Tepi town, Yeki wored, Sheka Zone, South West Ethiopia which is 609km from Addis Ababa. This study area is mainly known for its coffee production like *Keffa zone, Bench-Maji* zone and others in South-Western part of Ethiopia. In *Yeki* woreda around Tepi town there are more than 15 coffee producer enterprises. It is known that coffee production has many environmentally unfriendly waste products such as wasted coffee pulp and waste water from the production process. These coffee producers burns the dry coffee pulps and drains the wet coffee pulp and the waste water to the nearby river or nearby open space. This leads to water pollution, liberates bad odors to the nearby societies and releases greenhouse gases to the atmosphere from the burning of dry coffee pulp and contributes its part for global warming. Specifically the field Experiment was conducted at Ato Alemu Mehary's Wet and Dry Coffee Production Enterprise in Tepi, Ethiopia.

Materials

Regarding the field experiment various equipments have been used ranging from simple fiber rod for sealing purpose and hand tools to analytical instruments in the chemistry Laboratory of the chemistry Department of Mizan-Tepi University.

TABLE V:
MATERIALS REQUIRED IN THE CONSTRUCTION PROCESS

Material Description	*Unit*	*Quantity*
1. Plastic containers	*Piece*	*2*
2. PVC pipe	*meter*	*5*
3. Gate valves	*Piece*	*4*
4. Plastic Hose	*meter*	*8*
5. Black Paint	*Piece*	*10*
6. Wood fix/CDM Plaster	*liter*	*1/4*
7. Meter tap	*meter*	*5*
8. Fiber rod	*gram*	*500*
9. Hacksaw	*Piece*	*1*
10. PVC Elbow 90°	*Piece*	*4*
11. Nipples	*Piece*	*4*
12. Female Adapter	*Piece*	*4*
13. Male Adapter	*Piece*	*4*
14. Bajaj internal tire	*Piece*	*2*

B. Method of Preparing the Pilot Field Experiment Digester

The experimental setup for the study is batch type of digestion consisting of two plastic containers for wet waste coffee pulp and waste water and dry waste coffee pulp with a size of 300 L and 150 L respectively. By using the above listed materials the two field experiment biogas digesters are prepared as follows:

The Pilot Field Experiment Digester is made from two plastic containers, one for the wet waste coffee pulp and waste water and the second for dry waste coffee pulp by drilling the inlet at the top side by ϕ90mm and the outlet at the bottom side by ϕ75mm dimension and then ϕ90mm and ϕ75mm 90° PVC elbow are mounted on it by press fit. The size difference between and the inlet and outlet is due to the size of the slurry or digestate that will be small and suspension after digestion and can be discharged easily outward.

The gas outlet from the digester is prepared by drilling a hole by ϕ1/2 inch size and inserts a ϕ1/2 inch flexible plastic pipe with a 5m length on the top of the digesters. The gas flow control valve is also made from two ϕ1/2 inch gate valve one that is mounted on the tip of the digester and the second on the tip of plastic gas holder in order to make simple process of mounting and dismounting of the gas holder from the main digester when needed to test the gas. In addition to this the whole system is sealed by *kocho* fiber rod with wood fix in order to protect any gas leakage from the digester and gas holder.

Figure 5: Bio gas digester construction for wet and dry coffee pulp

C. Sample Preparation

The wet coffee pulp and waste water was collected from the outlet of wet coffee processing machine shop of Ato Alemu Mehary wet and dry coffee production enterprise from October to December and the dry coffee pulp waste was also collected from the same enterprise at the dry coffee (*Jenfel*) processing machine shop since Mid of January to Mid of April. These collected wet and dry waste coffee pulps were mashed and agitated.

Figure 6: Measurement and sample preparation

It is known as that of any cereal crops, coffee production is once per year but the process of getting the final pure coffee product that can be taken up to the market passes a lot of processes that can take one year depending on the amount of coffee that is going to be processed by the enterprise. That means most of the time wet coffee processing season that is about three to four months is expected to be the only season for coffee production per year but after the end of wet coffee production, the dry coffee production will start and stay up to five to six months per year and this secures the availability of the feedstock throughout the year for the purpose of biogas production. Therefore, for the pilot/field experiment bio gas digester 5 kg of the waste wet coffee pulp and 5 kg of waste dry coffee pulp were collected daily by using the plastic bags as shown in the figure 6 above and for laboratory experiment that is for analysis of percent of moisture matter content (MMC), percent of Dry Matter Content (DMC), percent of total solid (TS), percent of Volatile Solid (VS), percent of Ash Content (AC) and for determination of functional groups in the waste coffee pulp case the 200g of Wet Coffee Waste (WCW) and 50g of dry waste coffee pulp (DWCP) was also collected by using small plastic bags as shown in figure 7.

Figure 7: Ashing process in laboratory

PH-value test

The pH-value is the measure value of acidity or alkalinity of a solution (respectively of substrate mixture, in the case of Anaerobic Digester (AD)) and is expressed usually in *parts per million* (ppm). The pH measure of the AD substrate effects the growth of methanogenic bacteria and also affects the dissociation of some importance compounds of the AD process such as ammonia, sulphide, and organic acids.

Methane production takes place within a pH interval from about 5.5-8.5 with an optimum interval 6.5-8.0 for most methanogens process. Acidogenic microorganisms usually in lower value of optimum pH value [14].

The PH of the initial feedstock and the final slurry was determined by using digital pH meter with a Model of *HANNA INSTRUMENT* (*HI 2223 Calibration Check PH/ORP Meter)* at National Soil Research Center (NSRC) Tepi branch as shown figure below 8. Electrodes were thoroughly wetted and prepared according to the manufacturer's manual. The instruments were first checked with standard acetic acid buffer of pH 4.0.

Sample is prepared at normal atmospheric temperature of 28 ^{o}C continuous adding and shaking the solution to dilute it to make detectable to the pH meter. Then the probes of the pH meter inserted to the solution and the pH value of the solution is directly read from its screen. Therefore, the measured pH value of sample initial feedstock is basic (7.70), and sample at the final slurry after digestion is acidic (5.50). This indicates that the digestion process is optimal as expected.

International Journal of Recent Development in Engineering and Technology
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Figure 8: pH test by using HI2223 Calibration

Soil acidity is measured in pH units. The pH of soil is a measure of the attentiveness of hydrogen ions in the soil content solution. The growth plant and most its processes, including nutrient presence and microbial activity of the favored pH range of soil is 5.5–8.0. Acidy soil predominantly in the subsurface will also constrain root access to underground water and its nutrients. Therefore, according to this the slurry pH lay between the recommended range that is from 5.5 to 7.5 [15].

IV. Design And Analysis

A. Analytical Methods & Calculations for the feed stocks

The wet and dry coffee pulp samples were analyzed for percentage of total solid (TS), percentage of volatile Solids (VS), percentage of ash (AC), and percentage of moisture mater content (MMC) [9]. Therefore, these parameters are calculated as follows;

Total Solid Material

Total solid and moisture content in both waste wet and dry coffee pulp were determined in a typical experiment as follows: 50g and 200g of freshly collected samples of each of waste dry and wet coffee pulp were weighed using electrical balance, and placed inside an electric hot air-oven maintained at 105 °C using a crucible. The crucible was allowed to stay in the oven for 24 hours, then taken out, cooled in desiccators and weighed. The expression for calculating moisture content on wet basis is shown in equation below [10].

Therefore the percentage of Moisture Content was calculated as follows:

$$\%MC = \frac{w-d}{w} \times 100 - - - - - - 4.1$$

Where,
$\%MC = Moisture\ Content$
$w = initial\ \ weight\ of sample$
$d = final\ (dry) weight\ of\ sample$

The percentage of total solid (TS) of both waste dry and wet coffee pulp can be calculated by using the equation:

$$\%TS = \frac{wDs}{wFS} \times 100 - - - - - - - - 4.2$$

$\%TS = Total\ Solid$
$wDs = weight\ of\ dry\ sample$
$wFs = weight\ of\ Fresh\ sample$

Volatile Solids (VS) and Fixed Solids (FS) or Ash

The total solids obtained were heated to a constant weight at 550 °C in a furnace for three hours. Then, the sample was taken off from the furnace, and cooled in desiccators and finally weighed. The left behind solid matter represents fixed solid, and dissolved or suspended solid while the weight lost on ash represents the volatile solids of it. The following formula below was employed to calculate the percentage content of volatile solid content of the total solid TS [11].

$$\%VS = \left[TS - \left(\frac{w(Ash)}{wFs}\right)\right] \times - - - - - 4.3$$

Where,
$\%VS = percent\ of\ Volatile\ Solid$
$w(Ash) = remaining\ weight\ after\ ignition\ which\ is\ called\ Fixed\ solid\ (FS)$
Therefore,

$$TS = VS + FS - - - - - - - - - - - -4.4$$

TABLE VI:
COFFEE WASTE AND MOISTURE CONTENT [11]

Description	***Wet waste Coffee pulp***	***Dry waste coffee pulp***
Percent of Moisture Matter content (%MM C)	*88.185*	*6.23*
Percent of Total solid (%TS)	*11.815*	*93.77*
Percent of Volatile Solid (%VS)	*70.65*	*97.11*
Percent of(Fixed Solid (FS)) or Ash (%AC)	*29.34*	*1.35*
Percent of (% VS/FS)	*5.98*	*1.035*

B. Volumetric calculation for digester and hydraulic chamber

An important parameter for dimensioning and designing of the biogas digester is the hydraulic retention time (HRT). The HRT is an average time interval at which the substrate is kept inside the digester tank.

HRT is correlated to the digester volume and the volume of substrate fed per time unit, and determined according to the following equation:

$$HRT = \frac{V_{gs} \times V_f}{Q} = \frac{0.8V}{Q} - - - - - - - - 4.5$$

$$Working\ volume\ of\ digester$$
$$V = Vgs + Vf - - - - 4.6$$

Where:

$HRT = hydraulic\ Retention\ Time$

$V_{gs} = Volume\ of\ gas\ storage\ chamber$

$V_f = Volume\ of\ fermentation\ chambe$

$Q = Total\ influent$

$V = total\ volume\ of\ the\ digester$

According to FAO biogas technology training manual for extension, before feeding the digester, the waste coffee pulp has to be mixed with water at the ratio of 1:1 on a unit volume basis (i.e. same volume of water for a given volume of coffee pulp). However, if the feedstock is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the inputs (e.g. ratio could vary from 1:1.25 to even 1:2). The dilution should be made to maintain the total solids from 7 to 10 percent and most of the time 8 percent dilution is used. If the feedstock is too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of gas formed at the lower part of digester. In both cases, gas production will be less than optimal; therefore, the dilution should be maintained according to the recommendation that is 8% [12]. In order to determine the volume of the digester chamber for the pilot experiment it is assumed that the total discharge to be 5kg and from the total solid analysis the total solid factor for wet waste coffee pulp is determined to be 0.12. Therefore, the total solid of fresh discharge (TSFD) for the assumed 5kg mass is calculated as:

$$TSFD = 5Kg \times 0.12 = 0.6Kg$$

Therefore, in a 5kg of total discharge it is found that 0.6kg of total solid. Hence, by using the 8 percent dilution recommended by FAO-2008 biogas technology training manual the total influent (TI) required for the pilot experiment can be calculated as:

$$8kg\ TS = {}^{100Kg}/_{day}\ Total\ influent$$

$$0.6Kg\ TS = {}^{QKg}/_{day}\ Total\ Influent$$

From this analysis for 0.6Kg of TS a 7.5Kg/day of total influent (TI) is obtained. The water to be added to make the input 8% of concentration of TS:

$$7.5Kg - 5Kg = \frac{2.5Kg}{day} = 2.5m^3/day$$

Therefore, 2.5kg water is needed for dilution of a 5kg of total discharge. The Hydraulic retention time (HRT) for a pre-assumed volume of pilot experiment digester which is $0.3m^3$ is calculated by using formula (equation 4.5) above becomes:

$$HRT = \frac{0.8 \times V}{Q} = \frac{0.8 \times 0.3}{7.5} = 32days$$

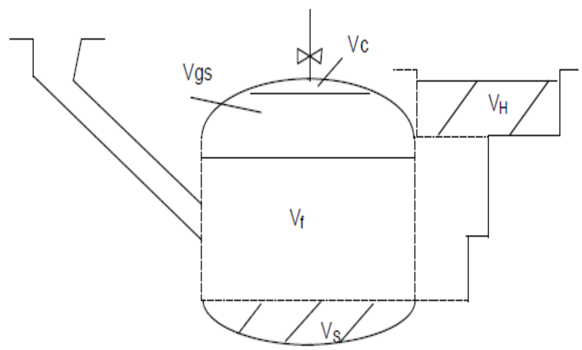

Figure 9: Cross section of the digester [13]

Where:

V_c = Volume of Gas Collecting chamber

V_{gs} = Volume of gas storage chamber

V_f = Volume of fermentation chamber

V_H = Volume of hydraulic chamber

V_s = Volume of sludge layer

Total volume of digester $V = V_c+V_{gs}+V_f+V_s$

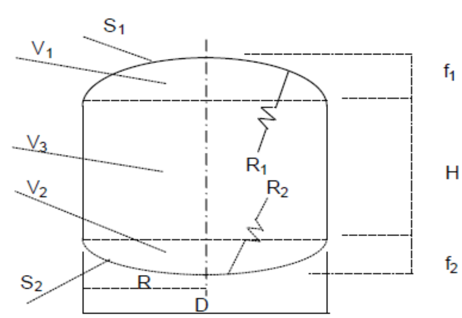

Figure 10: Geometrical Dimensions of the cylindrical shaped biogas digester body [13]

TABLE VII
VOLUME AND GEOMETRICAL DIMENSION ASSUMPTIONS [13]

For Volume	*For geometrical Assumption*
$Vc \leq 5\%V$	$D=1.3078 X V^{1/3}$
$Vs \leq 15\% V$	$V1=0.0827 D^3$
$Vgs+Vf = 80\%V$	$V2 = 0.05011 D^3$
$Vgs = VH$	$V3 = 0.3142 D^3$
$Vgs = 0.5 * (Vgs + Vf + Vs) * K$ Where, K = Gas production rate per m^3 digester volume per day. For $K = 0.4 m^3/m^3d$	$R1= 0.725 D$ $R2= 1.0625 D$ $f1 = D/5$ $f2 = D/8$ $S1 = 0.911 D^2$ $S2 = 0.8345 D^2$

The Volume and geometric assumption for biogas digester design are considered according to the training material prepared and collected from the booklets and research materials of biogas training (research) center (BRC). [13]

From geometrical assumptions:

$$D = 1.3078\, X\, V^{1/3} - - - - - - - - 4.7$$

$$D = 1.3078 \times 0.3^{1/3} = 0.875m \sim 0.9m$$

The cylindrical geometry volume calculation is carried out as follows:

$$V_3 = \frac{\pi \times D^2 \times H}{4} - - - - - - - - 4.8$$

From the above geometric assumption of digester design V_3 is calculated as:

$$V_3 = 0.3142D^3 - - - - - - - - 4.9$$

From the above "f" formulas $H$is calculated as:

$$V_3 = \frac{\pi \times D^2 \times H}{4} = 0.3142D^3$$
$$H = 0.36m$$

Now after knowing the dimensions for H and V_3 it is possible to find the rest of the dimensions for the Model experiment digester according to the geometric assumptions provided above. Therefore,

$$V_1 = 0.06m^3$$
$$V_2 = 0.02m^3$$
$$V_c(volume\ of\ gas\ collecting\ chaber) = 0.015m^3$$
$$R_1 = 0.65m$$
$$R_2 = 0.95m$$
$$f_1 = 0.225m$$
$$f_2 = 0.113$$

Volumetric Calculation for Hydraulic Chamber

From the geometric relation:

$$V_c = 0.05 \times \mathrm{V} = 0.05 \times 0.3\mathrm{m}^3 = 0.015\mathrm{m}^3$$
$$V_{gs} = 0.5 \times (0.8 \times \mathrm{V} + V_s) \times \mathrm{K}\,,\ V_2 = V_s$$

(Where K= gas production rate factor per m^3digester volume/day i.e., 0.4) [13]

$$V_{gs} = 0.5 \times (0.8 \times 0.3 + 0.02) \times 0.4 = 0.052\mathrm{m}^3$$
$$V_c + V_{gs} = 0.015 + 0.052 = 0.067\mathrm{m}^3$$
$$V_1 = \left(V_c + V_{gs}\right) - \frac{\pi D^2 H_1}{4}$$
$$0.06m^3 = 0.067 - \frac{\pi (0.9)^2 H_1}{4}$$
$$H_1 = 0.011m$$

It is fixed that; h = 800 mm water volume (1mm = 10 N/m^2)

$$h = h_3 + f_1 + H_1$$
$$0.8 = h_3 + 0.225 + 0.011$$
$$h_3 = 0.564m$$

Again from the volumetric assumption it is know that

$$V_{gs} = V_H$$
$$V_{gs} = \frac{\pi D_H^2 h_3}{4} - - - - - - 4.10$$
$$0.052m^3 = \frac{\pi D_H^2 h_3}{4}$$
$$D_H = 0.343\mathrm{m}$$

Now we know the dimension of hydraulic chamber. Moreover keeping h= 800 mm, we can choose or re-arrange the dimension considering availability of site and construction suitability. The same design procedure is followed for the dry coffee waste digester and also the daily feed rate is also calculated as it was done for the wet waste coffee pulp, i.e., the total fresh discharge used was 5kg and according to the analysis the total solid of the fresh discharge becomes 4.69 kg and the total influent also becomes 58.62 L/day. The total amount of water to be added to make the input 8% of concentration of TS is 53.93 L/day

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 6, Issue 1, January 2017)

C. Bio gas Production Rate

The production rate of bio gas from anaerobic digestion process is depends on temperature, pH value, solid material input, construction quality of digester as described in section II B.

Digester Temperature

The temperature stability is decisive for anaerobic digester. In practice, the operation temperature is chosen with consideration to the feedstock used and the necessary process temperature is provided by spray painting the body of the digester with black color. Therefore, the average temperature measured in our digester by inserting glass thermometer for the selected days of the digestion period indicates that our anaerobic digestion lay under the range of Mesophilic temperature that is 29 ^oC. Thus, the meteorology data and direct measured environmental atmospheric temperature of Tepi city is shown in figures 11 below.

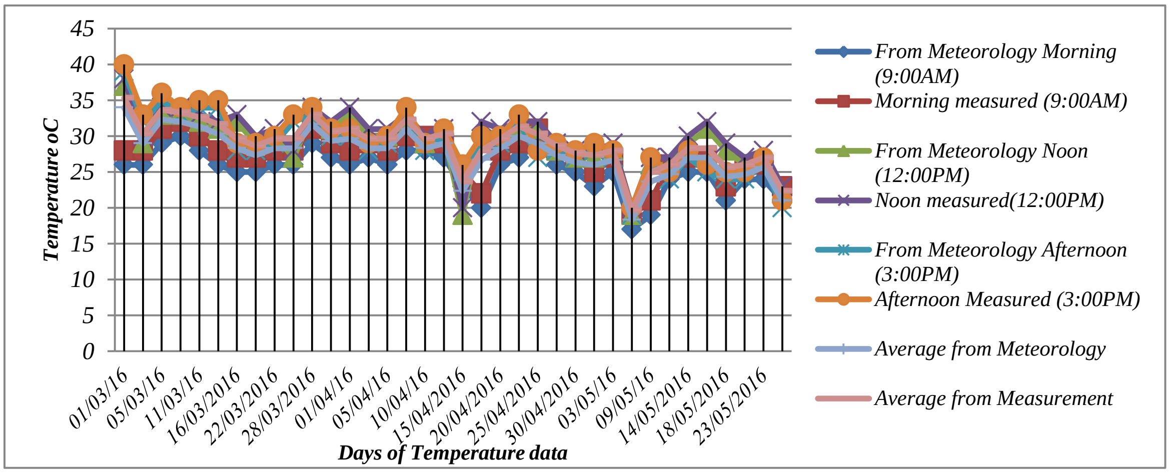

Figure 11: Temperature data of Tepi city

The rate of bio gas production from both wet and dry waste coffee pulp and its waste water is directly estimated by measuring its weight difference, assuming density of gas 1.25 kg/m^3. The first day of measure is after 32 days (its hydraulic retention time) filling digester and continues after week feeding the digester daily.

Bajaj tire internal conduit with the fitted gate valve and short pipe totally whose weight is 620 g is used to collect gas. Therefore, the weight of gas is the difference of its weight before and after gas collected in it during measurement intervals. Then, the volumetric rate calculated by dividing the mass production rate to its density and plotted in both wet and dry case shown in figure 12 and 13 below.

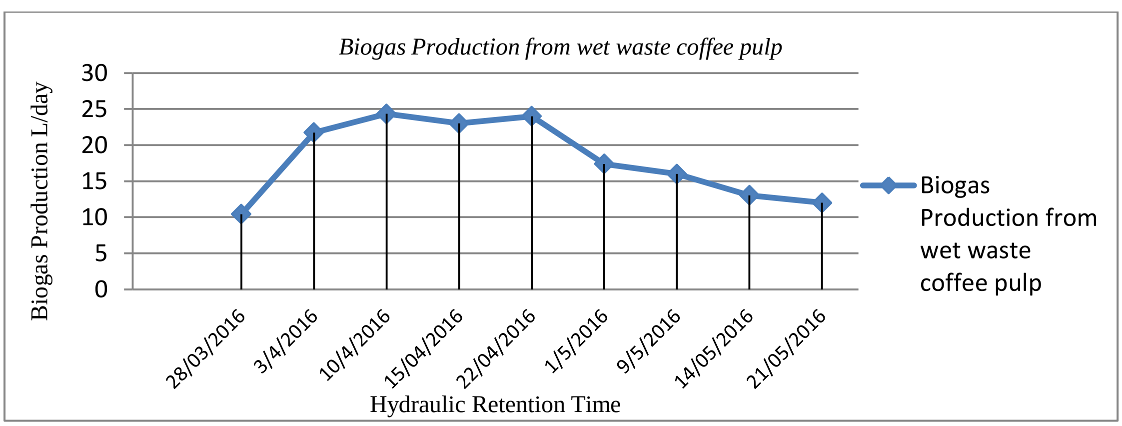

Figure 12: Bio gas production rate from wet waste coffee pulp

International Journal of Recent Development in Engineering and Technology
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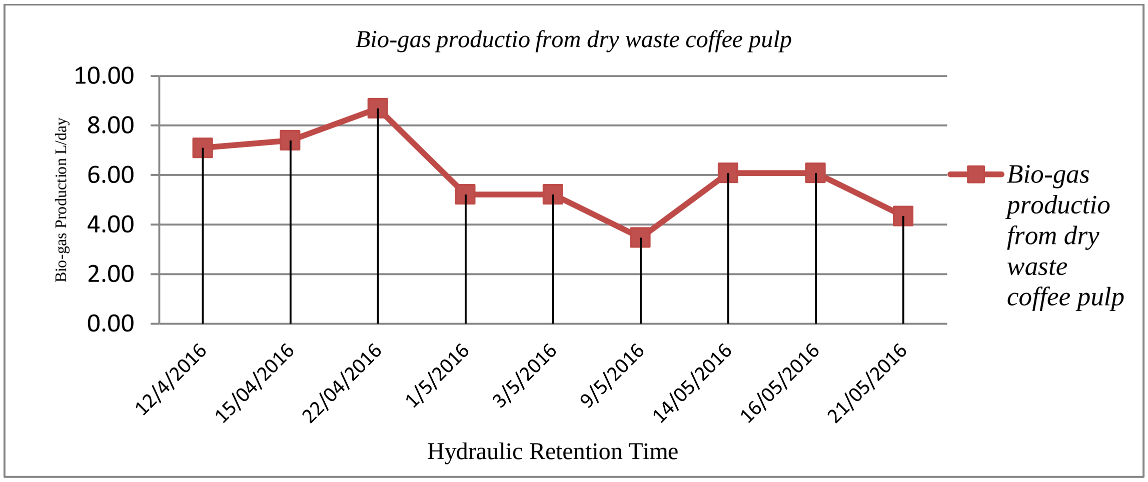

Figure 13: Bio gas production rate from wet waste coffee pulp

D. Combustibility of biogas

The combustibility of biogas generated in pilot field experiment digester was tested in the 32nd day of digestion period by using a Bunsen burner obtained from Mizan-Tepi University, Chemistry department laboratory by connecting the gas outlet of the gas collecting plastic bag. During the test a very short time blue flame was observed at the tip of the Bunsen indicating that the presence of methane in the collected biogas as shown figure 14 below. In our investigation, the moisture removal mechanism from the content of gas is not included. The presence of moisture in gas reduces the calorific value of energy, because it consumes energy to eliminate moisture as a vapor.

Figure 14: Bio gas burn test using Bunsen burner

V. Conclusion And Recommendation

A. Conclusion

Design and development of bio gas production system from waste coffee and its waste water is to convert these environments polluting waste coffee pulp and waste water to useful energy (methane) and digested slurry that can use exactly as a natural fertilizer.

The coffee pulp waste after separating non-degradable part, its chemical composition and anaerobic degradability and C/N ratio is approximately similar to that of cattle dung.

A Bio gas digester is designed for waste coffee pulp in both wet and dry case and its waste water. The system design conducted by using 300 L plastic water tank and Bajaj tire used to collect the output bio gas from the digester tank. Therefore, for the total volume the digester, the amount of daily fresh discharge estimated after its retention time (32 days) is 5 kg and required proportional mount of water is 2.5 liter for wet and 53.61 liter for dry case. Accordingly the estimation, bio gas production rate is plotted. However, the production rate of bio gas production differs as environmental temperature change the daily production amount of methane rich gas maximum 24.35 liter in wet case and 8.70 liter in dry case. Therefore, for the design and construction of bio gas digester in any size can easily estimate as the requirement of bio gas energy.

B. Recommendation

In the process of bio gas production from waste coffee and waste water, coffee waste has easily digesting and digest after long time anaerobic digestion thus has long hydraulic retention time than other organic materials.

The output bio gas contains between 30 to 100g water per m^3 bio gas in vapor form. Therefore, we recommend getting high quality gas, in bio gas production process moisture removal mechanism and further treatment of gas to be included.

Scrub the CO_2 by basic substances: lime, sodium hydroxide or potassium hydroxide so that the percentage of methane could be maximized and the gas could burn easily.

Due to the unavailability of chemical composition analyzing device, determining the chemical composition of the output gas recommended for further study and anybody interested to continue it this work may be base for it.

Acknowledgement

Our heartfelt thanks go to Mizan-Tepi University which sponsored for conducting this research project entitled *"Design and Development of Biogas production system from waste coffee pulp and its waste water around Tepi town"*.

We gratefully acknowledge Ato Alemu Mehary and his wet and dry coffee processing enterprise workers for allowing us to do our research project work at their enterprise compound.

We gratefully acknowledge staffs and technical assistances from Chemistry and Biology department for their helpful guidance, and for their invaluable critical comments and patiently assisted us in various aspects of this research project work starting from the very beginning.

Our deepest gratitude and grateful appreciation also goes to Department of Chemistry of Mizan Tepi for providing us the laboratory and equipment needed to perform field and laboratory experimental tasks.

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