Sustainable Energy, 2014, Vol. 2, No. 1, 12-19
Available online at http://pubs.sciepub.com/rse/2/1/3

DOI:10.12691/rse-2-1-3

Biogas Production Using Geomembrane Plastic Digesters as Alternative Rural Energy Source and Soil Fertility Management

Seid Yimer[1], Bezabih Yimer[2], Omprakash Sahu[1,*]

[1]Department of Chemical Engineering, KIOT, Wollo University, Kombolcha, Ethiopia
[2]Mersa Agricultural TVET College, Woldya, Ethiopia
*Corresponding author: ops0121@gmail.com

Received December 18, 2013; Revised January 10, 2014; Accepted January 20, 2014

Abstract The aim of work is to evaluate amount of gas production, economical feasibility and quality of slurry for geomembrane plastic biogas plants constructed below and above the ground surface and fixed-dome biogas plant of 3 m^3 capacity. Amount of gas and slurry were measured using calibrated biogas burner and weight balance respectively. The qualities of the slurry were analyzed in the laboratory using Kjeldahl and ash method respectively. Economic evaluation and comparison of the biodigester was carried out using cost-benefit analysis. Gas production and total-N was higher for a single layered and above ground plastic biodigester than others. Fermented slurry contained larger nitrogen content than fresh cow dung in both models of biodigester. The geomembrane plastic biogas plant gave higher net benefit than fixed-dome biogas plant. The biogas technology was found to increase income generation through increased crop production with the use of nutritive slurry as organic fertilizer and solve the problem of fuel shortage in the rural areas. Environmental impact assessment of the technology was studied and found that from the use of a geomembrane plastic biodigester, 360 m^3 of CO_2 and 600 m^3 CH_4 was prevented from emitting in to the atmosphere and save 0.562 hectare of forest per year from being deforested and hence attributed towards the decrease in global warming. Generally, the geomembrane cylindrical film biodigester technology was found cheap and simple way to produce gas in the study area.

Keywords: *economical, feasibility, geomembrane, slurry*

Cite This Article: Seid Yimer, Bezabih Yimer, and Omprakash Sahu, "Biogas Production Using Geomembrane Plastic Digesters as Alternative Rural Energy Source and Soil Fertility Management." *Sustainable Energy*, vol. 2, no. 1 (2014): 12-19. doi: 10.12691/rse-2-1-3.

1. Introduction

The continuous depletion of fossil fuel is sticking the concern into the search for new energy sources to be used. The potential energy sources have been emerged as renewable energy resources. For a long time multifarious sources of renewable energy are being investigated to meet the increasing energy consumption rate. To counteract with the growing demand researchers are exploring the new sources. The developing countries are going ahead to face the shortage of available energy. Dependency from biomass such as fuel wood, charcoal, dried cow dung cake and crop residue in Ethiopia amounts to 95% (Benjamin, 2004). According to MOA (2000), on average each rural household spends ten hours per week searching for fuel wood. Females & children are engaged to search fire wood for about 5-6 hours journey [1]. When all forest uses are included, the deforestation rate in Ethiopia is around 1.1% per year [2]. According to Bech et al. [3], the forest cover of North Wollo and Habru district is 37,183.58 hectare and 1614 hectare respectively. According to FAO (2000) [4], the combustion of fossil fuels has caused serious air pollution problems, likewise the excessive consumption of fire wood results in deforestation on a large scale. IUCN (1990) [5] estimated that high forests covered 16% of the land area of Ethiopia in the early 1950 s, 3.6% in the early 1980 s and 2.7% in 1989. Biogas digestion was introduced into developing countries as a low-cost alternative source of energy to partially alleviate the problem of acute energy shortage for households, reduces deforestation and soil erosion, avoids scarcity of firewood, benefits environment globally and provides excellent fertilizer [6].

Biogas plants are a closed container in which anaerobic fermentation of cellulose containing organic material takes place so as to produce biogas and slurry. There are three basic designs of biogas plant popular in the world. These are the floating-drum type, fixed-dome type and bag digester. The floating-drum and fixed-dome type biogas plants have been introduced to Ethiopia. However, they became an obstacle to the rapid diffusion of biogas technology, because it takes a relatively long time (3-5 week) to build a plant, high initial cost of investment, shortage of adequate skilled person who can undertake construction & installation of the plant and transportation problem of the prefabricated steel drum from the urban areas to the interior rural regions of Ethiopia [7]. The introduction of the geomembrane plastic bag digester have not yet been experimented in Ethiopia. Considering the problem of biogas technology dissemination with the existing biogas plants, the study was conducted on alternative biogas plants constructed using geomembrane plastic in cylindrical shape. In this regard's an effort has been made to introduce geomembrane plastic biogas plant, comparisons of gas and slurry yield and economic feasibility analysis with the fixed-dome biodigester should be done and accordingly, the outcome of the study may have some contribution to set remedy to the problem.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted in Mersa Agricultural T.V.E.T College, Ethiopia at 11°35'N latitude and 39°38'E longitude with an altitude of 1557 m above sea level. The area is classified under moist warm climatic zone with mean annual rainfall of 1090 mm and with an average daily temperature of 21.12°C.

2.2. Geomembrane Plastic Biodigester Design Parameters

A. Selection of materials.

Construction materials: geomembrane plastic 0.5 mm in thickness, PVC pipes. Input materials are cow dung and water.

B. Temperature: Mesophilic (21.4°C).

C. Mixing ratio of substrate 1:1. I.e. 75 kg of cattle dung was mixed with 75 liters of water. Total dung required per day was calculated as [8].

$$\text{Total dung required / day} = \frac{Gasproduction/day}{Gas/Kgofreshdung} \quad (1)$$

D. Hydraulic Retention Time (HRT).

For mesophilic temperature of Mersa locality, HRT is selected as 40 days.

Number of cattle required was calculated by using the formula,

$$\frac{Totaldung}{Dung/animal} \quad (2)$$

The volume of the digester was calculated as

$$\text{Quantity of daily dung required / digester} = \frac{Weightof\,(dung + water)}{Densityofslurry} \quad (3)$$

Minimum digester volume (D_O) = Volume of daily charge * Retention time

Actual digester volume = D_O + 0.1 D_O.

The volume of gas holder was calculated as,

$$\text{V} = (\text{volume of gas production}) \quad (4)$$

Total volume for geomembrane biodigester = Volume of digester + Volume of gas holder.

Hydrostatic pressure due to the slurry acting on the inner surface which exerts tensile load on the digester wall was calculated as = depth of slurry * density of slurry. According to Santra [9], a ratio of 4 in length to one in diameter was used to produce much gas and quality fertilizer in horizontal biogas plants. Where D = diameter and L= length and accordingly the dimension of the cylindrical plastic biodigester was calculated as

$$V = D2L/4 \quad (5)$$

2.3. Experimental Design and Layout

Four biodigester were made from single & double layered cylindrical geomembrane plastic film, constructed below the ground on a trench excavated at a dimension of 7 m * 1.5 m * 0.5 m and above the ground surface on a concrete block wall platform constructed at a dimension of 7 m*1.5 m*(0.75 m and 0.5 m) with a slope of 2°. One Chinese model fixed-dome biogas plant was also another treatment. The capacities of the digesters were 3 m^3. The experiment duration was from Nov. 2011 to July 2012. The treatments of the experiment were:

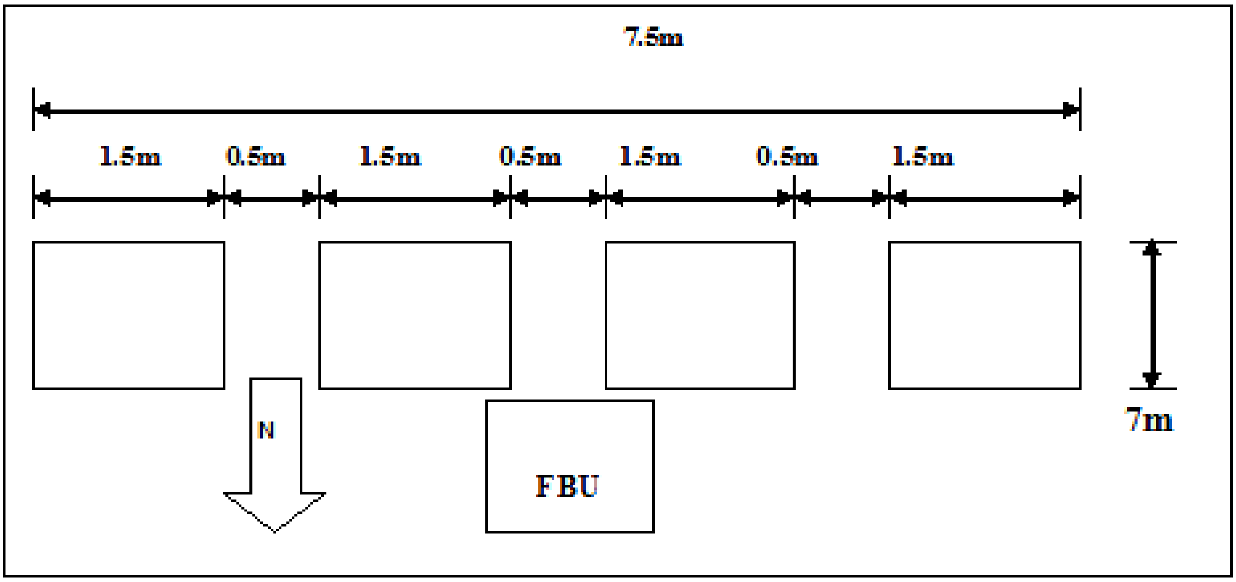

Figure 1. Layout of the Experimental Site

- PSA: plastic biodigester, single layered and constructed above ground.
- PDA: plastic biodigester double layered and constructed above ground.
- PSU plastic biodigester single layered and constructed under ground.
- PDA plastic biodigester double layered and constructed underground.
- FDU: Fixed dome biodigester constructed underground.

The manure was collected from Mersa Agricultural TVET College dairy farm and the nearby private cattle shed.

2.4. Geomembrane Plastic Construction Methodology

Materials used for the construction of geomembrane plastic biodigester were geomembrane plastic, PVC pipes, gate valves, GI caps, sockets, nipples, neoprene rubber hose and biogas stoves. Construction was done with the help of electrical geomembrane welding machine and CM-43 adhesive with other mixtures. The geomembrane plastic was cut at a dimension of 7 meter length and 4.50 meter width as per the design. Then, it was welded with the help of electrical plastic welding machine across the length and the circular part of the cylinder was fitted with the help of CM-43 adhesive and with other chemical mixtures. The biodigester has an inlet for entry of input materials, gas outlet for exit of produced gas and slurry outlet for disposal of fermented slurry. The digester and gas holder was made as one unit in a cylindrical shape.

Table 1. Technological Parameters of the Experimental geomembrane plastic biodigester

Constants	Value
Plastic width, m	2
Circumference, m	4
Internal diameter m	1.24
Plastic length, m	6.2
Loading rate, Kg ODM/m^3/day	10.36
Retention time, days	40
Quantity of daily dung required/digester, m^3	0.136
Minimum digester volume, m^3	5.44
Actual digester volume, m^3	5.984
Daily volume of gas production, m^3	3
Total volume of geomembrane plastic biodigester	7.484
Hydrostatic pressure due to the slurry, Kg/m^2	1023

2.5. Data Collection Procedures

Different data which were pertinent to the study objectives were collected following standard procedures. The following variables were measured and analyzed during the study. Amount of gas production, quantity of input and output slurry, temperature of the air, pH of the fresh cow dung and digested slurry, total–N and organic matter content of the substrate and the slurry. Daily rainfall, temperature of the air and slurry was also measured.

2.5.1. Input to the Digesters

The type of input material which was found feasible and available in the study area was cow dung as there was dairy farm at a distance of 25 meter from the experiential site. Manure inputs were measured using bucket of 25 liter. One bucket of cattle dung was mixed with 1 bucket of water [8]. Thus, as per the design three bucket of dung (75 Kg) were mixed with three bucket of pure water (75 litres) so as to produce 3 m^3 gas per day on May 5, 2007. After the slurry mixture has been fed in to the digester, 15 liters starter material prepared from cattle dung and water in 1:1 ratio and allowed to ferment for one month in a closed barrel were added at equal amount to all five biodigester to initiate and facilitate the fermentation process.

2.5.2. Measurement of Gas Production

The quantity of gas produced from the two models of biodigester were measured with the help of standard sized biogas burner which is, certified by ISO and manufactured by gas crafters in Bombe, India. The burner has a capacity of 0.45 m^3 per hour and it was adjusted with the help of its air shutter until blue flame comes to burn with its maximum capacity. Time to burn was taken by stop watch for consecutive hours of one day. So the daily gas production from the digester (s) is the sum total of the hours run by each burner and its gas consumption rate.

2.5.3. Temperature of the Air and Slurry

The temperature of the air was measured via mini-max thermometer in a metrological station found around the study area and the daily temperature of the slurry in the biodigester was measured using ordinary electronic thermometer.

2.5.4. Total-Solids (DM) Content

The dry matter content of the substrate and spent slurry was measured by drying a sample at 70°C in an oven and weighing the residue on a precision electronic balance.

2.5.5. The Organic Dry Matter (ODM)

Only the organic or volatile constituents of the feed material are important for the digestion process. For this reason, only the organic part of the dry matter content was considered and this was analyzed in the laboratory.

2.5.6. PH of the Fresh Cow Dung and Digested Slurry

The pH of the fresh cow dung and fermented manure was measured by pH-meter in the laboratory.

2.5.7. Quality of Output Slurry

The compositions of digested slurry produced by anaerobic fermentation in the two models of biogas plants were determined in the laboratory. Five digested slurry samples from all five biogas plant and two fresh manure samples from the cow dung fed to the two types of biogas plant were taken by random sampling technique.

According to AOAC (1990) [10], total-N was determined by Foss-Tecator Kjeldahl procedures after taking 1 gram of manure sample and digested with sulpheric acid and salicylic acid and estimated by Kjeldahl method. The process of digestion took about three and half hours in the laboratory.

Organic matter content was determined by the use of Toffle furnace by ash method. 10 gram of well mixed manure in dry nickel crucible or silica basin was weighted and was put in a low flame or hot plate till the organic matter begins to burn. The crucible in a muffle furnace was placed at about 550°C for 8 hours. The crucible with a grayish white ash formed was removed from the furnace cool in a desicator and weigh. Therefore, the residue represents the ash and the loss in weight represents the moisture and organic matter [11]. Fresh cow dung samples were taken on April, 2011 and fermented slurry samples were taken after gas was fully generated and measured i.e. on June, 2011 from five biodigester and two cattle sheds.

2.5.8. The Efficiency of Biodigester

It was evaluated by comparing its gas and slurry production with the amount of substrate fed in relation to the volume of the digester and compared by calculating their specific gas production. Specific gas production was determined by dividing the daily volume of gas measured by the amount of cow dung loaded into the plant.

3. Results and Discussion

3.1. Biogas Production

Gas was burnt and measured after gas has completely produced within the designed HRT of 40 days with the help of calibrated biogas burner and stop watch (Figure 2). As can be seen in Table 2, gas production as the proportion of biodigester liquid volume was higher for a single layered and above ground plastic biodigester than others and very less amount of gas was measured from the fixed-dome biodigester. This was because more sun light temperature (27.65°C-32.7°C) was absorbed in a black geomembrane plastic sheeting digester than reinforced concrete fixed-dome biodigester (Figure 3). Temperature is very important factor which positively or negatively affects the activity of microorganisms in the production of biogas.

Figure 2. Burning and Measuring of Biogas with a Biogas Burner after Gas Generation

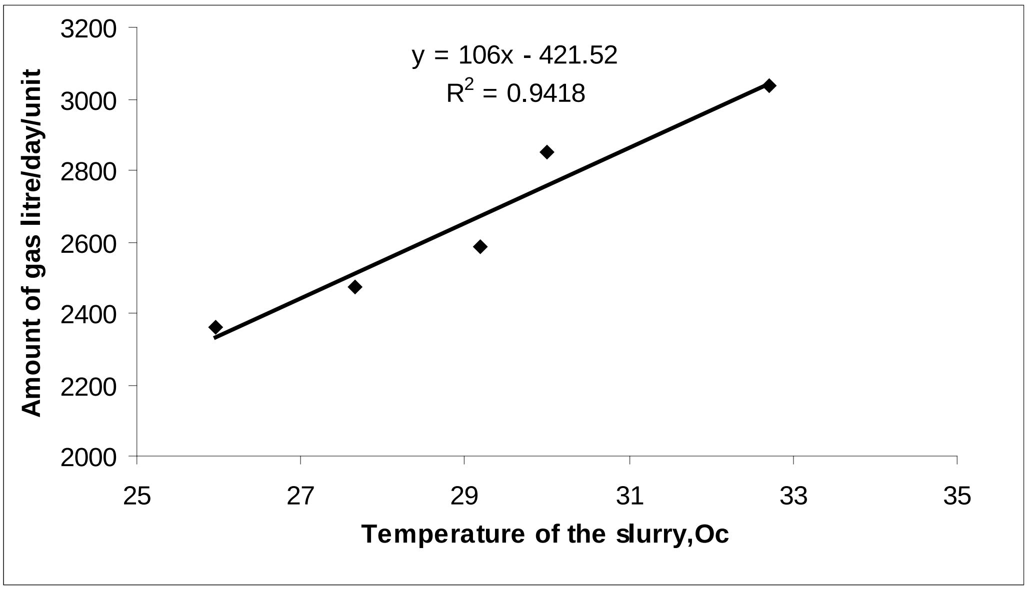

Figure 3. The Relationship between Temperature of the Slurry and amount of Gas Production for the Plastic and Fixed-Dome Biodigester

Table 2. Total Values for Biogas Production (9 Am to 4 Pm) in Biodigester with Different Types, Layers and Location of Installation

Biogas Production	BIODIGESTER TYPE					
	PDA	PSA	PDU	PSU	FBU	Average for plastic digesters
Hours recorded during burning of gas in a burner /plant	6.33	6.75	5.75	5.50	5.25	6.08
Liters/day/plant	2850	3037.5	2587.5	2475	2362.5	2737.5
Specific gas production per day (m^3/kg)	0.0380	0.0405	0.0345	0.033	0.0315	0.0365
Average daily slurry temperature °C	29.99	32.7	29.18	27.65	25.96	29.88

PDA: plastic biodigester, double layered and constructed above ground
PSA: plastic Biodigester, single layered and constructed above ground
PDU: plastic biodigester, double layered and constructed underground
PSU: plastic biodigester, double layered and constructed underground
FBU: fixed-dome biodigester constructed underground.

3.2. Temperature of the Air and Slurry

The average atmospheric temperature during fermentation time between May 5, 2007 and June 14, 2007 was 24.55°C. According to Grewal et al. [8], temperature is one of the factor affecting the growth rate of micro-organisms involved in the production of biogas and effective anaerobic fermentation is carried out in mesophilic temperatures averaging between 24°C and 45°C. The local average atmospheric temperature of Mersa was 21.12°C according to 12 years of data which was very suitable for biogas production.

According to Hu Qichun (1991) [12], a biogas plant could perform satisfactorily only where mean annual temperatures are around 20°C or above or when the average daily temperature is at least 18°C. With the range of 20-28°C mean temperature, gas production increases over proportionally. If the temperature of the biomass is below 15°C, gas production will be so slow that the biogas plant is no longer economically feasible. So, the temperature recorded in the study area was very suitable for normal fermentation and higher amount of gas was produced by mesophilic bacteria. The average temperature of the fermented material in the biodigester were in the range between 25.96°C and 32.7°C as described in (Table 3), which is greater than the critical 15°C. Thus, gas was completely produced within the designed HRT value of 40 days. As it is mentioned in Figure 3, R^2 is 0.945. Thus, 94.5% of the variability in the amount of gas produced by the biodigester was due to the variation in the slurry temperature.

The average temperature of the slurry measured in the geomembrane plastic biodigester exceed by 1.687°C to 6.737°C of the slurry in fixed-dome biodigester (Table 3). Thus, geomembrane bag was observed to have the best advantage of heating the digester contents easily and produce higher amount of gas (0.12-0.68 m^3 of gas per m^3 of digester per day) than fixed-dome biodigester made from reinforced concrete (Table 3). Since its walls are thin and black in color, it can be heated quickly with an external heat source, such as the sun radiation of the same degree in the study area. Similar results were reported by Bui Xuan and Preston [13] that found average temperatures in bag digesters, compared with dome types, are 2°C-7°C higher in the bag (0.235-0.61 m^3 of gas per m^3 of digester per day).

Table 3. Comparison of Average Slurry Temperature, °C and amount of Gas Produced, m^3/Day of the Biodigester

Types of GPBD	Average Slurry temperature, °C of GPBD	Amount of gas produce, m^3/day	GPBD, °C–FBU (25.963 °C)	GPBD, m^3/day–FBU, 2.36 m^3/day
PSA	32.700	3.04	6.737	0.68
PDA	29.988	2.85	4.025	0.49
PDU	29.175	2.59	3.212	0.23
PSU	27.650	2.48	1.687	0.12

GPBD: geomembrane plastic biodigester

3.3. Characteristics of Bio-Digested Slurry (Effluent) and the Influent

Organic substances passed through biogas plants not only produce a source of energy, but also a large quantity of digested slurry, which provides excellent organic fertilizer. The net weight of slurry discharged daily from the geomembrane plastic and fixed-dome biodigester were 123 Kg and 112.5 Kg respectively. Thus, the annual slurry output was 44895 Kg (45 tons i.e. 18% of the total substrate was lost) and 41062.5 Kg (41 tons i.e. 25% of the total substrate was lost), which was produced from 27375 kg of fresh dung fed to the digester annually, which in turn is equivalent to 13468.5 kg of dried dung cakes. Likewise, the loss in the amount of slurry have been reported by UNESCO (1982) [14], and states that during digestion, about 20% of the total slurry is volatilized. Thus, geomembrane plastic biogas plant produced higher amount of slurry than fixed-dome biogas plant of the same capacity and using equal amount of input material. So, with the use of geomembrane plastic biodigester, the farmers could get 45 tones of fermented slurry which could be used to apply on the farmland as organic fertilizer. Thus, by conversion of cow-dung in to a more convenient and high-value fertilizer (biogas slurry), organic matter is readily available for agricultural purposes, thus protecting soils from depletion and erosion.

Therefore, the farmers should be advised to use geomembrane plastic biogas plant so as to utilize the dung for dual purposes such as the produced gas as fuel for cooking and the remaining large quantity of slurry as organic fertilizer which helps to increase crop production by preventing it from burning in the form of dry dung cake and ashing down the good manure creating unhygienic conditions in the kitchen.

3.4. Characteristics of Total-N in the Slurry and Influent

The average total nitrogen of the substrate and digested manure of the geomembrane plastic and fixed-dome biodigester were 0.37%, 1.13% and 1.15% respectively as described in Table 4. Similarly, Grewal et al. [8], reported that the total-N content of fresh dung as 0.242% which is 34.6% less than the result of this study. Thus, fermented slurry contained larger nitrogen content than fresh cow dung in both models of the biodigester because in an air tight biogas digester more organic acid such as acetic acid, prop ionic acid, butyric acid, ethanol and acetone was produced doting anaerobic fermentation of soluble simple organic substances which helps to absorb and fix ammonia and minimize the loss of nitrogen thus conserving the fertility of the manure. So, the higher quantity of nitrogen was converted in to the useful nitrate and ammonia which is the most important ingredient for plant growth.

There was also a greater conversion of organic substrate to nitrogen during 40 days of the experiment because microbial anaerobic degradation was facilitated with higher temperature.

According to Hu Qichun [12] (1991), during anaerobic fermentation, part of the total nitrogen is mineralized to ammonium and nitrate. Thus, it can be more rapidly taken up by many plants and in a number of applications, slurry from biogas plants is even superior to fresh dung especially when the slurry is spread directly on fields with a permanently high nitrogen demand (e.g. fodder grasses) or when using slurry compost to improve the structure of the soil.

Processing evidence suggests, however, that slurry is much more effective than dung when applied as fertilizer, French (1979) [15], discusses that slurry is 13 % more effective than dung, and Van Buren (1974) [16], reported that the ammonia content of organic fertilizer fermented for 30 days in a pit in china increased by 19.3%.

As can be seen in Table 4, the single layered geomembrane plastic biodigester constructed above ground produced higher amount of total nitrogen than others. This was due to higher amount of slurry temperature (Table 3) absorbed in the single layered above ground biodigester activated anaerobic micro-organisms to convert more simple organic substances of the substrate in to simple organic acid so as to fix more ammonia. Therefore, total-N was affected by material and position of biodigester construction. Mersa ATVET dairy farm fermented cow manure contains 1.0164%-1.2026% N and 50-75% Organic matter. Thus, the annual output of slurry equivalent to 13468.5 kg of dry dung cake converted to 152.2 kg of N and 8127 kg of organic matter on the average. In the slurry which has higher total nitrogen content there is higher proportion of ammonium which constitutes the more valuable form of nitrogen for plant nutrition [17].

Table 4. Effect of Material & Position of Biodigester Construction on the Composition of the Effluent

Components of the effluent and influent	Biodigester types and fresh cow dung fed to the biodigester							
	PSU	PDU	FBU	PSA	PDA	IFB	IPB	Average(For Plastic digesters)
Organic matter, %	50	50	66.7	75	60	80	85.7	58.75
Organic matter (Kg)	37.5	37.5	50.025	56.25	45	60	64.28	44.06
Organic carbon, %	29	29	38.686	43.5	34.8	46.4	49.706	34.08
Total N, %	1.148	1.1368	1.1536	1.2026	1.0164	0.3626	0.3822	1.126
Total N, Mg/kg	11480	11368	11536	12026	10164	3626	3822	11259.5
Dry matter, %	0.2	0.2	0.5	0.6	0.4	0.7	1.0	0.35
pH	6.8	6.9	7.2	7.1	7.6	6.8	7.0	7.1

IFB: influent of fixed-dome biodigester, IPB: influent of plastic biodigester
pH: hydrogen ion concentration.

3.5. Characteristics of Organic Matter in the Slurry and Substrate

The application of digested slurry to crop serves as a dual purpose; a soil conditioner as well as a source of plant nutrients. According to Table 4, the effluent in PSA showed larger organic matter content than the effluent in FBU. This could be because the amount of organic matter in the influent of plastic biodigester (IPB) was higher than that in the influent of fixed-dome biodigester (IFB). Higher value of organic matter was recorded from fresh cow dung than the slurry (Table 4). Even if higher value was recorded for fresh manure, the use of excreta of dairy cattle in biogas plants was found to be better than the farmyard manure in several ways. A part of nitrogen which is ammonia, found in the slurry becomes available to the plants. The ability of the wet digested slurry to aggregate soil particles immediately after application is also very unique. The digested manure was available in 40 days as compared to 4-6 months taken in the usual method of composting in a manure pit. According to Grewal et al. [8], almost all plant nutrients are retained in the digested slurry in such finely divided state that, it mixes up with the soil quickly and thoroughly, and the soil bacterial activity increases substantially. Thus the application of digested slurry gives better yields for all crops as compared to farmyard manure (FYM) made from the same quantity of cattle dung. The digested slurry in this study was thin and used directly to the crops through the irrigation channels and by direct splashing on the farmland.

Moreover, it was also put in a fish pond of Mersa agricultural T.V.E.T. College and fishes were nourished. Thus, it was proved that, the waste that comes out of the digestion process as slurry was very useful both as feed and organic fertilizer. Studies by Sokoine Agricultural University in Tanzania have shown that slurry from biogas improves productivity of land and maintains soil quality that can support crop production over a long period of time [18].

3.6. Characteristics of pH of Fermented Slurry

It is generally recommended that the pH inside the biodigester should be above seven for normal fermentation and maximum gas production [8]. In the present study, the pH of the fermented slurry and fresh cow-dung was 6.8-7.6 and (Table 4) with a hydraulic retention time of 40 days. Thus, the condition inside the digester was very comfortable for anaerobic micro-organisms to accomplish normal fermentation, higher gas production and fertile manure.

3.7. Efficiency of the Biodigester

The average specific gas production of the single layered above ground geomembrane plastic biodigester was greater than others (Table 2). That was due to higher amount of sun light was absorbed by the digester (32.7°C) that used to facilitate the activity of micro-organisms and increase the amount of gas production per weight of the substrate (Figure 2). Thus, the construction of single layered aboveground biodigester is better than other biodigester as efficiency of conversion of substrate organic matter to biogas was higher.

3.8. Economic Evaluations

In order to compute the value of biogas in terms of the value of traditional fuels saved by utilizing biogas, it was necessary to estimate the amount of dried dung cakes or fire wood needed to produce an equivalent amount of energy. Thus, according to UNISCO [14], Van Buren [16], used in this study assume that 1 m^3 biogas substitutes for 3.47 kg of fire wood, 12.3 kg of dry dung fuel and 0.62 liter of kerosene oil.

Economic evaluation was also done for all biodigester using cost-benefit analysis which is the most commonly employed method used by many extension officers. It was able to evaluate the relative advantage of a geomembrane plastic biogas plant investment as compared to fixed dome biodigester on the basis of the anticipated minimum interest rate and economic life for the alternative designs. A discount rate of 18 % has been applied throughout the analysis according to Amhara regional state credit and saving institution (2007).

3.8.1. Market Price of Inputs

Dung: According to Senait Seyoum [19] (2007), the cost of dung was estimated in terms of.

Table 5. Summary of Market Value of Inputs and Outputs Used in the Analysis

Inputs	Market value (price in EB)
Dung (EB/kg)	0.50
Water (EB/5 m^3)	2.00
Labor (EB/day)	15.00
Outputs	
Biogas (EB/litre)	3.47
Slurry (EB/tone)	90.62

EB: Ethiopian Birr (1$ = 18 Birr)

- Dung's value as fertilizer determined by the cost of an equivalent amount of commercial fertilizer, or.
- The market value of dung cakes, if dung is sold.
- 1 ton of DAP is 16 tone of dry manure.

Price of 1 tone of DAP according to 2006/2007 year was 1450 ET Birr. This was determined from a receipt voucher issued to Mersa agricultural T.V.E.T College purchasing office. The price of dried cow dung according to Woldya market in 2006/2007 ranged from EB 5.00 to EB 8.00 per 50 kg sack, averaging EB 0.50 per kg of dried dung.

Water: This was valued according to the price charged by the water authority of Habru District, Mersa town. I.E. EB 2.00 per 5 m^3.

Labor: The Labor used to collect water and spread slurry was valued at EB 15 day^{-1}.

3.8.2. Market Price of Outputs

Biogas: The biogas produced by the digestor was valued at the market value of fire wood or dried cow dung cakes, which it replaces. The observed price of fire wood in Mersa was between EB 15 and EB 20 per bundle weighing 15-20 kg. It was estimated that firewood averages EB 1.00 kg^{-1}.

Slurry: Output digested slurry was valued at the official price of DAP (diammonium phosphate). N and P contents of DAP roughly approximated the proportions of these nutrients in dried cow dung. According to Senait Seyoum [19], 1 ton of DAP is roughly equivalent to 16 ton of dry manure. The 2006/2007 price of DAP was EB 1450 $tone^{-1}$, thus each ton of dry cow dung which has less nutrient content than the fermented slurry is worth EB 90.62. Therefore, the cost of 1 ton of fermented slurry was assumed to be EB 90.62 to the minimum.

Three important technical assumptions were made with respect to gas production and use, and the efficient use of inputs and their conversion in the analysis.

Table 6. Summary of total costs and total benefits of geomembrane plastic and fixed-dome biogas plants

No	Biogas Models	Total Benefit	When used as fuel wood		When used as manure	
			Total Cost	Net Benefit	Total Cost	Net Benefit
1	PSA	7925.05	4427.90	3498.05	5035.45	2889.6
2	PDA	7687.57	4604.69	3082.88	5222.25	2465.32
3	PSU	7212.61	4127.78	3084.83	5562.47	1650.14
4	PDU	7355.10	4191.63	3164.10	5229.25	2125.85
5	FBU	6710.14	5662.96	1047.18	6389.32	320.82

1. The average daily gas production for a year from the geomembrane plastic and fixed-dome biodigester was assumed to be 2.74 m^3 and 2.36 m^3 as to the measurement taken once in drier months, but this could vary considerably with daily ambient temperature fluctuations in a year.
2. In the analysis it was assumed that all gas produced would be used, and it would have the same use as the dry dung or wood replaced by biogas.
3. The amount of slurry produced daily from the geomembrane plastic and fixed-dome biodigester was 123 tons and 112.5 tones.

As per the design, the total quantity of fresh dung required for 3 m^3 size biogas plants in one year was 27375 kg or 27.375 tons but the quantity of fermented slurry collected after digestion and gas measurement was 45,000 kg and 41,000 kg in the geomembrane plastic and fixed-dome biodigester respectively. Thus, approximately 10 tons and 14 tons of digested slurry (18% and 25% of the input mixture) were lost during fermentation from the total of 55 tons of slurry mixture available in the geomembrane plastic and fixed-dome digesters respectively. The loss in the weight of the slurry was due to the loss of solids during fermentation. Similarly, UNESCO (1982), states that, during digestion, about 20% of the total slurry is volatilized. Thus, about 80% of the manure is collected from fresh dung. According to Grewal et al. [18], the loss of solids in the biogas plant rarely exceeds 27 percent even when maximum gas is generated.

3.8.3. Cost-Benefit Analysis of Biogas Plants

Therefore, the net benefit of geomembrane plastic biogas plants is greater than fixed-dome biogas plant and in particular the net benefit gained from PSA is greater than others. Thus, the use of geomembrane plastic biodigester is profitable than fixed-dome biodigester.

4. Conclusion

Generally, gas production and total nitrogen content as the proportion of biodigester liquid volume was higher for a single layered and above ground geomembrane plastic biodigester than the fixed-dome and other plastic biodigester. So the construction and use of single layered geomembrane plastic biodigester above the ground surface is preferable than other models and locations of installations of the biodigester. Fermented slurry contains larger nitrogen content than fresh cow dung in both models of biodigester. Thus fermented slurry has high fertilizer value in increasing the fertility of the soil than fresh cow dung. The geomembrane plastic biodigester gave higher net benefit than the fixed-dome biodigester. Thus, the geomembrane plastic biodigester is the cheapest model that an individual farmer could invest and acquire a better profit than the fixed-dome biodigester.

Considering the long-term benefit of plastic film biodigester technology both economically and environmentally, it is recommended to introduce the single layered above ground geomembrane plastic biogas plant to be used for the beneficiaries regardless of its higher net benefit, higher gas and fermented slurry production, simple construction and maintenance via extension education to promote its penetration and diffusion into rural areas. However, greater safety precaution during operation and usage of the plant and protection from damaging agents such as sharpened objects and rats is essential.

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